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ARGUMENTATIVE INTERACTIONS, DISCURSIVE OPERATIONS AND LEARNING TO MODEL IN SCIENCE

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Introduction

Doing science is essentially a group activity, and the same is often true of learning to do science. Since the activity of any group usually relies on communicative exchanges using language, in its various linguistic, symbolic and pictorial forms, then language is necessarily involved in doing science and in learning to do it. But linguistic exchanges are not just means of coordinating activities (c.f. Clark, 1996, 1999). Considered as a system of signs (Saussure, 1915/1972), language is also a cultural repository of concepts; and considered in its primary manifestation, as social interaction (Bahktine, 1929/1977), language is the means by which concepts are engendered. In the continuation of Vygotsky's work, social interactions are considered to be the primary means by which scientific notions are co-elaborated, building on their everyday correlates, with the scaffolding of a more capable person, such as a teacher.

In this chapter we argue that one particular type of social interaction — *argumentative interaction* — plays a specific and important role in one aspect of learning science: learning to *model*. In order to support this claim we first describe epistemic, cognitive and linguistic dimensions of modelling in science, and of argumentative interactions, and then propose general relations between them. These general claims are then illustrated by analysis of three specific interaction sequences, drawn from corpora collected in situations that were designed for learning to model. We conclude that argumentative interactions embody discursive operations by which different types of concepts and knowledge are dissociated from each other, this being a necessary precursor to establishing complex relations between models and their associated experimental fields, i.e. to modelling itself.

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Learning to model: epistemic, cognitive and linguistic dimensions

Modelling in science involves trying to establish complex relations between elements of a model (with its attendant syntax, and in relation to a theory) and objects and events in an experimental field (Tiberghien, 1994, 1996). Two aspects of the modelling process are important to remember in this context, since they are the ones that usually pose problems for students who are learning to model.

Firstly, it is not the case that every element of the model must have a correlate in the experimental field: there exist model elements, such as "the environment", that do not correspond to determinate tangible objects.

Secondly, it is not the case that *every* object or event in the experimental field must be taken into account (or represented) by the model. An obvious example would be that in modelling a simple electrical circuit, the colour of the wrapping of the battery is not normally to be taken into account. Apart from such simple examples, what is at stake here is the *way* in which the experimental field is to be represented, or conceptualised, and this is not all obvious for students. For example, suppose the students are asked to model energy in a simple electrical circuit involving a battery linked to a bulb by two wires. It may appear obvious that there are four elements in the experimental field to be taken into account: the battery, the first wire, the second wire and the bulb. However, the two wires should correspond to a single model element: a transfer of energy from the battery to the bulb, in terms of electrical work. Furthermore, students do not always even isolate precisely these four entities to be modelled: rather than selecting the battery as a whole, they may decide that it is its internal chemical structure, or the terminals, that are to be selected, and similarly with the bulb (the whole bulb or else just the filament?).

This process of selecting objects and events reveals the first way in which language enters into the picture. Modelling involves selecting elements in the material world, a way of conceptualising or representing them that will be specific to each spoken language; and such languages embody, amongst other things, ways of seeing, thinking, dividing up the world.

Modelling itself involves a complex process of matching between model and experimental field, that implies adjusting representations, or 'levels' of description, of each in order to get a 'fit' that satisfies all constraints in the problem-situation. Tiberghien (*op. cit.*) terms this process one of creating a *semantics* or *meaning* for the model and the experimental field. How is this done, since neither the model itself nor the experimental situation provides the answer directly? In addition to obeying model constraints, the student-modellers have to draw on *additional sources of knowledge* — from what they have learned in other areas of science, and from what they know about the material world from their everyday experience. For example, in modelling energy in electrical circuits, knowledge about electricity learned in school will come into play, if only to understand that this is just one type of energy (electrical work); knowledge from everyday life (such as the fact that if a wire is not connected, then the bulb will not light up) can be drawn upon, possibly in order to eliminate inadequate models.

This necessity to introduce new sources of knowledge reveals a second way in which language relates to modelling in science. Any scientific practice is of course carried out using different aspects of language — formal and 'natural' — and there is a continuum between the language that students use in their everyday life and the language they use in the science classroom. In some cases, clear lexical distinctions exist — such as the everyday word "weight" in comparison with the scientific term "mass" — but in others, a single word such as "energy" can occur in its (school or other) scientific context, as well as being able to participate in everyday language structures that can also be used with respect to tangible objects (e.g. "She's got a lot of energy!" vs. "She's got a lot of apples!"). When students use, therefore, such apparently scientific terms, the *sense* in which they are using them is not always clear (perhaps to them, and certainly not to the researcher).

If, therefore, being able to model involves to be able to elaborate relations between model and experimental field, using different types of knowledge, a necessary condition for modelling is to be able to *distinguish* or *dissociate* these types of knowledge and levels of description in the first place. An example of dissociating different types of school-learned knowledge would be understanding that energy is not the same as electricity, or, more generally, that the way in which things are described outside school is not the same as the way they should be described in school. An example of dissociating levels of description would be understanding that "lighting up [of a bulb]" is an event to be modelled in the experimental field, whereas "light rays" is a model-level term, used to describe a particular mode of energy transfer.

