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A proposal to support the design of experimental learning activities

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Abstract

This paper addresses the problem of designing computer environments to support collaborative scientific experimental learning from the authoring perspective. We aim at a range of learning tasks involving speculative and practical activities in the real world, so we need rich problem workspaces, as well as articulation mechanisms between the problem space and the communication space to refer to the actions and the outcome in the lab. Our approach incorporates insights both from cognitive analysis and activity theory, and proposes a representation allowing a declarative specification of the learning activities including the computer support. The description formalism is a mark-up language. From the specifications an operative environment to carry out learning activities is automatically generated. In this way the creation of new activities is done not only at an adequate abstraction level for the teachers, but also can be done by reusing components from previous definitions.

1. Introduction

This paper addresses the problem of designing computer environments to support collaborative scientific experimental learning. Architectures and frameworks for interoperable components is a critical issue to develop educational systems, and attract currently a lot of attention (IMS[1], Ariadne[2],CEN[3],LTSC[4]). Proposals are emerging (Koedinger, Forbus & Suthers,1999) (van Joolingen 2000) but further elaboration is needed to produce models supporting the practical design of CSCL applications, especially in distance learning settings.

Knowledge building in experimental science involves complex problem solving techniques such as making hypothesis, design and carry out tests as well as metacognitive strategies like monitoring, planning, assessing and repairing. Collaborative learning in science has been perceived as beneficial in early (Singer, Behrend & Roschelle, 1988) and recent studies (Springer, Stanne & Donovan, 1999). Social knowledge building involves peer interaction processes. Learners have to establish common ground, build and represent shared knowledge through argumentation and negotiation (Scardamalia & Bereiter, 1994). Both personal and social perspectives should be explicitly taken into account when designing CSCL for scientific matters. On one hand, discovery learning is an approach that has been quite productive in the analysis and understanding of cognitive process in scientific learning. A variety of learning environments ((De Jong, van Joolingen, Pieters & van del Hulst, 1993 93), (Edelson, Pea & Gomez, 1996) (Linn, 1996)) have been proposed including special cognitive tools as well as support for structuring the learning process. On the other hand, the socio-cultural framework provides the concept of Activity (Nardi, 1996) as a unit of analysis, with a rich internal structure to make the context of a situation explicit, specially the interlinks between the individual and social levels stressing the role of the tools as mediating artefacts.

In (Barros & Verdejo 2000) we have shown how activity theory can be used for modelling learning experiences as well as for designing a software system to support collaborative discourse. Now we aim at a range of learning tasks involving practical activities in the real world, so we need to enrich our previous representation to integrate a variety of tools, as well as to extend the existing articulation between the problem space and the communication space to refer to the actions and the outcome in the lab.

Here we will focus on the authoring perspective. Our approach incorporates insights both from cognitive analysis and activity theory, and proposes a representation allowing a declarative specification of the learning activities including the computer support. This specification is automatically processed in order to generate an operative environment to carry out learning activities.

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[1] IMS http:// www.imsproject.org
[2] ARIADNE http:// ariadne.unil.ch
[3] CEN http://www.cenorm.be/iss/workshop
[4] LTSC http:// ltsc.ieee.org

In this way the creation of new activities is done not only at an adequate abstraction level for the teachers, but also can be done by reusing components from previous definitions.

The organization of the paper is as follows; next section describes the motivation and the target of our work. Then we will focus on the designer perspective: sections 3 and 4 elaborate a conceptual approach for the design of CSCL environments for experimental learning. The goal is to facilitate the conception of the environment to educators and the prototyping of the supporting software to designers. An illustrative case study is included. The description formalism is reported in section 5. Future work is outlined in the final summary.

