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Missed opportunities for learning in collaborative problem-solving interactions

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Abstract: When students attempt to solve problems collaboratively in learning environments they may miss opportunities to use available resources for achieving learning goals. We present an approach to qualitative analysis of such "missed opportunities" ("MOs") in collaborative problem-solving interactions, and discuss how the analysis can contribute to the design of the "CHENE" Computer Supported Collaborative Learning ("CSCL") system, that is used to support physics modelling tasks. Since benefits of collaboration require involvement of both partners, we concentrate on MOs to use one's *partner as a resource* in achieving goals of co-constructing domain concepts. After presenting analyses of different cases of MOs of this type, we discuss why MOs occur and how they may be identified. In conclusion, we propose a "minimal graded intervention" approach to guidance in CSCL environments that is intended to address the problem of MOs for learning.

Introduction

The past decade has seen an increased interest in extending the field of AI and Education from systems supporting one-to-one teaching interactions to the development of a wide range of systems supporting collaborative teaching-learning interactions (e.g. Chan & Baskin, 1990; Dillenbourg & Self, 1992; Gilmore & Self, 1988). Our earlier and independent work focussed on the development of analysis and modelling techniques for collaborative problem-solving dialogues with the aim of providing an empirical basis for the development of collaborative systems (Baker, 1991, 1994; Bielaczyc, Pirolli & Brown, 1994). In particular, for collaborative learning from texts, Bielaczyc (1994) has shown the importance of (collaborative) *elaboration* of instructional materials in learning, and Baker's previous work (1994) provides a detailed model for how elaboration takes place in collaborative dialogue as a process of negotiation.

In this paper we discuss how the results of qualitative analytical work on collaborative dialogues can contribute towards the design of components of computer-supported collaborative learning ("CSCL") systems. We discuss these issues within the context of the development of the "CHENE" system, a network system used to support collaborative problem-solving on physics modelling tasks.

The focus of the present work is on "*missed opportunities*" (henceforth abbreviated to "MO"s) for learning that may occur during the course of collaborative problem-solving interactions. We aim to define what MOs are, why they occur, and to describe how "minimal intervention" guidance may be provided so that these opportunities for learning may be exploited by students.

The idea underlying MOs is that in a given learning environment, the students have many *resources* available to them (e.g. the other student, instructional materials, manipulables) that could be used in order to achieve the *learning goals*, although students might *miss* the opportunity, at a given point in the interaction, to take advantage of them. Identifying an MO therefore requires at least two things : (1) identifying the learning goal that could have been achieved at that point in the interaction (but was not), and (2) identifying the available resources that could have been (but were not) used to achieve the goal.

Goals within a collaborative learning environment may also include that the students solve the problem (although this is viewed here as a means to the end of learning conceptual knowledge), and that the collaboration functions smoothly. Here we concentrate on the goal of "co-constructing" conceptual knowledge in the domain of physics, concerning the theory of energy, for which the students are given "modelling" problems to solve.

A particularly salient example of a MO that we have observed occurs when one student correctly reasons about and explains an element in the modelling problem, but the contribution is not "taken up" (i.e. accepted or elaborated further) by the other student, with this necessary element dropping out of the dialogue and never forming part of the final agreed problem solution : an opportunity for co-constructing conceptual knowledge (and for solving the problem) has been missed. Several different cases are described later in the paper.

Our emphasis on resources available in a learning environment is linked to an underlying "minimal graded intervention" educational approach : we want to enable students to attain autonomy by encouraging them to use available resources or "affordances", before resorting to more direct teaching methods. This, together with the key notion of MOs, is proposed as a basis for guidance in CSCL environments.

In the rest of the paper, after describing the CHENE CSCL environment, we define MOs, discuss specific examples from interaction transcriptions, and conclude with implications for CSCL. We focus on MOs to use one's *partner as a resource* in collaborative learning of *domain concepts*.