Thus, several years ago in (unreported) work carried out with A. Tiberghien, and as part of a teaching sequence on energy, we first asked students to write a textual description of an electrical circuit, then to classify parts of their texts (words or clauses) into three categories: electricity, objects and events and "other" (i.e. what could not be in the other categories, in fact corresponding to energy). The idea was to help students to distinguish different levels of description as part of modelling, and for them to have an intellectual need to learn about energy.

In summary, modelling and learning to model can be seen as involving three types of dimensions. The *epistemic* dimension concerns the different types of knowledge that must be brought to bear on the problem at hand, relating to different social practices and areas of experience. The *cognitive* dimension concerns conceptualising or representing different areas of knowledge and perception — models and experimental fields, different sources of knowledge — and making adjustments to each of these representations so that a satisfactory matching can be made between them. The *linguistic* aspect involves using different types of sign systems and language registers in modelling, in producing written solutions and/or in communicative interaction with other people.

In distinguishing these three aspects we do not wish to suggest that they correspond to different mental, social or other faculties, for they can be viewed as, for our purposes here, aspects of a single human and social reality. In fact, modelling as we have described it involves doing cognitive work on and in language in relation to different areas of understanding and experience.

We now discuss how specific discursive processes at work in argumentative interactions can be closely linked to these dimensions of modelling.

Argumentative interactions: epistemic, cognitive and linguistic dimensions

In order to understand the specific role that argumentative interactions can play with respect to learning to modelling, we need to understand what argumentative interactions are, how they function with respect to cooperative problem-solving, and to describe the discursive processes at work in them.

Argumentative interactions

We consider the situation in which a group of people (interlocutors, L1, L2, …) cooperate in solving a particular problem, *P*.

The first condition for argumentative interaction is that there should exist, in the interactive context, a *diversity of proposals* concerning *P* (for example, solutions to it, or methods for obtaining such solutions), that we shall term $s_1, s_2, \ldots s_n$.

Secondly, $s_1, s_2, \ldots s_n$ can be differently distributed across interlocutors. For example, L1 could propose s_1, and L2 s_2; or else, L1 could propose s_1, then s_2, and, realising that both can not be accepted, engage L2 in finding arguments in order to determine which of s_1 or s_2 is more plausible.

Thirdly, from the points of view of the interlocutors, $s_1, s_2, \ldots s_n$ have *different epistemic statuses* — more or less plausible, true, believable, acceptable, etc.

Fourthly, the interlocutors feel obliged to *choose* between $s_1, s_2, \ldots s_n$, for different possible reasons inherent in the cooperative problem-solving situation — the proposals are seen as mutually contradictory, only a single solution is possible, etc. We describe this 'problem of choice' as an *interlocutionary* problem, *I*.

Finally, in order to resolve the *interlocutionary problem* — which proposal(s) should be accepted? — the interlocutors establish *links* between them and other proposals — called arguments or counter-arguments, the creation of which potentially modifies the epistemic statuses of the initial proposals — for example, one is now seen as false, less plausible, obviously better, etc. There is also a second way in which the epistemic statuses of proposals can be modified, which is to *transform their meaning*, using what we term *discursive operations*, to be described below. The idea is quite a simple one: the plausibility of a proposal depends on what is meant by it.

This point of view on argumentative interactions in cooperative problem-solving situations (developed in Baker, 1996, 1999) has several implications. Firstly, such interactions are not primarily, or only, *attempts to convince* (a rhetorical point of view), but are more generally oriented towards choosing what should be accepted or not. Secondly, argumentative interactions are not always purely adversarial, in which each interlocutor attempts to impose their proposals (a dialectical point of view); they can also take the form of *cooperative explorations of a dialogical space* of solutions (c.f. Walton, 1989; Nonnon, 1996). This is in fact the form that most argumentative interactions take in situations where students are trying to co-construct new knowledge.

We can now describe three dimensions of argumentative interactions, corresponding to those described above for modelling:

— The *cognitive* dimension of argumentative interaction relates to types of reasoning used (e.g. quasi-logical, inductive) and the generation and expression of arguments. One possible cooperative learning mechanism associated with argumentative interactions is thus that the necessity to express justifications or explanations as arguments causes knowledge restructuring (c.f. the "self-explanation effect", Chi et al., 1989; Chi & VanLehn, 1991).

— The *epistemic* dimension of argumentative interaction relates on one hand to the intrinsic nature of what is being discussed: some topics are more debatable by their nature than others (Golder, 1996). On the other hand, it relates to the diversity of types of knowledge that can be appealed to as arguments, each of which can have more or less 'weight'. For example, an argument that appeals to simple 'facts' of everyday experience (e.g. "when you're standing on the earth and you drop something it falls down") is likely to carry more weight than an argument that appeals to more or less complex reasoning. Furthermore, with respect to the capacity of argumentative interactions to trigger changes in epistemic statuses (e.g. "belief"), it is clear that certain types of knowledge or belief are more resistant to change (diSessa, 1982) or "epistemically entrenched" (Gardenförs, 1992) than others.

— The *linguistic* dimension of argumentative interactions concerns the choice of linguistic expressions, oriented towards certain points of view (e.g. describing a person as a "freedom fighter" or as a "terrorist"), the use of connectors (e.g. "therefore", "since") to structure discourse, and linguistic registers (e.g. formal, informal), relating to social situations in which language is used.