2. Motivation

2.1 The need to improve the learning situation.

In Distance Education Institutions, such as UNED[5], the study of experimental matters requiring lab work, is organized through turns, where students come to the University facilities to follow an intensive lab stage of three to six days in the middle or at the end of the academic year. They receive a handout with guidelines on how to perform the experiments before coming to the lab, and they have to write a report at home after performing the experiments. The lab is an interesting experience for students even if not satisfactory connected with their individual study along the academic year.

Networked technologies open the way to create new lab frameworks for science education in a distance setting. Physical presence and manipulation still remain crucial but this lab work should be better intertwined with the rest of the learning period. The challenge for developing collaborative activities in a traditional distance learning university is not only to build appropriate tools but also to transform established practices in the community. For these reasons, it is quite critical to look for opportunities of implementing collaborative learning experiences where students could perceive collaboration as a clear added-value to existing learning practices.

Our approach is to start from the current situation looking for opportunities to improve the process, with a very realistic and learned-centred perspective (Norman & Spohrer1996). First we have designed a pilot lab course, keeping in mind that it should be a scalable model, and considering the constraints of the social context where we are. This case study scenario is been developed in connection to the DiViLab[6] project. We have selected Chemistry as domain application, a subject matter offered in the second year of the Industrial Engineering School.

We have analysed the existing practice, following as observers a series of student lab sessions and discussing in depth with the teaching staff. As a result, we pointed out a couple of major problems:

- Students are provided with documentation about the lab work in advance but they do not work with or even look at the guidelines before coming to the sessions. The tight schedule of the lab sessions does not favour thinking and reflection. This, together with the fact of no previous preparation, make students in the lab to focus on figuring out what to do, interpreting on the fly the procedures outlined in the guidelines, like following recipes instructions. The result is a very poor articulation between the theoretical knowledge students could have and the practical manipulations they are carrying out.
- Experiments are performed by groups of two. There is not any previous experience of collaboration neither collaborative support for the work they have to perform together at the lab and later on. For instance, each student uses personal notepads to write his observations and its own copy of the guidelines to make annotations during the lab period. Usually they do not check whether their notes are complete, complementary or inconsistent. These sketchy notes are used afterwards for writing the final report. The final report is a document written from scratch.

The current situation can be characterized as guided experimentation; in this sense guidelines are quite detailed about the procedures to perform. A more discovery learning approach is not endorsed by the teaching staff by logistic and security reasons. However, they are willing to try more open and flexible approaches on a simulation setting. To cope with these problems, and considering that lab scheduling can not be changed for organizational reasons at the Institutional level, we have proposed to

[5] UNED is the Spanish Open University, operating worldwide with about 200.000 students
[6] DiViLab is a project funded by the EC under the IST - 5th framework program. The consortium includes Archimed, Aveiro University, Duisburg University, France Telecom, INESC, UNED, and UST Lille

include a pre-lab period where students, from home, at their own pace, could carry out virtual lab activities in collaboration. Next we outline the new global framework

The new framework

We consider three phases, PRELAB, this phase aims at acquiring conceptual prior knowledge of the subject matter and develop a bridge to the operational knowledge involved in the real experiments; LAB, where students will focus on real manipulation with chemical tools and chemical processes; and POSTLAB, for reflecting and articulate in depth theoretical background and the experimental work carried about in the lab. In order to support the whole cycle of social knowledge building, a computer-supported environment offers to the learning community a structured scenario for carrying out activities and mediating dialogue, as well as a variety of functionalities for sharing and accessing resources. Moreover, different collaborative strategies can be deployed, such as jigsaw, reciprocal teaching or peer sharing by assigning roles to participants.

Assistants are also actors in the learning commu nity; the system will support their task in the post-lab phase. Each assistant has to mark, comment and assess a group of students. There is a tool to read and annotate these reports as soon as students decide to submit them. Students will receive automatically a notification once this feedback would be available. A detailed description of the scenario is given in (Verdejo & Barros, 2000).

