# Adaptive System for Collaborative Online Laboratories

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Online engineering laboratories emerged in the early 2000s from research carried out at the MIT.[1] Using the Internet and Web-based technologies, online laboratories have worked to provide a laboratory learning experience to students who don't have physical access to a laboratory.

*Group activities are important aspects of the traditional laboratory experience. A framework using Semantic Web technologies supports collaborative strategies for online laboratories as well.*

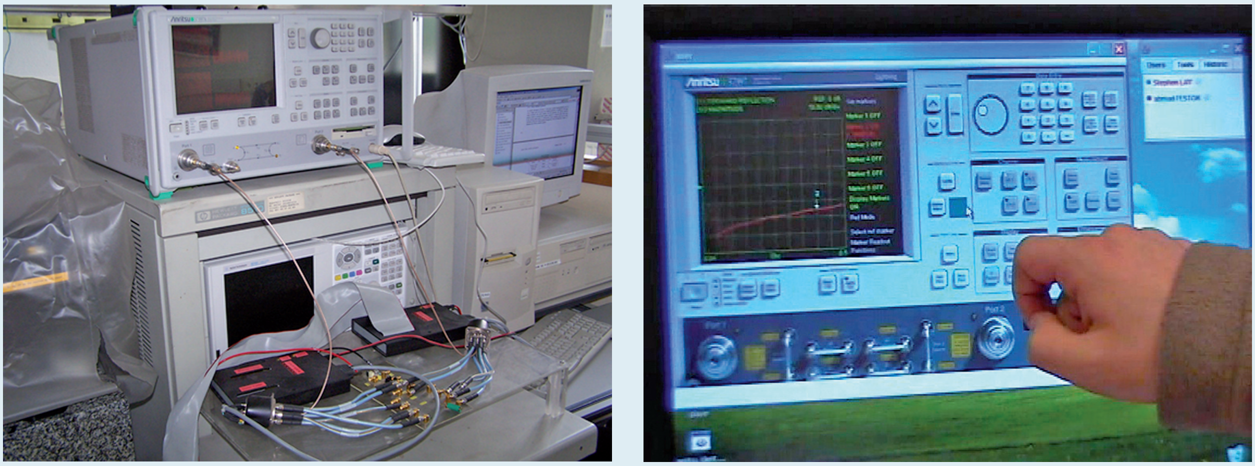
Online laboratories let students anywhere in the world perform engineering experiments online and use distance learning techniques to produce the pedagogical equivalent of in situ lab sessions.[1–5] The goal is accurate online reproduction of workbench activities during local laboratory sessions.[2,6,7]

Unlike traditional laboratories, most online laboratories don't support student collaboration.[8] When developing online systems, researchers are primarily interested in the mechanics of making a laboratory available online and integrating it with local information systems, especially learning-management systems. Although these issues are important, the inability to support multiple simultaneous users means the systems lack a key component of the traditional laboratory learning experience. Collaboration among students lets students exchange skills, results, and knowledge; form groups; and emulate other group members.[9] Recent research has focused on how to *scenarize* (generate scenarios for) these interactions.[10,11] Interaction with peers is also a basic collaborative-learning goal.

These various dimensions of collaboration are important in engineering education, particularly in lab settings, because they support teaching scenarios that are close to real-world distributed engineering teamwork.[12] By learning collaboratively, students also learn to work in a geographically distributed group, which is a skill otherwise difficult to acquire during lectures. Working at a distance is likely to be an important facet of an engineer's work life.[13]

To address these limitations, we have developed a collaborative online learning framework with integrated group awareness support.[14] This system notifies students connected to an online session of the outcomes of actions they perform on a real-world distant device, such as displaying a new curve on a remote oscilloscope, but also of the possible interactions between their actions and those of others. The system assigns each online student a unique visual indicator (usually a color) for a session's duration,


1541-1672/12/$31.00 
*Published by the IEEE Computer Society*



(a) (b)

**Figure 1. A typical scenario. (a) Equipment in a real laboratory and (b) associated software on a touchscreen. The equipment, a vector network analyzer, measures parameters of an electronic network to determine its signal transmission and reflection capacities. The touchscreen provides a virtual network analyzer interface.**

which identifies the author of each action. For example, if a student indicates the intention to use a widget, the widget then displays the visual indicator assigned to that student. Every connected user is thus aware of the author of every action and of its consequence. Figure 1 shows a typical scenario, which can also be viewed in an online demonstration video (http://diom.telecom-st-etienne.fr/satin/einst/einst_demo.avi).

