A Contradiction-Driven Approach of Learning in Discovery Learning Environments

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Abstract. *In Educational literature, Discovery Learning appears as an approach in which the learner builds up his/her own knowledge by performing experiments within a domain and inferring/increasing rules as a result. Such a constructivist approach has been largely exploited in the design of computational artifacts with learning purposes in what is today known as Discovery Learning Environments (DLE's). In this paper we are concerned with the design and usage of particular DLE's, within which learning events occur as a consequence of contradiction detection and overcoming, during human/machine cooperative work. We firstly introduce a model of an agent capable of handling such an approach of learning, by highlighting the exchanges that the agent should promote with a human learner. The model lies on the basis of the scientific rationale, particularly the empirical approach guided by the theory-experiment confrontation. We shall then reinforce the interest of the model for the design of DLE's, by presenting its exploitation in a real learning situation in Law.*

Key words: Discovery Learning, Contradiction, Human/Computer Cooperation.

1. Introduction

The model of knowledge formalizing known as Phi-calculus [da Nóbrega et al., 2002b] has appeared as an attempt to abstract a successful approach practiced since 1994 by the lawyers of the Company Fidal-KPMG grouping 1200 lawyers in France. Lawyer's daily activity consists of understanding, proving and comparing contracts. The issue for innovation for them is that laws and norms change continuously, so contracts have to be conceived accordingly. The Company has identified classes of contracts, and for each class has decided to offer lawyers a *Contractual Framework* (CF). A CF represents the knowledge that enables the artificial agent *fid@ct* to assist the lawyers in their activity. Whenever the Company identifies a contract class, it delegates the design of the corresponding CF to a team composed of a senior lawyer and two novice lawyers, who are supposed to interact both with each other and with fid@ct aiming a CF.

Fidal's method to design a CF may be summarized as follows (Figure 1): after having analyzed a number of contracts previously written by experimented lawyers of the Company, the novice lawyers propose a CF, and then test and revise it under the supervision of the senior lawyer. The cycle is repeated until a CF is judged stable by the senior. CFs thus constructed are used by fid@ct to assist about 400 lawyers of the Company, and it takes about 30 minutes instead of several hours, for a lawyer to write a contract assisted by the agent. The Company has patented both the method and the agent fid@ct.

While a Contractual Framework itself is the object of main interest for Fidal's lawyers, from the perspective of Human Learning, we are mainly interested in its *process of construction*. The main question we address is: do novice lawyers learn something due to the interaction both with the senior lawyer and the fid@ct agent during the process of construction of a CF? In a previous paper [da Nóbrega et al., 2001], we argue on a characterization of a Learning Environment (LE) for Fidal's method. As a starting point, we adopt as a principle the view of Human Learning as a potential, indirect side effect of Dialogues, the agreement resulting from discussions by eminent scholars, as summarized in [Cerri, 1994].

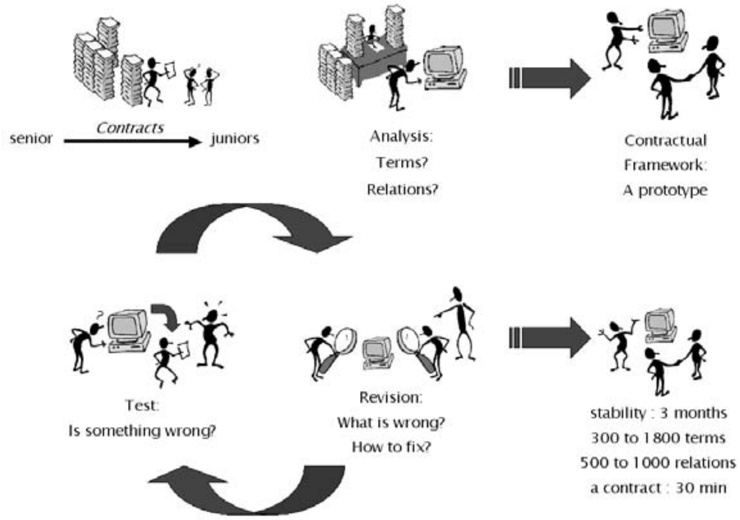

Figure 1: Scenario of Fidal's method.