2.2 The need to facilitate the design of collaborative activities

From the teachers point of view there is a crucial need to systematize the whole cycle of designing and implementing distance learning activities in science with a realistic cost effective approach. Academic teams and systems designers have to share a common language and work together to establish a framework allowing the definition of new activities in an easy way. From these definitions, an operative environment should be generated as automatically as possible.

As pointed out before, we have started from a deep analysis of the current situation. The study combined two learning perspectives: individual and social. First, we carried out a task and domain analysis to select key aspects of the problem-solving techniques involved. Secondly we broadened the focus to pay attention to the context and the participants, for this phase *activity theory* (Nardi 1996) provided an adequate framework.

We repeatedly performed a bottom-up and top-down cycle in order to find useful abstraction levels for both purposes: mediating teacher system designer dialogue and facilitating the engineering of a supporting environment. Next section describes the task analysis phase.

3. Task and domain analysis

In this phase, we needed to identify terms for the description of tasks and problem-solving methods. The aim is to build a list of tasks, as a first step for organizing a task ontology for scientific experimental activities. This kind of approach comes from Knowledge-based engineering (Chandrasekaran 1986) (Steels 1990) and has been extensively used in IIS authoring (Van Marck 1992) (Mizoguchi, Sinitsa & Ikeda, 1996) (Paquette 1999).

The tasks involved are at different level of granularity. We will start here with general tasks related to scientific experimentation, involving methods and /or strategies of a generic nature. Usually a task can be performed using different methods. We will list the options without paying attention at the conditions to be fulfilled in order for a method to be selected.

3.1. Generic tasks& alternative methods, and *domain tasks*:

For some tasks we will indicate some domain tasks belonging to the generic task as well as examples for illustration purposes

A lab experiment is either a simple task or a complex task.

Dividing a task in subtasks is the most used problem solving strategy for the later case. Sometimes the order between subtasks is unique, fixed and derived from domain restrictions, sometimes is optional and then, if performed in collaboration, can be negotiated. Usually students receive precise guidelines on this point and there is not reflection on problem solving strategies at this level. So, at least two approaches can be distinguished, and three methods identified.

- Task: complex task
  Methods: Divide the task in subtasks

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Think about
Based on domain knowledge
Based on negotiated arrangements
Follow the guidelines

Lab experiments involve mainly two types of generic tasks: analysis and synthesis. An example of the first in our scenario is *Elemental functional and organic analysis* , an example of the second is: *Synthesizing a dye.* At the moment we have focused our study on the first type. Two methods used for analysis are experimental identification and interpretation.

Identification of elements, components, or functional groups involves in some cases simple domain actions in others more elaborated approaches. Two common general problem-solving methods for the second case are searching in a space of solutions and, classifying.

- Experimental Identification
  Methods: Searching a problem space
  Classifying

The problem space can be finite and explicitly defined, for instance the case of step 2 in our previous example, or can be implicitly defined and then a procedure to generate candidates should be included. Searching can be generally expressed as:

- Generate candidates, discard/select candidate, and test

To select a candidate, a variety of methods can be applied, two of them are:

- Select candidate
  Method: Based on guidelines
  Based on accumulated evidence

- Test
  Method: Obtain data and compare
- Obtain data (about property)

Here, a variety of methods are applicable, some of them are domain specific.

Method By chemical manipulation (*Reactivity)*
By a physical technique (*Solubility essay, Filtering, Filtering with folder, Filtering with Buckner, Measuring)*
By searching in a database
By simulation
By asking an expert
By direct observation (*Smell, Colour..)*

- Compare
  Comparison by value
  Comparison by pattern matching

Linked to the problem-solving strategies are some orthogonal methods we would like to represent explicitly, for instance selecting a candidate can be an individual task or a collaborative task, in the first case, for learning purposes, we can ask the student to justify the decision taken, in the second situation depending on the collaborative strategy it could be the case to negotiate first the decision and then to justify the agreed solution.