In such a system, multiple simultaneous users attempting to manipulate the same resource can lead to “widget wars,” which can negatively affect collaboration among learners. In general, a tutor monitors intended actions and mediates as needed. To provide assistance to the tutor in managing the group of connected students, we have developed an ontology-based intelligent system to encode and execute collaboration policies. These policies can embody the rules governing student collaboration according to the context of the learning environment and the tutor’s pedagogical goals. Using semantic technologies to assist education activities is a relatively recent development.[15]

## User Interactions in Collaborative Online Laboratories

A typical distance-learning example will illustrate the requirements for moderating user interactions. Two students, Bob and Alice, have participated in many laboratories together during the first two of their three-year master’s curriculum at the University of Saint-Etienne. In their final year, both have chosen a distance-learning curriculum that lets them take nine-month rather than the traditional six-month internships. Alice is working in a company in London, and Bob has an internship position at the University of Tokyo. Once a week, they participate in distance-learning sessions that include a collaborative online laboratory, which involves dealing with signal reflection and transmission in telecommunications and requires the use of a network vector analyzer (see Figure 1b). Their participation takes place under the guidance of Mr. Smith, who is connected to the online lab at the same time as Bob and Alice. In addition to the lab activity’s subject-specific goal, learning how to collaborate is also an important part of Bob and Alice’s learning experience.

Anticipating user interactions during a session is difficult: the goals of a particular session can vary depending on the instructor’s pedagogical goals and a session’s individual circumstances. For example, Mr. Smith may decide that Bob, who arrived late to an online session, should receive extra lab time to let him catch up with Alice. Or instead, he might want to proceed according to the schedule and let Bob catch up on his own time. Alternatively, the tutor may decide to give more time to the student who’s less confident about the session’s topic.

Whatever the scenario, the range of possible collaboration policies is wide, and each policy can potentially be modified to target the goals of an individual session. For these reasons, it is generally not practical to build a moderation agent that can anticipate all possible collaborative policies. Instead, a more practical solution is to develop a library of policies that covers a range of possible scenarios.

## A Domain Ontology for Collaborative Online Laboratories

Using Semantic Web technologies, we have developed such a library. Using the

Web Ontology Language (OWL; http://www.w3.org/TR/owl-features/)[16] and the associated Semantic Web Rule Language (SWRL; www.w3.org/Submission/SWRL/), our knowledge-based system describes and operationalizes policies in a collaborative online laboratory. The system uses OWL to describe a domain ontology containing the core entities of a typical collaborative online environment and then uses SWRL, a declarative language based on OWL, to encode individual collaborative policies in terms of these domain entities. SWRL's semantics, built on the same descriptive logic foundation that underlies OWL, lets users write rules in terms of OWL ontology concepts. SWRL rules are stored in the associated OWL ontology and effectively form part of it. An individual policy thus corresponds to a set of SWRL rules; the tutor can select a particular policy by activating the rule set describing that policy. Figure 2 shows a simplified representation of this ontology.