A popular property of LEs is that they often embody some "true" knowledge that is supposed to be "acquired" by the learner by interacting with the system. Socratic tutoring methods, on the contrary, attempt to emulate the autonomous discovery process for the causes of inconsistencies by the learner as a consequence of challenging him/her with dialectic arguments. In this direction, "the concept of discovery learning has appeared numerous times throughout history as a part of the educational philosophy of many great philosophers particularly Rousseau, Pestalozzi and Dewey, 'there is an intimate and necessary relation between the process of actual experience and education [Dewey, 1938]'. It also enjoys the support of learning theorists/psychologists Piaget, Bruner, and Papert, 'Insofar as possible, a method of instruction should have the objective of leading the child to discover for himself' [Bruner, 1967]" [Bartasis and Palumbo, 1995]. In spite of these pedagogical suggestions, few LEs are founded on these principles. Rather, most LEs developers wish "the truth in a domain" to be acquired by learners exposed to "the truth". In Fidal's method, in order to propose a CF, novice lawyers perform abstraction by themselves as they analyze achieved contracts in order to establish what terms should appear in a Contractual Framework for the corresponding contract class. Also, they infer autonomously logical constraints stressing relations among those terms, in a meaningful manner. In Human Learning, as stated by [Cañas et al., 2002], building meaningful relations should reflect the student's understanding of a domain, being a harder task than coming up with the concepts themselves. Moreover, within fid@act, the prominent view that the "true" knowledge should be in the machine is changed, since it is provided only with the capability of handling propositional constraints among terms. Such a capability allows the agent to work like a *mirror*, reflecting thus to the novices inconsistencies in the knowledge that they have externalized during the process.

Discovery learning is also characterized as an iterative approach, in which errors work like a source of revision, as knowledge is supposed to be constructed by trial and error from experience. This issue is also present in the rationale of Fidal's lawyers: inconsistencies detected are exploited aiming to improve a CF. The convergence, often a problem with this kind of approach, is achieved thanks to the fact that knowledge represented by RFs reflect the way of thinking and working of a group, and according to the Law to which they are submitted. This meets the constructivist views of learning, from which knowledge and learning are dependent of context, person, and social situation [Jonassen, 1991].

Recent work [Baker et al., 2001] privilege methods and tools facilitating the acquisition of meta cognitive skills, the so- called soft skills, with respect to domain independent "true" knowledge and skills. We see the development of cognitive skills as a potential consequence of discovery learning activities, since explanation and argumentation capabilities are crucial to perform tasks like build up a hypothesis or interpret experimental results such as required to revise or confirm hypotheses. At the same time, soft skills are also a requirement whenever the control is transferred to the learner interacting with a system [Aleven and Koedinger, 2000]. In Fidal's method these two (in principle controversing) perspectives co-exist and are even complementary since individuals are embedded in a collaborative environment. The relevance of *collaborative* learning has a classical consensus in the Educational community [Goodman et al., 1998, Andrade et al., 2001]. In addition, recent work on ITS [van Joolingen, 2000] points out how discovery learning and collaborative learning may be joined to design effective learning environments.

The dialectic, autonomous, domain-independent, constructivist, and collaborative aspects of the Fidal's approach suggest us a positive answer to the question that we are addressing (do novices lawyers learn anything...?). Expecting to confirm our assumption (that the answer is positive), we have decided to expose real learners to the method. In order to support the learner's work, we have implemented a Web-served LE, called *PhiInEd* [da Nóbrega et al., 2002a, da Nóbrega et al., 2002]. From a widespread perspective, the work on PhiInEd can be seen as an attempt to validate the model Phi-calculus when this latter meets the cause of Human Learning.

In §2 we partially present Phi-calculus, as a model for the design of DLEs; these could be though of as artificial agents supposed to stimulate learning by handling contradictions, while interacting with a human learner. In §3 we reinforce the interest of the model by reporting a real study situation held upon the server PhiInEd. Finally, in §4 we present our concluding remarks and point out ongoing work.