Discursive operations

We mentioned above that one way of choosing what proposal(s) to accept is to weigh arguments in the balance, and that another — that we now discuss — was to transform, explore or *negotiate* the meaning of those proposals.

For our purposes here it is useful to consider processes that work along *all three* of the dimensions discussed above: epistemic, cognitive and linguistic. These are processes whereby *language is used to do cognitive work on knowledge or understanding*. We term these processes *discursive operations*. Similarly, Vignaux (1988, 1990) terms them "*linguistic-cognitive operations"*: they are "the means by which discourse performs … cognitive work on representations" (Vignaux, 1990, p. 307). The idea is again quite simple: in producing discourse about some aspect of experience, we do not simply 'describe' it, but rather (re-)present it in a certain way; and in successively elaborating our discourse, especially in collaboration with other people, we elaborate or transform our way of (re-)presenting that experience (c.f. Edwards & Potter, 1992; Edwards, 1993; Harré & Gillet, 1994).

Argumentative interactions are, we would claim, contexts in which the use of such discursive operations is particularly intense, since the precise meaning of proposals is especially at stake. An argumentative interaction involving particular topics (or theses) is not simply a matter of exchanging (counter-)arguments in order to win a dialectical game. Most often, the topics debated are not fixed, but undergo shifts in meaning and topic as a result of the interaction. This is part of common experience, since common rejoinders are often "If by x you mean y, then I don't agree" or, "That's not what I meant”. Thus, the result of a constructive debate (Baker, 1999) is not so much determining who has won, but rather a deepened understanding of the topic under debate, and the different possible points of view about it. Naess (1966) terms this “precization” (the process of making more precise). Debates often begin with a ‘surface’ difference of opinion, and then shift towards more general or fundamental oppositions of underlying points of view. Thus Walton (1992) describes the example of a debate on the desirability of the institution of tipping in the USA, that gradually transforms itself into a debate on the more fundamental issue of what should be the role of the state in regulating work practices.

In the rest of this chapter we discuss and illustrate three principal discursive operations at work in argumentative interactions: *negotiation of meaning, conceptual dissociation*, and *conceptual association*.

By *negotiation of meaning*, we mean what is perhaps the most general(ised) type of discursive operation, by which different or alternate meanings of linguistic expressions are compared and successively refined in verbal interactions. Take the example of a debate where one person claims that “Is it always wrong to take life away from a person” and another claims that it is not always wrong. Then it is clear that the debate can turn around what is meant by “wrong” (subjective, intersubjective or objective?), by “life” (is a plant alive in the way in which a mammal is?) and by “person” (is a fœtus a person?, is an insane person to be considered as a person in the same sense?). Arguments and counterarguments will then be produced under certain meanings of what they are intended to attack or defend. This is what we mean by the discursive operation of negotiation of meaning.

Secondly, and more specifically, a claim or thesis can be made more precise by *dissociating* the concepts that underlie or relate to it. This corresponds to what Perelman and Olbrechts-Tyteca (1958/1988) term “argument by dissociation”. For example, Grootendorst (1999) analyses the (highly contentious) case where, in a papal declaration, in order to defend the catholic church against possible accusations of “anti-semitism” during the second world war, the writer of the declaration dissociates the concept of “anti-semitism” from that of “anti-judaism”, denying the former and partially conceding the latter. Of course, such conceptual dissociations could be performed in any type of interactive context, but the point is that in this case they perform a specific function in a (written) debate: defense against an attack by partial concession. This is what we mean by the discursive operation of *conceptual dissociation*.

Thirdly, conceptual dissociation has a counterpart, in the form of *conceptual association*. This involves attempting to subsume different proposals under a single, usually more general concept, so as to ‘dissolve’ the opposition between them. Suppose that one person claims that “It is better to eat animals rather than plants”, whereas another claims that “It is better to eat plants rather than animals”. Either could attempt to ‘dissolve’ the verbal conflict by associating both plants and animals under the same category of “living things”: “They’re the same! — plants and animals are both living things, so neither is better than the other”. (Of course, the debate could continue with a new attempt at conceptual differentiation: they’re both living things, but they get their energy in different ways, one from digestion and the other from photosynthesis).

All three of these discursive operations can fulfil different functions in argumentative interactions: defending or attacking a thesis, or negotiating a compromise outcome in which each participant can be 'right', within specific meanings of what they are saying. We now discuss how they relate to modelling.

Relations between argumentative interactions and modelling

From the previous two sections, the special relations between modelling in science and argumentative interactions should now be evident. Modelling involves establishing complex relations between different levels of description (model and experimental field), which in turn requires adjusting representations or descriptions on these two levels, and bringing new sources of knowledge to bear on the problem. Doing modelling effectively presupposes that such levels of description and types of knowledge can be effectively distinguished from each other on a conceptual plane.

When modelling is carried out in predominantly languaged-based interaction, — and in argumentative interactions in particular — then specific discursive operations may be put into play, that work precisely on the level of transforming representations and descriptions of concepts and knowledge. Thus, argumentative interactions can play an integral role in cooperatively learning to model, to the extent that they can oblige students to 'work on' scientific conceptualisations of the material world.