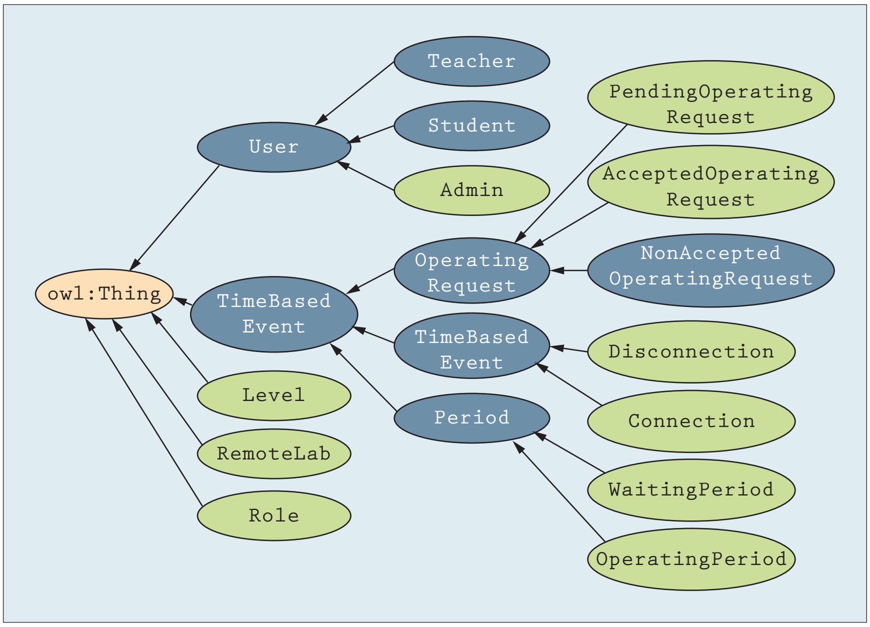



**Figure 2. A simplified view of the ontology of collaborative online laboratory events. A light background shading indicates primitive classes, and a darker background shading indicates defined classes.**

The ontology focuses on three basic areas:

- The user's *role* in an online session. Session participants include learners, tutors, and administrators. Policies are generally focused on learners, with the ability to formulate policies typically restricted to tutors and administrators. Each of these participant types is associated with different capabilities.
- The user's *experience level*. Users can be beginner, intermediate, advanced, or expert. The experience levels can constrain the activities a user can perform in a session and formulate policies based on a user's experience level.
- *Time-based elements*. The ontology describes the various temporal properties of the entities involved in a session, such as a user's connection time or the amount of time a user has waited or has been an operator. Policies are generally expressed in terms of the duration, timing, and sequence of events in an online session.

A major goal for our ontology (http://dev.telecom-st-etienne.fr/satin/rlab/collaborativev4.swrl.owl) was simplicity, because simplicity generally favors an ontology's reusability, evolution, and sustainability.[17] An additional advantage is that a simple ontology makes it easier to author and maintain policy rules.

## Basic Collaborative Policies

We can use our ontology to develop collaborative learning policies—for example, the learning experiences that Mr. Smith wants to provide Bob and Alice. Each policy can encode access conditions for whoever is the operator in a particular session. Individual policies must also anticipate that collaborative sessions evolve and consider the state or collaborative context at a particular time in a session, encoding permissible actions within each context. In other words, users are able to perform commands in a group only if the collaborative context satisfies a given policy.

In our system, we described these collaborative policies using sets of declarative rules in SWRL. (For an introduction to how SWRL rules are constructed, see http://protege.cim3.net/cgi-bin/wiki.pl?SWRLLanguageFAQ.) For example, a collaborative policy rule expressed in natural language might state,

> *If a user has an administrative role and a pending request for being operator, then make this user the new operator.*

Under this collaborative policy, when Mr. Smith requests the operator role, he becomes the operator even if other users are connected. The next step is to take that natural-language description and express it as a SWRL rule, which can be written as follows:

```
Def_hasOperator: RemoteLab(?r)
  ^ User(?x) ^ hasRole(?x,
  Administrate) ^ hasPending
  OperatingRequest(?x, ?r)
  => hasNextOperator(?r, ?x).
```

This rule can also be expressed as two separate rules, one for user qualification and one for asserting the next operator:

- `Def_isAdmin: User(?x) ^ hasRole(?x, Administrate) => Admin(?x)`
- `Def_hasOperator: RemoteLab(?r) ^ Admin(?x) ^ hasPendingOperatingRequest(?x, ?r) => hasNextOperator(?r, ?x).`

Separating the rules in this way favors reusability because their results can be used by other rules. (To download these and all other rule sets described in this article, see http://dev.telecom-st-etienne.fr/satin/rlab/policies/rules.zip.)