2. A contradiction-driven computational learning model

In order to present Phi-calculus as a model for the design of DLEs we shall consider:

- An Artificial Agent provided with no initial knowledge, but having two skills, namely, *(i)* handling propositional logical constraints, and *(ii)* learning from examples;
- An illustrating scenario developed upon a classical toy domain, which has been chosen in order to facilitate the presentation of both structural and functional elements of the model. Structural elements account for "Knowledge Types", each of which representing a state that an evolving theory can assume. Functional elements account for the mechanisms required for each agent to contribute for the theory evolution; The whole formalizes what we have called a Reasoning Framework, the current abstraction for the notion of Contractual Framework introduced in §1.
- A perspective of the exchanges that can take place between the Artificial Agent and a Human Agent (referred as to the Learner) while a theory is built/revised as a consequence of contradiction detection and overcoming. Such a perspective is based upon the speech acts *ask* and *tell*, which role is to model messages that carry out the Knowledge Types mentioned above.

Considering the scientific rationale based upon the iterative and (eventually) converging cycle "experiment-and-theory", three main phases are proposed to support the exchanges among the agents: *(i)* Collecting information, *(ii)* Analyzing and Prototyping, and *(iii)* Testing and Revising. Let us consider these phases in the context of a dialogue between a learner Human Agent and his/her Artificial Agent, during which the former one drives a study about a certain concept.

2.1 Collecting information

In this phase, the information available to feed the theory formation process is collected. This might be or not a process allowed by the Artificial Agent. Let us consider the negative case, and, thus, we shall not consider the exchanges that could model the Collecting phase.

Let us now start our hypothetical scenario by supposing that a History student interested in historical monuments intends to formalize the concept of "Arch". Let us suppose that, during a trip around the world, the student has taken some pictures in order to begin the study. The hypothetical images are those of Figure 2.

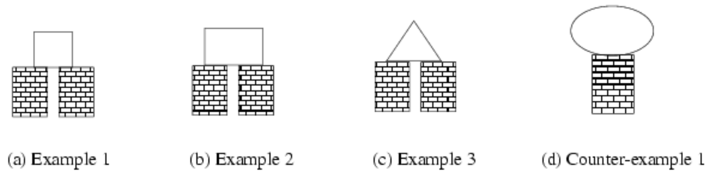

Figure 2: Hypothetical available objects to begin the study of the concept "Arch".

2.2 Analyzing and Prototyping

This phase should lead to *(i)* a Hierarchy of Terms representing the vocabulary supporting the study, and *(ii)* a Set of Constraints, which role is to constrain the usage of those Terms, as the constraints achieve formal relations among the Terms. The sub-phases leading to such structures are described below.

Hierarchically organizing a vocabulary. To go on with the hypothetical scenario introduced above, let us suppose that the student considers each object as being composed of a number of pieces, each one generally named, say, a form. Then he observes that the "forms" can be grouped together according to a classifying criterion, for instance, "to distinguish the forms that should roll when put on a planar surface from those that should not". By using such a criterion, the student could obtain on the one hand, stable forms (square, triangle, rectangle, block), and, on the other hand, unstable forms (oval). Such a student's reasoning would lead to a hierarchy as the one shown in the left-hand side of Figure 3. The exchanges needed for the agents to formalize such a hierarchy are shown in the right-hand side of Figure 3.