- Select candidate
  Methods:
  Make (an hypothesis)
  Make and justify (an hypothesis)
  Propose and agree (an hypothesis)

The final strategy will combine the selection of methods to generate a specific full specification, for instance

Select: based on the guidelines, propose and agree a candidate

Others generic methods belonging to this orthogonal dimension are: propose a decision, explain a decision and agree on a decision.

4. A collaborative learning approach

While the previous analysis focused on problem solving, we need to consider the experiment and the context from a broader perspective. For this purpose, activity theory offers an adequate framework. Let us look at an example, the definition of the Elemental functional and organic analysis of a substance X to be carried out in the lab. It can be described as follows:

This ACTIVITY is a kind of *collaborative complex experimentation* involving *analysis.* It belongs *to the chemical domain,* it is subdivided *in subtasks, which are sequential and predefined by domain knowledge*: Produce alkaline fusion, Identification of components, Guessing the functional group and Confirming the identity. It is an activity to be carried out *in the lab in a supervised way*. Students will work two by two. The learning COMMUNITY includes groups of students by pairs, and lab assistants. A division of labour is expressed through ROLES: student and assistant. The SUBJECT performing the learning task is a student. Assistants monitor and provide help on demand. The OBJECT of the activity is to perform the analysis of a substance X. The result of the activity is twofold: on one hand the outcome, data and conclusions and, on the other, the process rationale. All this is recorded and organized in a structured document. MEDIATING tools are classified in four types:

1. Physical material: chemistry instrumentation and substances
2. Computer Supported environment, a kind of active document, containing experiments descriptions, and a structured notebook, dynamically linked to tasks, where students can either write or import, record, collect, and annotate data obtained from the different available resources.
3. Computer-based resources, to be used individually or collaboratively such as:
   - A database containing multimedia data, for instance infrared spectra.
   - Information search engine
   - A knowledge-based glossary, referring to theoretical background and practical information
   - Specialized word processor for chemical formulation
   - Simulation tool to obtain some data
   - Data Modelling tool
4. Human experts: teachers

There are some general norms accepted by the community, such as:

- Students and assistants have to follow security norms
- Students may request advice to assistants
- Students have to follow assistants directions
- Students have to perform subtasks using the MEDIATING tools and following the guidelines indicated in the active document.
- Students have to participate collaboratively in the discussions and decisions

The definition has the following structure:

An indication of the related generic activity: *Collaborative complex experimentation*
With a specialization: Involving *analysis*
Related to a particular domain: *Chemical domain*
In a particular context: *Supervised Laboratory*

The idea is to build a library of generic activity models, partially defined, that could be used by the teachers to define new instances.

A second example, at a finer-grained level, is the definition of the following sub-activity :

Collaborative guessing the presence of components in a substance using the method *select a candidate from a finite set of candidates and test*

The two subactivities involved are defined from the generic subactivities: SELECT a component and TEST a component, as shown by figure 1 below. In this case students are working together in the lab, they will discuss face to face without a conversational mediating tool. A unique type of role, for both of them is needed. Nevertheless they have to write a justification, as expressed in the result. They have to