### Complex Collaborative Policies

Collaborative environments generally require more-elaborate policies than the one just described. One example—again, expressed first in natural language—might be

> *Give operator status to learners upon request only if they have accumulated less operating time than the current user.*

This restriction doesn't apply to tutors and administrators, who are granted preemptive access. Again, this policy can be expressed as a set of SWRL rules:

- `Def_hasAdminOperator: RemoteLab(?r) ^ Admin(?x) ^ hasPendingOperatingRequest (?x, ?r) => hasNextOperator (?r, ?x)`
- `Def_hasTeacherOperator: RemoteLab(?r) ^ Teacher(?x) ^ hasPendingOperatingRequest (?x, ?r) => hasNextOperator (?r, ?x)`
- `Def_hasStudentOperator: RemoteLab(?r) ^ hasOperator(?r, ?s1) ^ Student(?s2) ^ hasPendingOperatingRequest (?s2, ?r) ^ hasOperatingPeriod(?s1, ?op1) ^ hasOperatingPeriod(?s2, ?op2) ^ hasDuration(?op1, ?d1) ^ hasDuration(?op2, ?d2) ^ swrlb:lessThan(?d2, ?d1) => hasNextOperator(?r, ?s2)`

Other collaborative policies are possible. For example, for the situation "When Bob requests the device control," policies would include these:

- he is granted operator status if Bob has less operating time than Alice,
- he is granted operator status if it is the first time that he has requested it,
- he is granted operator status if he was connected before Alice,
- it is refused if he has had more than five disconnections in the current session, or
- he is granted operator status only if he has entered the session more than 10 minutes ago.

Another policy would be that users are granted a preemptive and dedicated access of 15 minutes, within which they cannot be preempted by other users (except by administrators and tutors), nor can they preempt other users when it is not their time slot.

Many additional policy rules are possible, which can be combined and reused in many ways to achieve a tutor's goals. Although our underlying domain ontology is relatively simple, SWRL rules afford considerable expressivity. Our policy rules make extensive use of a SWRL temporal library (see http://protege.cim3.net/cgi-bin/wiki.pl?SWRLTemporalBuiltIns) to address the time element that plays an important role in most policy rules.

## Implementation of the Knowledge-Based System

The collaborative logic and knowledge base are implemented by a collaborative agent logic module (see Figure 3). This module

- provides connections between a collaborative online laboratory and collaborative policies,
- stores all the knowledge related to collaboration and the current state of a session,
- updates knowledge upon new actions in the online laboratory, and
- decides, according to the collaborative policy in place, whether or not to grant a user operator status when requested.

The system implementation relies on widely available, open source Semantic Web software and APIs. We developed the domain ontology using Protégé-OWL, and developed and executed the SWRL policy rules with the SWRLTab plug-in.[18]

All sessions in an online laboratory can't use the same collaborative policy, and the tutor may want to change the policies even within a single session. For these reasons, we have introduced an adaptive module that's responsible for switching from one rule set to another. At the application level, this process involves dynamically switching rule sets, but the process must maintain the current system state.

An example scenario has Mr. Smith setting the collaborative policy to the administrator policy so that he can prepare the session for Bob and Alice. Bob and Alice can join the session and see what Mr. Smith is doing, but they are not allowed to perform any actions themselves. Afterward, because Mr. Smith wants both Bob and Alice to test the collaborative online laboratory, he sets the policy to favor latecomers.

The system discards the previous collaborative policy rule set and loads the new one. Later, to avoid unequal access, Mr. Smith sets the collaborative policy to favor users with less operating time. Again, the system has to seamlessly switch from one rule set to another. (This approach to implementing collaborative policies is not specific to online laboratories and thus could be used by other knowledge-based systems that require similar policy mechanisms.)