The CHENE system

"CHENE" (CHaîne ENErgétique ="Energy Chain") is a computer-based learning environment designed for teaching the process of *modelling* in science, for the specific case of the theory and model of *energy* in physics. It is used in classrooms with students aged 16-17 years as part of a regular teaching sequence of around 8 hours. Modelling is itself an important but little understood process (Greeno, 1989 ; Tiberghien, 1994) that involves establishing complex relations between the objects and events of an experimental situation and the theoretical terms of the scientific model.

The students' task with CHENE is to produce "energy chains" using a graphic interface, for a carefully designed series of three experiments involving simple circuits, and motion (a motor linked to a battery pulls up a weight, or the weight descends and lights up a bulb). An initial text is provided that gives basic definitions of elements of the chain (energy reservoirs, transformers and transfers), and rules for their combination (e.g. "a complete energy chain must start and end with a reservoir"). The tasks have been designed so that in order to solve these problems students have to (co-)construct a deeper understanding (the focus of our study) of the concept of *energy* . This is so since the problems can not be solved by simple one-to-one matching of experimental objects and events with model elements. For example, in a battery-bulb circuit, it is not the case that *both* wires correspond to two energy transfers (there is only one), and some notions (such as, obviously, "energy") at the theory-model level have no obvious physical counterparts. In a sense we can say that the students' task is to construct a meaning, or *semantics* for the model, given its *lexicon* and *syntax* (Tiberghien 1994). Typically, it is when the students try to surmount an "impasse" caused by necessity to satisfy one of the model rules (e.g. finding the 'last reservoir') that they are most led to make their conceptual understanding (explanations) explicit and to co-elaborate a common understanding of the model, particularly when there is disagreement and argumentation.

Figure 1 below shows an example energy chain (translated into English) for a simple battery-wires-bulb circuit, drawn by two students working together with CHENE via TIMBUKTU™ in a network, together with the trace of their written natural language dialogue. The main (and typical) errors made by these students were that they assumed that a model element (such as an energy transfer) must correspond to each object in the experiment (two wires between battery and bulb) and they were not able to generalise the "last reservoir" to the notion of the "environment". The students' modelling processes have been analysed in detail by Megalagaki & Tiberghien (1995) and a computational model capable of simulating the students' problem-solving for these tasks has been implemented (Bental et al, 1995 ; see also Bental & Brna, this volume).

In improving the design of the CHENE system we are specifically interested in using the results of analytical work on collaborative dialogues in the design of two particular components : (1) **design of the students' interface and communication tools**, and (2) **design of a component for automatic analysis** of certain aspects of the students' collaborative interaction (written dialogue, and trace of graphical interface) that can be used to guide the pedagogical intervention process. Our proposed approach combines (i) constraining ("scripting") use of the collaborative interaction interface by the students, (ii) generating minimal intervention guidance based on limited automatic analysis, and (iii) providing human teachers with information on the students' activities that will enable them to give guidance. Application of our analysis method to these questions will be discussed later in the paper.