Clearly, all of these discursive operations described above can occur outside argumentative interactions. But we would claim that, when there is no manifest interpersonal 'problem' or disagreement, nothing *compels* the interactants to perform these operations. But once such a disagreement arises, and argumentative interaction ensues, then the interactants are under a special *interactional pressure* to defend their views and 'themselves' (their self-images), in a sense relating to their interpersonal relationship (see Muntigl & Turnbull, 1998). This pressure forces meanings to undergo transformations, by the use of discursive operations.

In the next three sections of this chapter we discuss three examples of argumentative interaction sequences taken from corpora collected in situations in which students carried out modelling problems in science. The examples illustrate the different discursive operations carried out in argumentative interactions, in close relation to modelling.

First example: conceptual dissociation and association as argumentative defenses

This following example of argumentative interaction (extracts of which are shown in Tables 1 and 2 below) is taken from a corpus collected in a classroom situation (Langlois & Tiberghien, 1990). The students' task was to define a property of balls of different substances that can explain their different rebound behaviours (in fact, the coefficient of restitution), by carrying out experiments (dropping the balls from different heights).

Table 1: Corpus example 1, extract 1[†]

N	*Loc*	*Dialogue*
86	Laurent	it [the ball] rebounds all the same a bit lower, that's normal, but after all ...
87	Hortense	yes but look, with respect to the masses, look, one can see that the steel one is … is heavier
88	Laurent	yes, but it's not a matter of mass
89	Hortense	well, all the same there's the potential energy involved, I'm sorry! < 3 sec>
90	Laurent	... ok, but if you had ...
91	Hortense	if we had ...?
92	Laurent	if you had a big steel ball ... it would rebound
93	Hortense	and if we release them at the same height, so that one has a greater mass than the other, the one with the greater mass would have a higher potential energy ...
94	Laurent	yes but
95	Hortense	so there would be more
96	Laurent	do you think that if … if you had an enormous rubber ball like that, that's a kilogramme, do you think it would rebound a lot?
97	**Hortense**	**yes, but that's only valid in the case of an elastic impact**
98	Laurent	well
99	Hortense	in fact I think ...
100	Laurent	we'd be better off thinking about that since, theoretically, it's more simple, given that it's a soft impact
101	Hortense	well yes, there is precisely … <laughs>
102	Laurent	so what can we say if there is a soft impact? < 2 sec>

[†] In this table, as in other similar ones below, the column labelled "N" corresponds to the numbering of the intervention, "Loc" is a name identifying the locutor (the students' names have been changed, whilst preserving gender, for confidentiality), and "Dialogue" reproduces a transcription of the students' verbal interaction. As with all other extracts from interactions shown in this chapter, this extract has been translated by the author from the original French.

Just prior to the sequence shown in Table 1, the students had performed an experiment where they dropped two balls of the same size from the same height, one of which was made of rubber and the other of steel.

In line 86, Laurent observes that the rubber ball rebounded to a slightly lower height than the steel one. Hortense then produces an utterance that is interpreted by Laurent as saying that the observation can be explained by the differences in mass of the two balls, which is what Laurent then denies (line 88). Since the students' task is to produce a general expression for explaining rebound behaviour, any proposal about a particular experiment can be interpreted as such a potentially general statement. We can therefore reconstruct the initial verbal conflict that initiates the argumentation sequence as follows:

Hortense: (*The "mass explains rebound" thesis*). The rubber ball rebounded less than the steel one because the rubber ball is less heavier than the steel one: *difference in rebound behaviour is due to difference in mass*.

Laurent: No: *difference in rebound behaviour is not due to difference in mass*.

Here we have a single thesis that is proposed, with respect to which the students attribute different epistemic statuses.

Throughout the sequence 89 to 96, the students develop their own arguments (in the case of Hortense) and counterarguments (in the case of Laurent), with respect to the "mass explains rebound thesis", neither really attending to the other. Hortense's argument in favour of her thesis is basically that, since "mass" is a term in the potential energy equation, then mass must be involved in the situation; since the steel ball has a higher mass, it has more potential energy, and so will rebound higher (and so the rubber ball lower). With respect to our remarks on the epistemic dimensions of modelling and of argumentative interactions, this is an argument that appeals to *school science knowledge*. Laurent's counter argument appeals to a different type of knowledge, derived from *everyday intuition*: what would happen with a very big rubber ball? Surely it would not rebound much? So it is not mass that explains rebound behaviour, but the substance.

What is interesting for our discussion here, is how Hortense defends her thesis against this counterargument, in line 97 (marked in bold in Table 1): **"yes, but that's only valid in the case of an elastic impact"**. This is a case *of conceptual dissociation* in argumentative interaction, during a modelling problem. The students were discussing "impacts" in general, and Hortense introduces a conceptual distinction: "[perfectly] elastic impact" / "soft [inelastic] impact". Furthermore, this discursive operation fulfils a specific function in the argumentative interaction: it is a specific type of defense of a thesis against an attack, that partitions the universe of discourse into two domains, within each of which both interlocutors can be 'right' (or at least not clearly wrong). The verbal conflict is thus 'dissolved', or redefined, so that it no longer obtains; and in fact the defense is successful to the extent that Laurent concedes indirectly by taking up the topic of "soft" impacts.