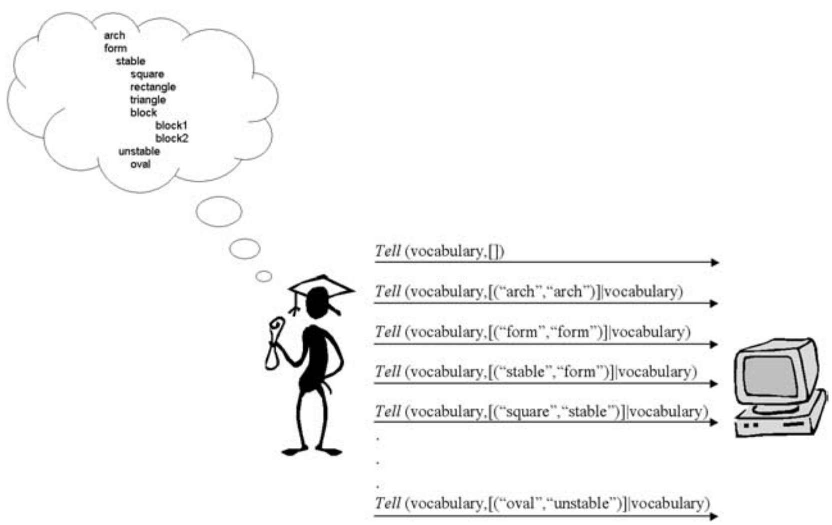

Figure 3: The Learner tells the Artificial Agent the vocabulary supporting the study.

Constraining a vocabulary. The model suggests that, in a given moment, a theory is represented by an Axiomatics. Considering the dynamical character of a theory, Axioms may join or leave an Axiomatics, according to experiments carried out. The model allows for Axioms to join an existing Axiomatics either in a direct or an indirect manner. The former case accounts for the situation in which the user is able to identify a certain relation between the objects being studied, and then build up the corresponding constraints to stress the relations. The latter case accounts for the situation in which the user recalls the Artificial Agent's learning skill in order to look for suitable relations. Hereafter, we show the exchanges modeling the indirect case, to which the following sub-phases take place: *(i)* Describing Examples to the Artificial Agent, *(ii)* Building up Constraints out of the Examples, and *(iii)* Filtering Learnt Knowledge.

Describing Examples to the Artificial Agent. In order to show up the exchanges allowing the Human Agent to describe an object to the Artificial Agent as an Example, let us consider the object named *Example1* from Figure 2(a). These exchanges are shown in Figure 4: *Example1* is described by stating that a square is *present*, a first block is *present*, a second block is *present*, and an arch is *present*.

The description of an object corresponds in the model to the Knowledge Type “Theorem”, standing for a theorem to be proved out of the Axioms representing a theory. Once a Theorem is built, it may become an Example, such an operation modeling the fact that the Artificial Agent should memorize the object for latter use.

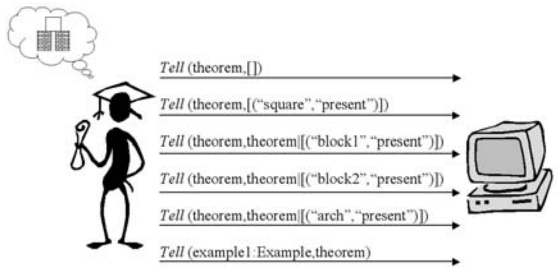

Figure 4: The Learner proposes an object to the Artificial Agent.

The Artificial Agent proposes a number of Constraints. Let us assume that the Artificial Agent knows the Examples representing the objects of Figure 2, and thus it is ready to learn general rules (Constraints) about them. The model Phi-calculus assigns each learnt rule to a Knowledge Type “Lemma”. The exchanges between the agents are shown in Figure 5, over two illustrating Constraints that could have been learnt from the provided descriptions of the objects from Figure 2.

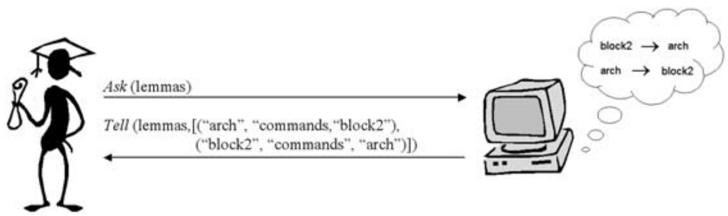

Figure 5: The Artificial Agent tells Lemmas to the Human Agent.