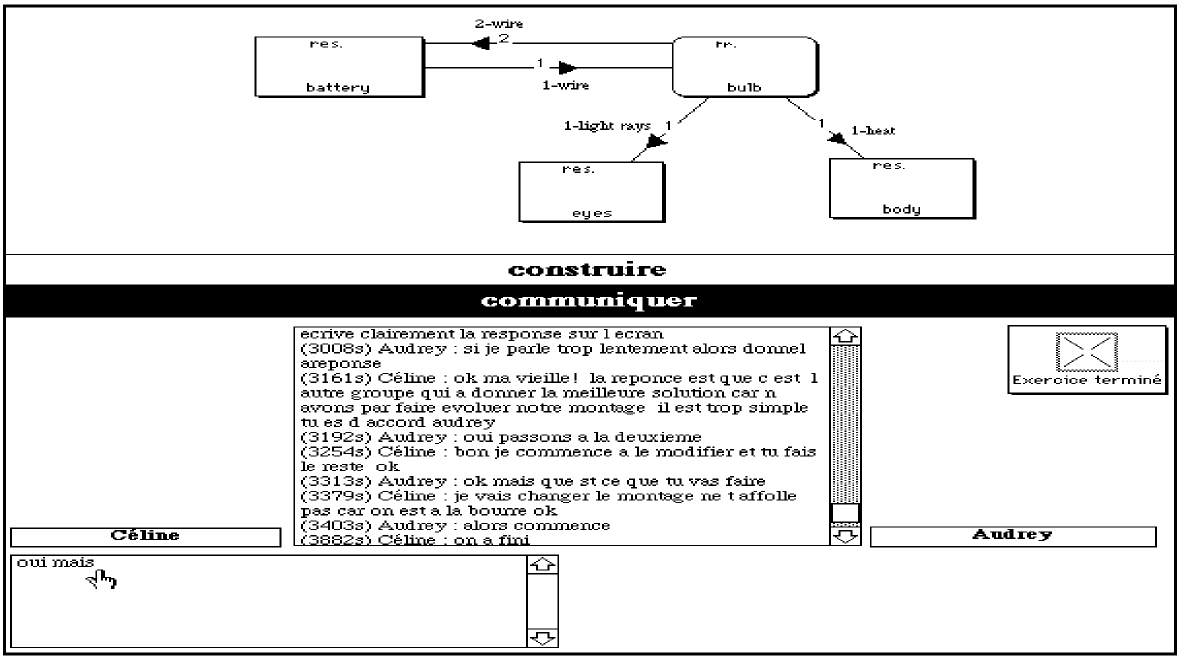

Figure 1. Energy chain produced by two students with dialogue in network situation.

Qualitative analysis of "missed opportunities"

What are "missed opportunities" (MOs) ?

In the task we are considering, the point is not necessarily that the students should "get the right answers" to energy-chain modelling problems, but rather that they should co-construct appropriate concepts or understanding in this domain (energy). To that extent, solving these kinds of problems is viewed as a means to learning, since the energy model they are working on has been devised for this purpose.

In the present paper we focus on two general classes of learning goals for the given problem solving task :

(1) *domain concept construction* - that the students should co-construct domain concepts, and engage in "higher level" reasoning activities (such as explanation), during the course of solving the problem ;

(2) *modelling* - that the students should learn how to determine and represent relationships between objects and events in experimental situations and their theoretical counterparts.

The concept of MOs is defined principally with respect to these goals :

Definition of a missed opporitunity : a "missed opportunity" occurs in a collaborative problem solving interaction when the **resources** available to the students provide an opportunity to achieve one or more of the **learning goals**, but the students did not use the resources towards this end.

Based on this definition, we developed a normative model in order to classify specific cases of MOs. Identifying an MO involves specifying two main components in the above definition :

1. the *goals* achievable at that point in the interaction ;
2. *resources* that could have been used to achieve the goals.

One set of learning goals has been described above. Particular examples include understanding the nature of energy - that it is always conserved, does not directly correspond to a physical entity, and may take several forms.

"Resources" are defined as entities that may afford learning opportunites in the given context. They may include the following : (1) partner ("as a resource") ; (2) the past statements and actions of the students within the current session (publicly available trace) ; (3) instructional materials (eg problem statement, text, information on previous solutions, for example) ; (4) the experimental apparatus, and results of experiments ; (5) the current solution drawing.

The analysis approach is as follows. The joint problem space (Roschelle & Teasley, 1995) of interest is taken as a point where students are working on a particular component of the energy chain model. For the given component, check whether the students are engaged in (1) higher level reasoning and domain concept co-construction, and (2) the appropriate modelling. If students engage in neither (1) nor (2) for that particular component, then all points in the interaction where students focus on that component are examined in order to determine the resources available for doing either 1 or 2. A characterisation is then made regarding how the particular resource provides an opportunity to achieve the learning goals, and a choice is made concerning guidance to be generated for the given resources that could be used.