The students therefore decide to discuss the case of "soft" impacts, and the additional factors that would need to be taken into account in explaining the experimental result, as shown in Table 2 below.

Table 2: Corpus example 1, extract 2

N	*Loc*	*Dialogue*
111	Laurent	wait ... soft impact, well, y've got conservation of momentum but … the kinetic energy isn't conserved! I think that that's what we've seen … by contrast, in an elastic impact, both are conserved...
112	Hortense	yes, elastic impact, there is the total energy that's conserved
113	Laurent	yes
114	Hortense	yes, but there is the friction … of the air!
115	Laurent	oh, I don't think that that's especially the air friction that enters into it!
116	Hortense	but yes it is, otherwise, it would rebound to the same height
117	Laurent	no [it wouldn't]
118	Hortense	yes [it would]
119	Laurent	it's the loss at the moment of impact
120	**Hortense**	**it's the same, it's also a sort of friction! it's a sort of friction either with the ground or with the air**
121	Laurent	yes but, after all, air friction in comparison with friction … if if you call that friction with the ground, it's rather negligible
122	Hortense	ah well yes

At first, the students engage in a comparative discussion about energy and momentum in the two types of impact introduced previously. The students disagree with respect to Hortense's claim (that becomes a thesis to be defended) that *air friction* should be taken into account, since (she argues, in line 116) “otherwise it [the ball] would rebound to the same height”. This defense (rebounding to the same height) then introduces a subsidiary verbal conflict, since Laurent disagrees with it, and introduces a counter-thesis: “loss at the moment of impact” is the factor to be taken into account, rather than air friction.

As with the previous extract, it is Hortense who performs a specific discursive operation in the attempt to dissolve the conflict between the two theses (air friction / loss at impact), that this time corresponds to *conceptual association*, i.e. the inverse of conceptual dissociation: “**it's [loss at impact] the same, it's also a sort of friction! it's a sort of friction either with the ground or with the air**”. Since, as Hortense claims, air friction and loss at impact, are both types of friction, there is no fundamental conflict, and thus nothing to argue about. This time, however, her argumentative move is not successful, since she has to concede that loss at impact viewed as “friction with the ground” is negligible.

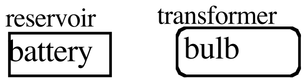
In our analyses of two extracts of an argumentation sequence in a physics modelling situation we have illustrated two discursive operations — conceptual dissociation and association — that reconceptualise the universe of discourse, and function as argumentative defenses (successful or not). It is clear that such operations are potential mechanisms of conceptual change, given that they work on a conceptual plane (whether or not, in a given case, the change is normatively positive or not).

Second example: negotiation of meaning and gradual dissociation of types of knowledge

The corpus from which the sequence analysed here was taken, was collected in a physics class of a secondary school (students aged 16-17 years) in the Lyon area (France). The class was experimental to the extent that a new teaching sequence (Tiberghien, 1996) on the theory and model of energy in physics, was being tried out on the students. The students' task was designed for learning about modelling in physics, and the theory/model of energy in particular (Tiberghien, 1994, 1996; Devi, Tiberghien, Baker & Brna, 1996). In the part of the energy modelling teaching sequence discussed here, students are asked to produce a qualitative model (diagram) called an "energy chain" in order to represent energy storage, transfer and transformation in a simple experimental situation involving a bulb connected to a battery by two wires. They do this on pencil and paper, sitting side by side in the classroom.

Table 3 below shows the first extract from an argumentation sequence involving two students. Their common solution up to this point is quite usual for this task: they have understood that the battery is a reservoir of energy and that the bulb is a transformer of energy. Their problem now is to determine the nature of the *transfer(s) of energy* between the battery and the bulb, and it is on this point that they disagree and engage in argumentative interaction.

Table 3: Corpus example 2, extract 1

N	*Loc*	*Dialogue*
		(Common solution up to this point:) 
181	Gordon	So, right, now the transfers. So, the transfer
182	Fiona	The transfer, there are two
183	Gordon	The transfers. So, modes of transfer
184	Fiona	In face have to do an arrow in each direction. Transfer 1, transfer 2. We do a transfer like that and a transfer like that, that we'll name afterwards
185	Gordon	Then, wait, euh, so from the battery there's a transfer
186	Fiona	We've got a transfer that is uhh
187	Gordon	So that is ((*inaudible*)) by two conducting wires. So the first conducting wire
188	Fiona	So uhh I do an arrow like that, I put, one, transfer one, like that, Gordon?
189	Gordon	Mm!
190	Fiona	And uhh I put wire, first conducting wire? ... Transfer 1, first conducting wire? ... And after I put transfer 2, second conducting wire
191	Gordon	Therefore, mode of transfer. So first wire, conducting wire, you put it underneath
192	Fiona	We'll put transfer. And there, we'll do another one in the other direction, it's the second
193	Gordon	Ah, no, no, no, no!
194	Fiona	But yes it is, but the circuit, it's obviously got to be closed
195	Gordon	Yeah, but the battery
196	**Fiona**	**Ah yes, but there isn't any energy, there isn't the case where, in fact, the bulb doesn't produce energy, so the wire that goes back to the battery, it's just for closing the circuit, it's not a transfer**

In the first part of the sequence (lines 181 to 191), Fiona proposes and elaborates a quite common (and doubly erroneous) solution to the question of the transfers, that is represented in Figure 1 below.