The Human Agent filters the Learnt Knowledge. Once he is informed about learnt Lemmas, the Human Agent may analyze them in order to compose what is formalized by the Knowledge Type “Conjecture”. A Conjecture should retain only those Lemmas estimated by the Human Agent as pertinent. Once the analysis is over, the resuting Conjecture is memorized by the Artificial Agent as an Axiomatics ready to be exploited. In Figure 6 we show the exchanges supporting the composition of a Conjecture and then its status changing to become an Axiomatics. In our scenario, we suppose that the Human Agent accepts as a Conjecture (then as an Axiomatics) both two Constraints proposed by the Artificial Agent.

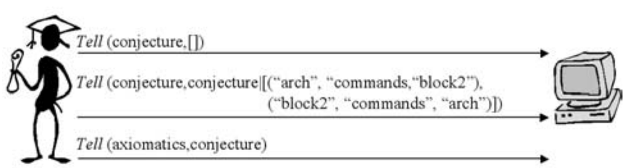

Figure 6: The Learner tells the Artificial Agent a Conjecture.

2.3 Testing and Revising

Up to this point we have shown Phi-calculus through some of the exchanges required to build a theory. As stated before, the model assumes that a theory is something constantly evolving as a consequence of experiments carried out. Once the Artificial Agent knows an Axiomatics, the Human Agent may then test its validity, by proposing a number of objects unknown by the first agent and then asking this agent about the object's *Adequacy* with respect to the current Axiomatics. The exchanges modeling such a situation are shown in Figure 7. The testing object, proposed through the Knowledge Type “Theorem”, is the one shown on the left-hand side of the picture. The figure shows as well the exchanges allowing the Human Agent to know the object's adequacy (with respect to the Artificial Agent's current Axiomatics).

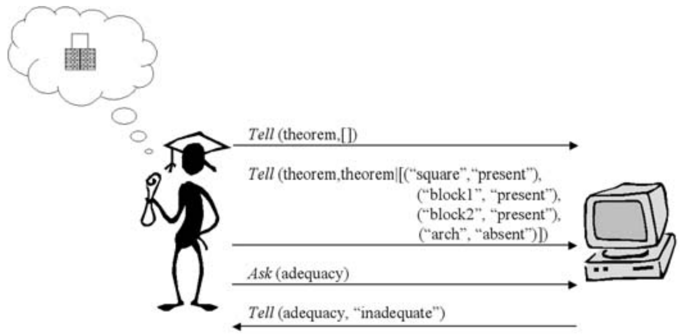

Figure 7: Learner proposes an unknown object to the Artificial Agent, who judges the object as Inadequate.

At this point we reach the heart of Phi-calculus as a contradiction-driven approach to theory formation. The Inadequacy of an object declared by the Artificial Agent lies on the basis of a *contradiction* revealed while the agent confronts the object description with the current Axiomatics. A revision process should then take place in order to reach a coherent behavior for the Artificial Agent. Such a revision process would require, however, the Human Agent to know *how* to reestablish the coherent status of the theory. As this is not always evident, before such a revision process could take place, the Human Agent may need to find out *why* a contradiction arises. The exchanges are shown in Figure 8, in which the Human Agent asks the Artificial Agent the reasons of its judgment.

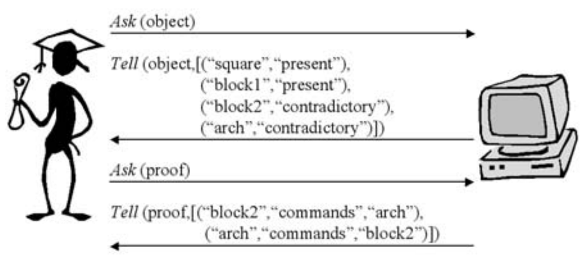

Figure 8: The Learner asks the Artificial Agent the reasons of its judgment; the Agent answers.