As our interest is in the collaborative interactions that occur during joint problem solving, we concentrate here on the possible and missed opportunities for using one's *partner as a learning resource*. Three examples are discussed in the next section.

Examples of missed opportunities to use one’s partner as a resource

One’s partner can provide a valuable resource for learning - as a learning model, an information provider, critic, and so on (see Bielaczyc, 1994 ; Linn & Burbules, 1991; Slavin, Sharan, Kagan, Hertz-Lazarowitz, Webb, & Schmuck, 1985). In the case of CHENE we are particularly interested in the opportunity to use one’s partner in order to co-construct *explanations* about the domain and engage in shared reasoning about modelling. In the three examples shown below, the focus is on whether students collaboratively engage in such “higher forms” of reasoning. If there is to be any benefit from collaboration, then it is important for both partners to be involved in this reasoning process (Webb, 1989 ; Bielaczyc et al, 1994).

<u>MO example 1 : one partner engaged in higher level elaboration, other partner does not join in.</u>

In the dialogue extract shown in Figure 2, students "F" and "L" [names have been changed throughout this paper] are attempting to construct an energy model for an experiment involving a bulb linked to a battery by two wires. It is very close to the beginning of the interaction, and the students begin (as do all the others we have studied) by considering the battery (in accordance with "linear causal reasoning", the battery being the "first cause").

F. The reservoir stores. Hey, Laurent ? Storage, is it... **The reservoir stores energy, so it is the battery. In the battery, there is energy**, you agree? So, put battery, arrow, storage	
	L. Battery.
F. But you are really slow. Battery, arrow, storage.	
	L. Battery, arrow, storage. The transformer is transforming energy. Well, it's the bulb.
F. No, it's the contact. Isn't it? Yes, yes, you are right. **It's the bulb, because it is transforming energy into light.**	
	L. Transformer. So there are wire conductors which are bound to be transfers.

Figure 2. Missed Opportunity example 1 : one partner elaborates, other does not join in.

The MO can be described as follows. In the course of the extract, the students determine various components of the energy chain : the battery-reservoir correspondence, the bulb-transformer correspondence, the wire-transfer correspondence. However, in determining these correspondences, F and L are both operating at different levels. During F's turn, she provides rationales for why the experimental elements correspond to the particular energy chain components (in **bold**), thus satisfying the *goal* of elaborating domain explanations, and attempts to establish agreement with her partner (e.g. "Isn't it?").

Rather than using this opportunity to build upon F's contributions and discussing these underlying reasons further (perhaps by identifying what form of energy the bulb transformed into light ?), student L does not "take them up", and remains at the 'matching' level (he goes on to match the energy transfers with the wires). Even though he is "collaborating" in the sense of making a contribution to the joint solution, he is not jointly constructing domain concepts and exploiting the *resource* provided by his partner's contributions. We therefore claim that an opportunity for higher level reasoning and learning has been "missed" by both partners.

<u>MO example 2 : both partners miss the opportunity for higher level reasoning</u>

In this example, students P and F are attempting to solve the same problem as the students in the previous example. Whereas in example 1 both students were operating at different levels, in this example *both* students remain at the 'surface' level of matching elements of the experiment (the bulb) with model elements (the transformer). The students thus miss the opportunity for achieving the *goal* of engaging in higher level reasoning as to why the bulb is a transformer, what it transforms, into what, and so on. They could have, however, used the *resources* provided by the instructional materials (text), where basic definitions of transformers and reservoirs are designed to trigger reflection on the concept of energy and with respect to an underlying model based on linear causal reasoning.

P : Here it is. And the bulb.	
	F : And the bulb, it will be the...
P : ... the …	
	F : ...transformation, yes.
P : Yeah.	