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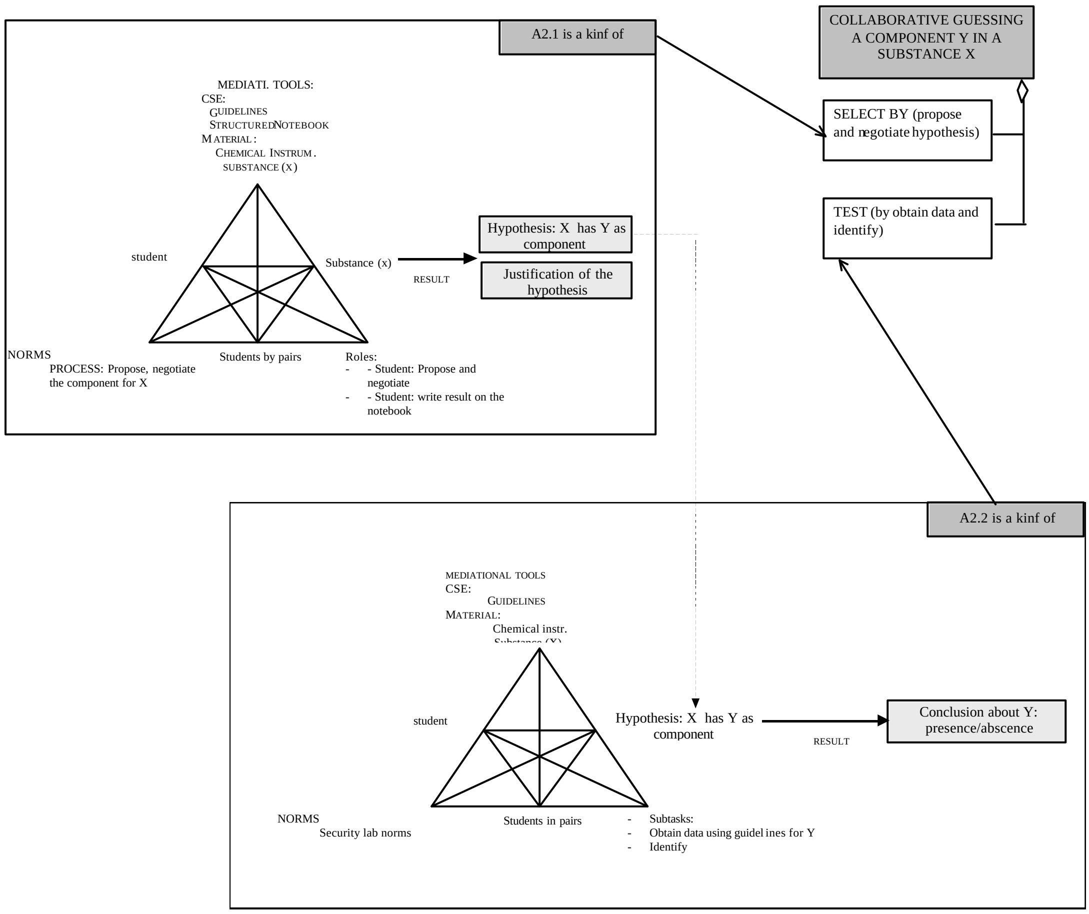
use their notebook to write their hypothesis and justifications. These results are tightly connected with the TEST subactivity. Other collaborative modes are foreseen for the pre-lab and post-lab phases.



-Figure1-

Requirements for making operational this representation

To make this kind of description an operational model, we need to refine several aspects. One of them is to distinguish the elements to be represented and supported by the computer environment. Subjects form a learning community, and subjects can be involved in an activity with diverse collaboration methods. For example for the pre-lab phase we foresee reciprocal teaching as an interesting mode, while for post-lab report production, jigsaw method could be more appropriate. A method can be expressed through norms, division of labour and roles. Roles can be just named, but an operational semantic can be defined in terms of constraints relating tasks, roles and tools. For instance we can have an "information seeking" role, as the one allowed to access the database or the information search engine. In this sense the system can effectively monitor the collaborative performance of activities. Other norms such as "follow security norms" should be assumed and accepted by the participants, and they would be represented in the environment just as information.

We need as well to find a computable formalism to express the activities description. Activities can be interconnected, and references between them easy to express. This formalism should be declarative, allowing the use of generic activities as for example *Collaborative complex experimentation* so that the definition of a new activity like *Elemental functional and organic analysis of a substance X,* could be done as an instance of the generic activity with particular values/restrictions.

A computable formalism means that a learning environment integrating the necessary tools could be generated from the description. We have already developed PALO (Rodriguez-Artacho, Verdejo, Mayorga & Calero, 1999) an XML-like language and interpreter to define "active" documents. Next section outlines a proposal to extend PALO in order to fulfil the requirements for expressing collaborative activities.