Figure 1. The solution initially proposed by Fiona

The first error with this solution is that it is not necessarily the case that a model element must correspond to every object in the experimental field: it is not because there are two wires that there must be two transfers. Secondly, this solution confounds two bodies of (school physics) knowledge: concerning electricity and concerning energy. Fiona proposes that the transfers go round in a circle because she is thinking of electrical current in the circuit. In fact, there should be just one energy transfer, from battery to bulb, called “electrical work”.

During this sequence, it is clear that Gordon does not fully follow Fiona’s reasoning (as shown by “wait” in line 185 and the “Mm!” in line 189); he is concentrating on his own line of thinking, as shown by his repeated insistence on determining the “mode” of transfer.

It is only when Fiona makes explicit what she is going to draw (line 192 “there, we'll do another one in the other direction”) that Gordon realises that he disagrees (line 193, “ Ah, no, no, no, no!”). Fiona’s defense, in line 194 reveals the electrical model with which she had been thinking: “ But yes it is, but the circuit, it's obviously got to be closed”. However, she quickly rectifies her error, on the basis of everyday knowledge — bulbs don’t store or produce energy — and retracts her thesis. In so doing (line 196; see also the later line 206), she *negotiates a more refined meaning* of the term “transfer” — the wire is not a transfer, it’s just for closing the circuit — by (the beginnings of) *conceptual dissociation* (/energy/electricity/).

However, Gordon has not yet understood this conceptual difference. The continuation of their interaction is shown in Table 4 below.

Table 4: Corpus example 2, extract 2

N	*Loc*	*Dialogue*
197	Gordon	Yeah but hang on, ok but wait, there's a negative pole. So, it goes from the negative pole to the negative pole? And from the positive pole to the positive pole?
198	Fiona	No, from the positive pole to the negative pole
199	Gordon	That's exactly what I thought!
200	Fiona	((*laughs*))
		<…>
206	**Fiona**	**No but look, there really is a second transfer for closing the circuit. But in fact, it's not a transfer, it's just for closing the circuit, so that the energy can go through.**
207	Gordon	Hang on, the current circulates from the positive pole of the battery to the negative pole of the bulb, but from that thing there, on the stand ...
208	Fiona	And then after, it comes back from the positive to the negative or from the negative to the positive. Mmm.
209	Gordon	plus, minus and plus to minus... Well then yes it is, that's right, there are two transfers!
210	Fiona	But no, there aren't two transfers.
211	Gordon	But yes there are!
212	Fiona	But no, because look, you can't … or else …
213	Gordon	But in any case, if there's only one, it won't work, I'm sorry
214	Fiona	Well yes, but that's all you keep on saying
215	**Gordon**	**Ah yes, in fact there's only one mode of transfer, it's true**
216	Fiona	No, there's only one transfer because
217	Gordon	The mode of transfer it's …
218	Fiona	Look, you go from the plus to the minus
219	Gordon	Yes, yes no but
220	Fiona	After that it goes from the plus to the minus, minus plus. Yes, no but what I mean to say is …
221	Gordon	There's only one mode of transfer that …
222	**Fiona**	**The issue is, I really agree with you that there is a second wire that closes the circuit, but the question is whether it's a transfer or not**
223	Gordon	No but ok. No, it's not a transfer
224	Fiona	Because she says clearly that a transfer is the thing that
225	**Gordon**	**It's a sort of, it's a mode**
226	**Fiona**	**It's a system … a transfer**

From lines 197 to 209, roles in the argumentation now switch round: Gordon now defends Fiona’s thesis, that he had previously rejected (!), and that she has now retracted. This illustrates clearly the fact that in argumentative interactions in such problem-solving situations, students’ thinking is highly volatile. We can thus not expect firm commitments to theses and strictly adversarial argumentation. Gordon is now fixed on the idea that there must be two “transfers”, otherwise the circuit wouldn’t be closed, and it wouldn’t “work”. In countering this view, Fiona further refines what is meant by “transfer”, and the dissociation between energy and electricity (see line 206). It is only when Gordon establishes the link between what Fiona is saying, and his previous insistence on the idea of “mode”, that his view wavers: (line 215) “Ah yes, in fact there’s only one mode of transfer, it’s true”. Fiona sums up their discussion in line 221 (“The issue is, I really agree with you that there is a second wire that closes the circuit, but the question is whether it's a transfer or not"), and Gordon now understands, so concedes (line 223: "No but ok. No, it's not a transfer").

In summary, this sequence of argumentative interaction provides a clear example of negotiation of meaning, turning around the terms and notions /transfer/ and /mode/, that is associated with a *gradual* dissociation of concepts and types of knowledge relating to /energy/ and /electricity/. It is important to note that both students do not achieve these dissociations at the same time; in fact, their intersubjective differences in points of view create a tension that 'drives' these discursive operations. Within the argumentative interaction, the function of these discursive operations is firstly for one student to retract their initial point of view, and then, when it is adopted by their interlocutor, to provide a counterargument against it. Conceptual dissociation therefore has a *critical*, or *counterattacking* function in this example, whereas in the previous one, it had a basically *defensive* function.