	F : It will be the transformer.
P : Yes. Well, let’s write.	
<…23 turns omitted …>	
P : This time it is a transformer.	
	F : Yes, that's it.
P : That we call the lamp.	
	F : Bulb or lamp?
P : Lamp	
	F : The lamp
P : ...it's shorter.	
	F : We call it the lamp or the bulb?
P : Well, it’s the same, eh.	
	F : ... Yes, it’s better, lamp. Tac, tac, tac. Yes, it is going fast.

Figure 3. Missed Opportunity example 2 : Neither partner seizes the opportunity.

With respect to this example it is important to note that at no time in the course of solving the problem do the students elaborate the transformer-lamp connection. They visit this component twice, once when planning the solution and secondly when typing it in on the computer and setting up the labels that the transformer is the lamp. In a sense we might say that in this case there is a kind of "false consensus", an agreement reached too easily - the collaboration goes smoothly and an energy chain is constructed, however the students do not make explanations or provide rationales. In this manner an opportunity for higher level learning is missed.

<u>MO example 3 : one partner cues elaboration of explanations, other partner does not join in.</u>

In the two previous examples, opportunities for higher level learning were missed either because one student actually initiated such reasoning and the other did not elaborate this, or because neither student did such reasoning. In this example, neither student actually initiates higher level reasoning, although one partner (P) "cues" the higher level by asking her partner (F) to clarify his reasoning as to why heat and radiation are relevant to the current problem (the learning goal). This question could have elicited co-construction of concepts through justification and reasoning, but the opportunity was missed since it is not taken up by F and not pursued further by P.

	F : Uh, transfer between a reservoir and a transformer or between two reservoirs. Transfer of energy. Well, we know that. Different modes of transfer of energy, from one system to another one, or work, heat, and radiation. For us it is heat and radiation.
P : **Of what?**	
	F : There
P : Mmm.	

Figure 4. Missed Opportunity example 3 : one partner cues explanation elaboration, other does not respond.

This example illustrates the fact that one partner's contribution can become a common *resource* to be exploited not only by providing a concrete example of a partial attainment of a learning goal, but also by identifying a possible opportunity when the goal could be attained (an opportunity that may or may not be missed).

This is a particularly salient example because F has contributed *part of the right answer* (the transfer does correspond to heat and radiation), but it is not elaborated on by either partner ; it *never appears* elsewhere in the protocol, and does not form part of the final solution proposed by the students. Thus, not only do students not engage in constructive activities regarding these components of the energy chain, but they also "lose" these components as part of the solution.

Discussion

Why are learning opportunities missed ?

We discuss possible reasons as to why opportunities may be missed to use one's partner as a resource in collaborative learning of domain concepts and high level reasoning processes, in relation to the above examples.

(1) One possible reason relates to *spontaneous collaborative task division without role switching*. For instance, in example 1, student F adopts the role of attending to underlying causes and higher level reasoning, often drawing on everyday knowledge, whereas student L takes care of "getting the right answer", often referring back to the task instructions and the given problem statement. This division is relatively *stable* throughout the whole interaction. Such task divisions and roles have been found to switch back and forth over the course of the interactions (Miyake 1986 ; Teasley & Roschelle, 1995), and this is particularly important in the present context where both students should be elaborating and actively engaged in order to benefit.

(2) A second possible reason relates to what we term "*non-interlocking phases*" in the collaboration between students. Students may not elaborate each other's contributions simply because they are each at a different phase of problem solving - one may be still at the phase of trying to understand the question, or doing the experiment, whilst the other has progressed to higher level reasoning. They may thus not elaborate or respond to questions concerning underlying reasons for the solutions proposed, missing opportunities to use each other constructively in deepening understanding.

(3) A third possible reason concerns what we have termed a *false compromise* in collaboration viewed as negotiation (Baker 1994). In the collaborative situations studied here, the students are asked to reach *agreement* on a single solution ; but this may have the perverse effect that they may be too easily agreed, without adopting a sufficiently critical attitude with respect to *explanation* and *verification* of solutions (see example 2 above). In this case we need to find some way of encouraging the students to ask the right kinds of questions concerning underlying reasons, *and* to attempt to answer them (see example 3 above).