By means of the Knowledge Type "Object", the Artificial Agent shows how the proposed object looks like to it: the resulting description is a result of both the description from the Human Agent and the propagation of the Constraints (Axioms) from the current Axiomatics. In our scenario, the Term *Arch* is evaluated both as *present* (as a consequence of propagating the constraint **Block2 $\rightarrow$ Arch**) and *absent*, (from the Human Agent's description), thus, *contradictory*. Moreover, by means of the Knowledge Type "Proof", the Artificial Agent shows to the Learner the Axioms causing its judgment (i.e., the violated Constraints).

Having found out that the theory is over-constrained, the revision process consists for the Human Agent to tell the Artificial Agent to forget Axioms. This maybe a relatively simple way of revision. A more complex revision process is the one requiring to go back farest in the theory formation process, for instance, the need to reformulate the vocabulary and then to reformulate the way of describing the Examples, and yet to ask the Agent to re-learn over the Examples, and so on. In fact, this whole reformulation would be the case if we would go on with our scenario, since, provided that we would relax the Axioms responsible for Inadequacy, the Artificial Agent would not be able to decide about the property of being an Arch neither for Example 1 nor for Counter-Example 2. One might then notice that, except for the evaluation of the Term *Arch* itself, the description of these two objects are quite similar, so that the learnt rules could not capture their distinctions.

3 A contradiction-driven study of Contractual Techniques in Law

In this section we highlight the interest of Phi-calculus for the design of Discovery Learning Environments by reporting a real study situation held upon the server PhiInEd. We leave the hypothetical scenario developed above upon the block's world, and we recall the Law domain, already evoked in §1. Here, however, a pedagogical context is voluntarily created. A class of twenty-seven students of D.E.A. (*Diplôme d'Etudes Avancés*), from *Université Montpellier* I, Montpellier (France), under the supervision of Prof. Dr. Didier Ferrier (referred as to the Teacher), have been using the server during seven sessions of three hours.

The subject of study. The chosen subject of study for the course was the so-called *General Conditions of Sale* (GCS). The definition of GCS requires the understanding of the process of formation of a contract. This latter is established whenever an offer meets an acceptance resulting in an agreement that constrains the behavior that the two sides intend to adopt with respect to the other. In such a context, the GCS are defined as an offer of contracting addressed by a seller to any buyer interested on acquiring his products. This offer constitutes then the individual norm of the behavior that the seller intends to impose to his potential buyers. The simple unconditional adhesion of the seller's conditions by a buyer should be enough to form the contract, and the individual norm composed of the seller's conditions becomes then the norm common to the two sides.

The scenario. The Teacher has initially chosen the GCS as the subject of study. A Reasoning Framework (RF) should then be constructed for this contract class. The goal was to obtain a single RF as a result of the work of the whole group. Firstly, students were distributed in seven working groups, each group working around a single machine. Each group should then prepare a RF by analyzing a GCS document from the Web. Secondly, a single RF should be generated as a fusion of RFs from the groups. Finally, this resulting RF should be revised under the supervision of the Teacher, up to be considered by the group as stable. Below, we detail this scenario through the two phases of a course taken into account by the server PhiInEd, namely, *Planning* and *Running* [da Nóbrega et al., 2002a].

3.1 Planning

Global Objectives. These were stated as "To be able to elaborate, criticize and improve particular contracts; to be able to apply general contractual techniques to specific contract classes."

The resulting Plan. The course was planned along six Lessons, each of which is introduced hereafter, through its local objectives, Resources/Exercises, and a report on how the students carried it out. Notice that Resources are, in the server, Web pages giving technical support to the corresponding conceptual notion of *Example* from the model. Examples here are not Arch pictures, but legal contracts. On the other hand, Exercises have no corresponding conceptual notion in the model, they are here as a way to provide some guidance for the students during the study.

3.2 Running

Lesson 1: An overview of the server. The Local Objective is to apprehend the server through its components, their functionalities and information they handle. By means of an example - a very simplified RF of General Conditions of Buying - all the components are covered for the students to become familiarized with the work needed to construct a Reasoning Framework. A Resource is supplied with an explanative text, which is available in a Web page, while the students explore the server through the RF-example.