Third example: conceptual dissociation as an argumentative outcome

The third and final example that we discuss below is taken from a corpus of computer-mediated interactions, produced by students using the CONNECT Computer-Supported Collaborative Learning environment (Baker, de Vries & Lund, 1999; de Vries, Lund & Baker, *in press*). Although such typewritten and synchronous interactions, carried out via the Internet, are different in many significant respects to spoken face-to-face interactions (Clark & Brennan, 1991), our example shows that similar discursive operations can occur in them to those discussed above. In fact, CONNECT was specifically designed to favour the production of argumentative and explanatory interactions, bearing on scientific notions.

CONNECT comprises two interfaces, on the first of which two students compare their individual texts, written to solve a specific problem, and engage in a typewritten discussion whilst so doing. On the second interface, the students can write a common text on the basis of their individual texts. We have carried out a study with secondary school students (aged 16-17 years), performing a task that involves modelling sound in physics, using a molecular model. The students are asked to write a text that explains sound in terms of movements of molecules, for the following experimental situation:

> Two tambourines, T1 and T2, are hanging from a support, a small ball suspended from support touches skin of T2. When the skin of T1 is struck, the small ball resting on the skin of T2 moves. Consider three zones of molecules, from left to right, between T1 and T2: A (against T1), B (inbetween A and C), C (against T2).
>
> Question: What happens to the molecules near tambourine 1, the molecules in between the two tambourines, and the molecules near tambourine 2 (A, B, and C in the figure)? What changes in the behaviour of the little ball when tambourine is hit harder with the stick? Using two tambourines with a lower sound having a skin that is much less tight, what changes in the behaviour of the skin of the second tambourine when hitting the first?

From the point of view of studying argumentation about scientific notions, this task is interesting since students typically have a range of different conceptions with respect to it — e.g. sound as a type of wind, left to right displacement of molecules, and so on (Linder & Erickson, 1989; Maurines, 1998) — that create a wide potential space of debate.

In the extract analysed below, the students discuss two segments of their individual texts. On the first interface of CONNECT, the students are invited to express their attitudes (using check boxes) with respect to all segments of their own and their partners' texts, in terms of either "YES", "NO" or "?". We required them to do this so that they would read the texts attentively, and so that combinations of attitudes could focus their discussion. In Table 5 below, the two text segments are shown, together with the students' expressed attitudes. It is interesting to remark, from the point of view of social dimensions of argumentation, that Andrew does not express a direct "NO" with respect to Boris' sentence, but rather an ambiguous and non-committal "?".

Table 5: Text segments discussion and attitudes expressed by the students

Student	*Sentence discussed (text)*	*Attitudes expressed*	
		Andrew	*Boris*
Andrew	7. The less tight skin of tambourine 2 absorbs vibrations more, and so vibrates less itself	**YES**	**YES**
Boris	7. The less tight skin can be more easily moved by the molecules, but the ball moves less	**?**	**YES**

Table 6 shows an extract from the student's computer-mediated interaction, that is initiated by the apparently paradoxical nature of Boris' statement that the tambourine skin can be more easily moved, yet the ball moves less. In fact, the meaning of the verb "*to move*" will be an object of negotiation in the ensuing debate, since one conceptual difficulty associated with sound is that it is a type of *movement (propagation) of a movement (vibration)* of molecules. The students will thus have to dissociate these two specific types of movement.

It appears that what Boris initially means by "move", is amplitude, i.e. the extent to which the skin of the tambourine will stretch outwards, as shown by his defense of his claim (Table 6, line 44), according to which the slack skin will "move more" (i.e. a long way outwards), but will wrap around the little ball, thus making it "move less".

Table 6: Corpus extract (two tambourines problem)*

N	*T (m:s)*	*Loc*	*Dialogue / actions on the interface*
43	16:19	Andrew	If the skin moves more, why does the ball move less?
44	19:15	Boris	the skin moves more because it is less tight, but the air pressure exerted is the same. This skin therefore "wraps around" the form of the ball.
45	21:24	Andrew	Don't agree. In my opinion, the skin of T2 moves less (see my phrase 7).
46	27:20	Boris	difficult to know once one looks at the skin, one sees it move more that the one with the tighter skin when you hit something hard, which is stable in space, il won't move, whilst a piece of cloth that's not under tension, for example, yes [it will move]
47	33:14	Andrew	Another explanation: take a string that's not under tension. If you touch it, it's going to move a lot but it won't vibrate much. By contrast, a string under tension, like a guitar one, it will move little but vibrate a lot.
48	**36:37**	**Boris**	**i agree with your 7 but at one point I thought that you didn't agree with mine. For me the two phrases are right, it's just that simply they don't explain the same thing (vibrations and movements)**
49	39:23	Andrew	NO. If a less tense skin vibrates less, itm movesss more, therefore the ball must move more as well.
50	40:34	Andrew	pardon,have you understood?
51	43:29	Boris	Hypothesis: with the same air force exerted on T2: a tight skin will vibrate more that a less tight skin but will move less than the latter
52	43:37	Andrew	*[attitude "YES" expressed with respect to sentence 1 of Boris: "It perturbs the air molecules contained between t1 and t2. They move further away from each other."]*
53	43:44	Andrew	Yes
54	43:47	Andrew	Yes
55	47:55	Boris	as for the ball, I think that it would move less with the less tight skin since the skin would vibrate less so it would "transmit" a lot less vibrations.
56	0:01	—	*[change to phase 3 – cooperative writing task interface]*
57	0:33	Boris	Agreed?
58	1:17	Andrew	Maybe

* In this table, the "dialogue" column is a direct translation from the original French that was typed by the students themselves on the chat interface. In translation we have attempted to transliterate typing and/or spelling errors (e.g. "movesss"). The "T(m:s)" column shows the time at which the students sent their message, in minutes and seconds, as measured from the start of the interaction.