OWL's monotonic inference mechanism must be considered when switching rule sets. Because SWRL rules are logically part of an OWL ontology, retracting one set of rules and asserting another can make the system nonmonotonic. Designers of adaptive systems that use OWL must deal with this issue. One possible solution is to discard all current session knowledge when switching policies, but this is unsatisfactory because the adaptation should preserve the original context when loading new rules that encode different policies. Instead, we explicitly identify assertions made by policy rules and associate a temporal scope or dimension with them to identify their period of validity. Any further assertions made using these assertions must be similarly scoped. When a new policy is activated, those assertions are no longer valid. Our solution ensures that switching rule sets does not introduce inconsistencies, but it is not a general solution for all adaptive systems. Developers of such systems might need to develop custom solutions for their domain, although the temporal scoping mechanism outlined here is quite robust for this specific system.

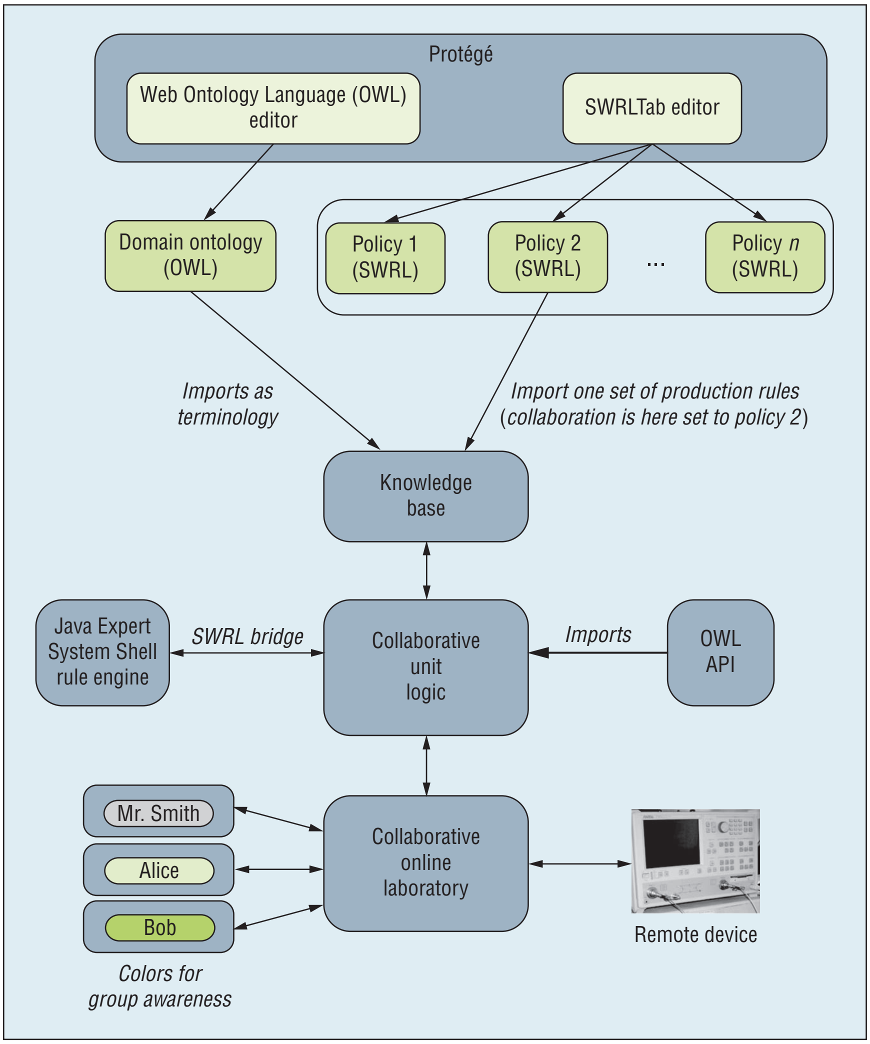



**Figure 3. Implementation of the collaborative process agent. The knowledge base is the cornerstone of the architecture. After initialization, it stores the policies for the online engineering session to come, and coupled with the Semantic Web Rule Language (SWRL) engine, it then enforces the policies at runtime.**

## User Evaluation

To evaluate user satisfaction with the system, we arranged 12 three-hour sessions. Each session involved 45 students, divided into groups of four (and one group of 5 students). Each group was connected to its own remote workbench device using a single touchscreen. Users remotely managed the workbench while facing questions on the purpose of their hands-on session. The logging system shows that an average of 95 commands were relayed per hour per group.