Students exhibited curious to discover PhiInEd, and some of them had preferred to work individually, instead of in groups. Also, they found it not evident to apprehend in a first moment "all the concepts" of the server.

Lesson 2: Let's start to work. The Local Objective is to stimulate the capacity of abstraction by analyzing examples. Concretely, to apprehend the notion of a good GCS from GCS documents. No

Resource is foreseen for this Lesson. Part of a RF of General Conditions of Sale (GCS) is supplied, as a starting point for the work. Such part consists on a Hierarchy of Terms, voluntarily prepared to be incomplete. As an Exercise, the students are asked firstly to observe the Terms and how they are organized. Then to search on the Web, and then to retrieve, a page containing a GCS. They are instructed to analyze this page, and to improve the Hierarchy accordingly.

Faced with a real case to work out, students found positive the fact of working in small groups, since they could discuss with each other. In some cases, discussions were even too long: 20 minutes before they could agree on adding a single Term! They became more familiarized with the server, and even suggested improvements concerning the edition of the Terms Hierarchy. This necessity was due to the dynamism on updating the initial Terms Hierarchy, in part caused by discussions, in part caused by the progressive analysis of the Web page they have chosen to study.

Lesson 3: Entering a Document, and Constraints. One Local Objective is to be introduced to the activity of exemplification, i.e.: to instantiate a contract in a RF. Another Local Objective is to learn the link between clauses in a GCS, by constraining the use of Terms in clauses, through the identification of logical relations among Terms. The single Exercise asks students to describe the contents of their working GCS document, by using the Terms of their working Hierarchy. The Exercise asks them as well to identify relations among Terms and then to build up the corresponding Constraints. Figure 9 shows some of the Constraints from one group, who worked out a GCS document for spectacle tickets. An example of Constraint is "group fee *excludes* individual fee".

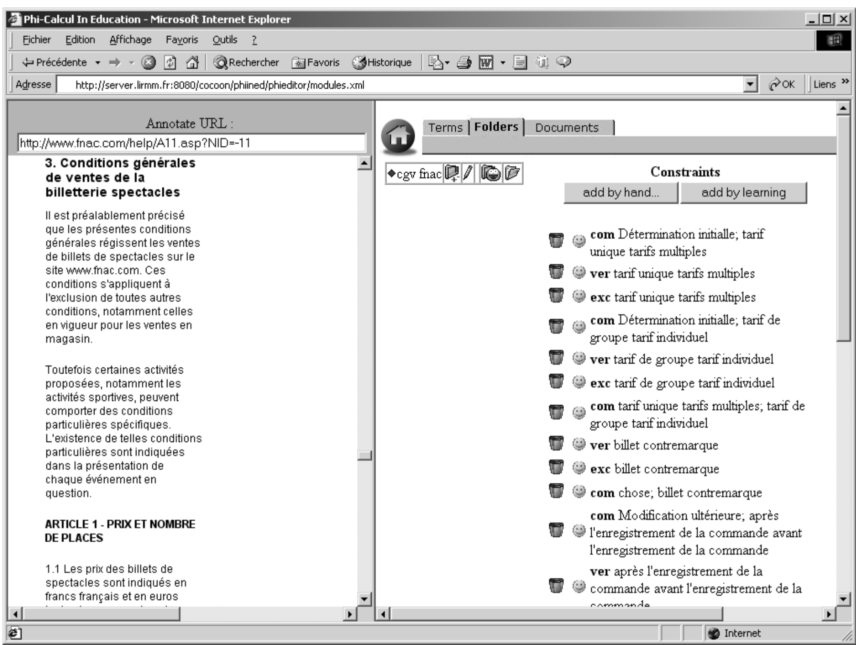

Figure 9: Web page of GCS and some added Constraints.

Students exhibited an initial difficulty to build up Constraints, although these were introduced in Lesson 1 through a simplified RF. Such a difficulty was quickly overcame, due both to the practice, and overall, to the understanding that Constraints were nothing but a formal way of stressing relations among Terms representing clauses, something to which they are, as lawyers, actually familiarized.