Identifying MOs : implications for design and guidance in CSCL environments

We now discuss the identification of MOs and their relevance for the design of AI & Education systems.

The difficulty of identifying MOs computationally in a CSCL environment such as CHENE depends on the goals and resources concerned. Problem solving goals could be identified by model tracing using the computational model for solving energy chain problems that has been developed (Bental et al, 1995), combining analysis of graphical interface actions with limited natural language understanding techniques to analyse the students' written utterances. An effective representation of semantic links between resources and goals to which they are relevant is also required.

However, identification of MOs where the students' dialogue contributions themselves are considered as resources poses problems that stretch existing techniques up to and beyond their limits, such as determining whether an utterance corresponds to an "explanation", and determining the degree to which subsequent interventions are "relevant elaborations" of such explanations.

For these reasons we are adopting an approach that involves a combination of (1) developing a new constrained communication interface, (2) generating flexible guidance for the collaborating pair, and (3) generating explanations for human teachers concerning the students' activities. The first approach involves providing buttons for communicative functions, such as "give reasons", "elaborate on contribution", "contribute solution element", "agree", and so on. The existence of such units helps to structure the students' interaction, to implicitly suggest that these activities can be engaged in, and to alleviate some typing difficulties. It also provides us with the means for tracing the interaction in a form that is structured so as to facilitate limited automatic analysis on which guidance can be based.

At a given point in the interaction, the system could mark several points on the ongoing transcript where an MO has occurred, together with the appropriate resources. The intervention method could then be based on notifying students that an MO has occurred and having the students themselves address the MO. Such notifications could include : MO for using one's partner as a resource for higher level reasoning ; MO to follow up on partner's question ; MO to use the information provided in the problem statement ; and so on. The ongoing transcript of the students' interaction (provided in CHENE) itself provides students with a tangible trace of their activities, allowing them to reflect on what they themselves have previously said or done. The importance of using such traces for reflective activities has been discussed by Collins & Brown (1988) and Katz & Lesgold (1993).

Guidance in terms of MO's can be handled according to a ZPD intervention scheme (see Campione & Brown, 1990), corresponding to the following graded levels of intervention :

Level 1. For a given missed opportunity indicate to the students the location and type of missed opportunity. Ask the students to resolve these missed opportunities on their own.

Level 2. If the students are unable to satisfactorally resolve the missed opportunity at level 1, then teacher may prompt students further.

Level 3. If the students are unable to satisfactorally resolve the missed opportunity at level 2, then teacher may model for the students the desired way to resolve the missed opportunity.

In this manner, we are proposing to use the scheme of MOs as a basis for addressing the classic problems of "when", "what" and "how" to intervene that were first raised in the context of individualised coaching systems (Burton & Brown 1982), but within the context of *collaborative* learning environments.

Conclusion

In this paper we have proposed a theoretical and empirically based approach to generating minimal intervention guidance in CSCL environments, based on the notion of "missed opportunities" for learning high level reasoning processes and domain concepts, concentrating on the use of the collaborative partner as a resource.

We have proposed a method for qualitative analysis of MOs that may be useful to CSCL designers as well as to educational researchers. The approach is fundamentally *learner centred* in that it emphasises the possible opportunites for learners to use resources in the learning environment adapted to their achieving their own goals, rather than the planning, execution and achievement of the system-teacher's goals. In other words, instead of posing the question "what intervention should the system-teacher do now ?" we ask "what could the learners have done in this context ?", and "what minimal guidance could help them to achieve their goals ?".

We plan to use the analysis method described here as the basis for future developments of the CHENE CSCL system, for which our further work will concentrate on computational analysis of MOs and generation of minimal intervention guidance.

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