A primary objective of online laboratories is to offer a learning experience simulating the real world as closely as possible. In particular, the device's human-computer interaction (HCI) is expected to be an accurate facsimile of the physical device's interface, and frequently, learning to use the HCI of a specific piece of equipment is itself a pedagogical objective. In general, HCI quality tends to strongly affect user-perceived quality of the collaborative online laboratory experience. So, our survey evaluated users' satisfaction with the online device's HCI in addition to evaluating their overall perception of the system.

The survey questionnaire had two sections. First, to evaluate the HCI, we generated a user-interface evaluation questionnaire using commonly available Web software.[19] We used three common evaluation heuristics: Jakob Nielsen's Attributes of Usability (http://hcibib.org/perlman/question.cgi?form=NAU), James R. Lewis's works on IBM Computer Usability Satisfaction Questionnaire (http://hcibib.org/perlman/question.cgi?form=CSUQ), and John P. Chin's Questionnaire for User Interface Satisfaction (http://hcibib.org/perlman/question.cgi?form=QUIS). The survey questionnaire's second section was dedicated to the learning experience. The list of survey questions is accessible at http://hal.inria.fr/docs/00/28/76/37/PDF/CG.pdf.

### Survey Results

In general, the participants thought that a collaborative online laboratory was a very good idea (82 percent). In response to the question "In your opinion, is it important to collaborate with other people?", more than half (58.82 percent) thought it was useful to help one another, and 32.35 percent said they enjoyed comparing their experimental results with other people. (The remaining 8.82 percent talked about student parties.) Participants also noted (92.60 percent) that using a collaborative online laboratory instead of a local laboratory helped them significantly when writing reports, particularly when reproducing graphs of their results. Each of the three HCI evaluation heuristics gave approximately the same result for device usability: 62.04 percent satisfaction in the questionnaire based on Nielsen's work, 59.14 percent for the one based on Lewis's work, and 57.50 percent for the questionnaire from Chin's work, for an overall spread of 4.54 percent. More than half (55.56 percent) considered the GUI to be very like the real interface of the remote device, and 40.47 percent noticed that it exhibited only a few differences. The overall platform performances were judged to be satisfactory by 77.78 percent of users, even those working on slow laptops (with Intel Celeron processors and 256 MBytes of RAM). Interestingly, 62.96 percent of students, driven primarily by curiosity, intentionally attempted actions that were not foreseen by the hands-on session questions.

### Informal results

The tutors were also generally satisfied with the system. They stressed three main points: First, the platform allowed them to satisfactorily provide an online laboratory. For most of them, this was the first time that they had participated in such a laboratory. Most saw it as a positive pedagogical experience that contributed to their knowledge of distance learning.

Tutors tend to place a high importance on group awareness and appreciated that the platform allowed them to clearly see which students were more active than others. In local laboratories, tutors can easily identify weak or strong students. But distance can decrease awareness significantly, and group awareness support can be key in compensating for this deficit. They stressed, however, that they may also have to develop new group awareness skills when managing online laboratories.

Finally, the tutors recognized that many-to-many online laboratories offer a way to encourage students to exchange results and provide peer assistance, in addition to letting tutors manage more students than they could in a point-to-point online laboratory.

Our solution supports the development of policies that reflect the pedagogy that a tutor wishes to promote in collaborative online learning sessions. Future work will consist of trace-mining the events occurring during an online session to measure collaboration quality. Models based on Semantic Web technologies could help in building sequences of learner actions, so as to infer the quality of the learners' behavior. That would enable adapting the user interface for the group according to the possible sequences of actions that could be triggered by the past few actions, so that the system could guide the learners in their progression. This mining can also be used to identify possible student leaders, for example, or to identify weak students who may require more assistance. The underlying challenge is to enhance the learning experience of students in collaborative online learning laboratories to meet the goals of both tutors and students.

## Acknowledgments

This work was funded by the Conseil Général de la Loire. Martin O'Connor was supported in part by grants LM007885 and LM009607 from the US National Library of Medicine.

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