Lesson 4: We present our results. A first Local Objective of this Lesson is to stimulate the capacity of comparison between an abstraction and an example. Concretely, since students have built a RF, they are supposed to have in mind the notion of a good GCS (at least their own!), and thus, they should be able to identify in GCS documents both positive and negative points with respect to their RF. Up to this point students work organized in seven groups. In this Lesson they are invited to work as a whole group. The single Exercise asks each group to present their RF to the larger group, to present their analysis about the RF they received, the Terms and Constraints they created, and yet to criticize the GCS they have chosen with respect to their own RF. Another Local Objective is to stimulate the capacity of argumentation and explanation, by means of debate: in case of different viewpoints (between groups) when students compare their RF with other's GCS documents, or even their RFs to each other. Before starting the expositions, the groups exchange their RFs by sending a message to each group.

The results presented were more complementary than conflicting to each other. An interesting case was the one of two groups that had chosen, as a coincidence, the same Web page to work out. They had, as expected, some common results, but also they had perceived different aspects in the document, over which they finally agreed as complementary.

Lesson 5: How about putting altogether? The Local Objective is to reinforce the capabilities stimulated in Lessons 2, 3, and 4: after knowing the others' work, students should formalize what they eventually apprehend from the debate with the larger group. Concretely, they should compose a reduced group responsible for generating a single RF, as a result of merging the RFs from the groups. The single Exercise asks students to consider the RF of their corresponding group, and to create a new RF resulting from all RFs together.

Voluntarily, a member of each group presented himself to compose the reduced group. They have adopted the strategy of performing partial fusions (two by two) due to the amount of information they obtained as a result of a single fusion. Finally, the complementarity observed in the previous session was not so confirmed, since they discussed yet a lot, before arriving to a final result. This lead us to think that even if they do not agree with other's work, students hesitate in criticizing. The fact of working together around a common and concrete objective seems to provide an actual collaborative environment, in such a way to make them naturally criticize without having the feeling of ``hurting" their peers.

Lesson 6: Finally, did we reach an agreement? The Local Objective is to improve the notion of a good GCS that students have built up to this point. By proposing a number of GCS documents specially chosen to stimulate revision, the Teacher together with a group of several invited lawyers attempt to invalidate the Reasoning Framework representing the agreement among twenty-seven students.

Some specific points have hardly been identified by the invited lawyers in order to provoke the debate foreseen for this last Lesson, suggesting that an agreement was reached (achieving such an agreement represents is the model the criterion of a *stable* Reasoning Framework). Some improvements were orally pointed out but not performed on the RF, due to the lack of time.

4 Conclusion

In §1, we introduce an iterative and interactive method used by lawyers to explicitate the knowledge that enables an artificial agent to assist the tasks of contract analysis, verification, and construction. We also make the assumption that novice lawyers taking part in the process of knowledge explicitation learn something, thanks to the interaction both with humans and with the artificial agent. Such an assumption is firstly supported by the identification of some features previously pointed out by researchers from the Educational Community as important for learning events to occur in a Learning Environment. The results of the work carried out by real learners are for us an evidence (even if informal) that our initial assumption was right.

The main focus of our work is on the exam of how rationality emerges from - and simultaneously drives - the interactions between a human agent (or group) and an artificial agent both embedded in a process supposed to result in considerable intellectual gain for the human side. Concerning human learning, the source of general criticisms addressed to the discovery learning approach, i.e., the convergence of the learning process (often dependent on the student's autonomy degree), does not appear to us a major impeachment for Phi-calculus to succeed. Taking a careful look at some of the features of Fidal's method, one might notice that something there particularly conspires in favor of convergence: the fact that knowledge built up has no universal pretension at all, it is instead emerging *from* a group and *to* (be exploited by) a group that intends to reach an agreement. However, a formal answer to the question "under what conditions the theory construction process underlying the model actually converges" is yet to be provided. Moreover, in spite of empirical evidence of the success of Phi-calculus as a model for the design of Discovery Learning Environments, a formal experiment is also foreseen.

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