Andrew's attack, in line 45, reveals that he is working with a different meaning of "move", as *vibration*, a specific type of movement. In fact, in the original French of this transcription, the students both use, up to this point, a verb from everyday language ("bouger", to move") to describe movement, a more scientific term, that also exists in French in the form of a noun ("mouvement" = movement). The negotiation of meaning of "movement" and "to move" is therefore carried out in a situation where the following intersubjective difference obtains:

Boris: "to move" ("bouger") = amplitude

Andrew: "to move" ("bouger") = vibration

In line 46, Boris appeals to an everyday analogy (with a piece of cloth) in an attempt to defend his point of view, in fact trying to relativise the question: "difficult to know …". In his reply (line 47), Andrew in fact explicitly dissociates "vibration" and "movement", and Boris takes up this proposal (line 48), agreeing that although "vibration" and "movement" (now the scientific form of the noun, in French) are not the same (conceptual dissociation), both of the students' claims can be 'right'. In his reply (line 49), Andrew rejects this attempt to dissolve the verbal conflict, and in fact further refines the difference between vibration and movement*: if something vibrates less, it moves more*. This is a third proposed interpretation for "movement", as *frequency* (the number of times the string moves back and forth in a certain time). The argumentation sequence ends with no clear agreement: "Agreed?", "Maybe".

In summary, in this argumentation sequence, we can see the students attempting to negotiate shared meanings for the terms "vibration" and "movement" (in its everyday and scientific terminologies), and thus to dissociate the related concepts. This is in fact a crucial distinction to be made, in order that sound can be understood as a movement (displacement) of a vibration of molecules, but which is not successfully achieved in this case.

Synthesis and conclusions

In this chapter, we have argued that argumentative interactions put special socio-interactional pressure on people who engage in them to define what they mean, and thus to perform *certain discursive operations*: *negotiation of meaning*, *conceptual dissociation*, and *conceptual association*. In order to defend or attack a view or thesis, its meaning will need to be more precisely defined; an attack or defense may be effective under one interpretation of a thesis, but not under another. A discursive operation is a transformation of meaning, understanding or concepts, viewed as indistinguishable wholes with their linguistic counterparts, that is accomplished in and by discourse. It is a means by which discourse does work on meanings. Negotiation of meaning involves adjusting meanings in order to attain mutual understanding, conceptual dissociation involves distinguishing concepts from each other and conceptual association involves subsuming concepts under more general ones.

Modelling involves adjusting different levels of description (model, experimental field) in order that a matching can be found between them. In order to do this, different types of (school-learned and everyday) knowledge need to be brought to bear on the question. A prerequisite for being about to model is to be able to clearly distinguish these different types of description and knowledge in the first place, and in cooperative modelling situations, language necessarily plays an important role in these processes.

We conclude that the discursive operations described above, at work in argumentative interactions, can precisely play an important role in learning to model, since they can enable types of descriptions and knowledge to be differentiated from each other, and more clearly understood, this being a prerequisite for modelling.

Analysis of three extracts from interaction corpora collected in cooperative modelling situations revealed that the discursive operations described here function essentially as means of defense against argumentative attacks, or as attempts to 'dissolve' verbal conflicts. In the first extract, one student dissociated elastic and inelastic impacts as a means of enabling each student to be 'right', then associated air friction with "loss at impact", claiming that both were types of "friction". In the second extract, the students negotiated the meaning of the term "transfer" — of energy or of electricity? — in order to gradually dissociate these two types of knowledge. In the third extract, the students attempted to untangle complex semantic relations between the concepts of "vibration" and of "movement", with the latter appearing in everyday and technical language forms.

It was clear that the discursive operations carried out in these argumentative contexts did not necessarily lead to elaboration of more refined, or normatively preferred, meanings of concepts underlying modelling tasks. Thus, in analogy with the title of Toulmin's (1958) classic work, *The Uses of Argument*, we should perhaps speak here of *The Uses and Abuses of Argumentation*, since students can use it to attempt to avoid or else to address complex conceptual issues. However, since it is well known that students often solve problems without genuine understanding of underlying notions (Driver, Guesne & Tiberghien, 1985), we can at least say that the interactive processes and discursive operations we have described are *potentially constructive*, given that they do in fact work on a conceptual-linguistic (i.e. discursive) plane.

Argumentative interactions are therefore to be seen as embodying interactive and discursive processes that create *potential opportunities* for conceptual learning, rather than as cooperative learning mechanisms *per se*. The most important question for further research is therefore to understand how to create situations, involving direct teacher intervention and/or specially adapted pedagogical materials, in which this potential can be realised.

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