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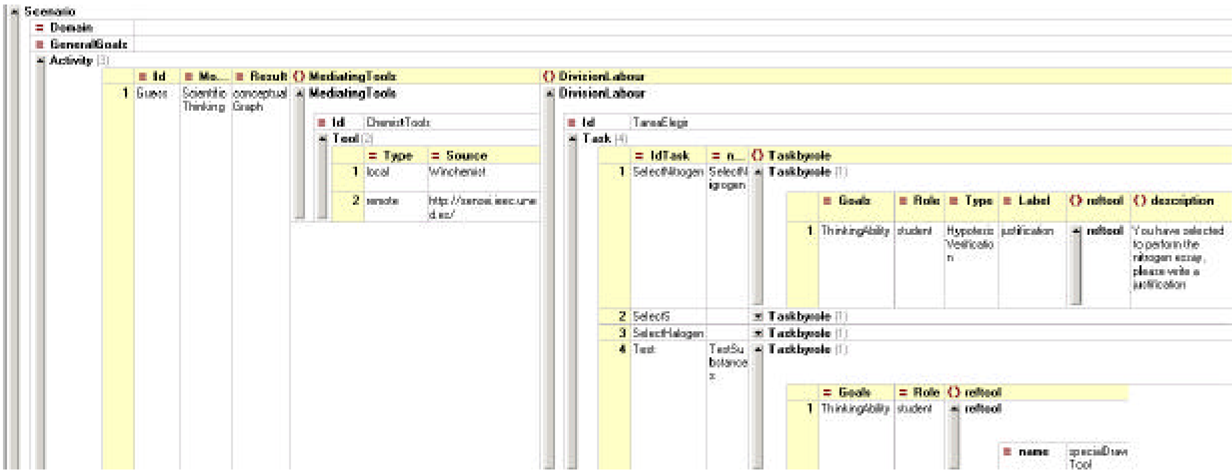
5. A proposal using a mark-up language

The idea is to use XML to define a library of DTDs for generic activities, where the vocabulary will refer to task and domain ontology's, and then create lab experiences as instances of documents. These instances are interpreted and a web environment is automatically generated with links to the tools specified. The following excerpt gives an illustration of a partial concrete definition.



The DTD considers all the elements for defining an activity and adds in the tools the possibility of specifying a parameter in order to be applied to different components. With this DTD we can define "active documents" for different activities. The "active document" for the example above includes the task ="SelectNitrogen", to be carried out by a subject with the role "student". When activated, the description "You have selected to perform the nitrogen essay, please write a justification" would be visible, and a workspace in the document linked to the tool "Winchemist", a domain tailored word processor, would be available. The environment allows the use of a variety of tools with different purposes, to produce different outcomes. A way to share semantic across tools is by the task definition, especially through attributes that are expressed in terms of the ontology. For instance in the example above, Type=" hypothesisverification". Results obtained would be loosely or tightly combined, depending on the nature of their description. At least they can be imported and labelled, as indicated in the example by Label= "justification".

5. Summary and future work

In this paper we have presented an approach to support the task of designing collaborative activities for scientific learning, involving real and virtual experimentation. For such rich environments, we need to take advantage of different and complementary tools to support learners. There is a challenge not only in combining them within a unified framework for a learning community, but also to facilitate the design of the learning scenario and the implementation of the computer environment Two key ideas directed our work, on one hand to increase reusability and on the other to bridge the gap between the educators designers and the implementation. A framework combining ontologies and activity theory provides a powerful mechanism for incremental design with a terminology close to the designers. Furthermore, the proposed mark-up language provides a computable definition to generate a web-based environment. We have created a demonstration that serves as a case example; the scenario presented a simplified schema, enough for a first testable prototype. Further research is planned to extend the work through formative evaluation in order to scale up the approach.

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