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A distributed collaborative science learning laboratory on the internet

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A Distributed Collaborative Science Learning Laboratory on the Internet

Laura R. Winer, Martine Chomienne, and Jesús Vázquez-Abad

Abstract

A Distributed Collaborative Science Learning Laboratory (DCSLL) was designed, prototyped, and pilot-tested as the "Electrical Circuit Simulator." This laboratory was part of a module on electricity within an introductory distance course for postsecondary students on the scientific method. The concept of DCSLL emerged from work in distance education and new technologies, cooperative/collaborative learning, and science education. Instructional design principles derived from these areas are presented, and their implementation in the DCSLL is described, followed by results from the pilot test. Analysis of the results led to the articulation of six instructional design guidelines, identified as being key to the development of such learning environments.

Introduction

One area that has proved particularly resistant to implementation in a distance education context is the laboratory component of science courses. In order to offer distance students a full range of courses, however, new ways must be found to provide this aspect of science courses. A growing interest in collaborative work within the distance education community focuses on reducing high attrition rates, finding ways to provide cognitive and metacognitive support, as well as addressing individual differences, both cognitive and affective. In exploring the potential of Internet-based collaborative learning, we were able to articulate preliminary principles based on existing work and use them as guides for the design of a prototype Distributed Collaborative Science Learning Laboratory (DCSLL). The prototype was pilot-tested, and the results obtained were used to elaborate and clarify the design principles.

Origins of a DCSLL

The concept of a DCSLL emerged from work in distance education, cooperative/collaborative learning, and science education.
Distance Education and New Technologies. The defining characteristic of distance education is the distribution of students across time and space, from the instructor or tutor and, often, from each other. The learners are usually adults who normally work part- or full-time while taking courses. Bourdeau and Bates (1997) provide guidelines for instructional design specific to a distance education context. The challenges facing the instructional designer include (1) responding to the high attrition rate caused by student isolation, lack of a sense of belonging, and problems in sustaining motivation and commitment; (2) adapting to individual cognitive and affective profiles; and (3) providing adequate cognitive and metacognitive support to the learners. New technologies and collaborative approaches offer the promise of alternative means and methods that may help meet these challenges.

Dede (1996) discusses the implications of new media for distance education. He identified three new forms of distributed learning: collective knowledge webs (complementing traditional information sources), virtual communities (complementing face-to-face interaction), and immersive experiences in shared synthetic environments (extending learning-by-doing in real-world settings). These three forms of distributed learning are presented as providing extensions of learning-by-doing in a collaborative mode. However, we feel that collective knowledge webs and virtual communities can be more accurately described as "collaboration in discourse" and that immersive experiences in shared synthetic environments enter the realm of "collaboration in action." By collaboration in discourse, we refer to learning situations in which sharing is based on conversation, whereas collaboration in action refers to learners acting together to complete tasks.

The introduction of new technologies also has implications for the nature of interactions. Hillman, Willis, and Gunawardena (1994) add the relationship between the learner and the technological interface to the standard learner-content, learner-instructor, and learner-learner interactions. This learner-interface interaction is especially significant when working within mediated communication. While many think this is merely a novice's problem that will expire on its own as the population becomes more technologically sophisticated, Hillman et al. point out that even experienced drivers may have problems operating the windshield wipers on rented cars. The analogy is worthwhile because each technological environment has its own idiosyncrasies that must be learned, no matter how "standardized" they are.
Many authors, notably Anderson and Garrison (1995), Dede (1996), and Hillman et al. (1994), have identified the need for appropriate instructional design research that exploits the potential of new technologies as the key to successful future developments in distance education.

With computer technologies creating opportunities for increased collaboration, distance education is moving from an individual, solo endeavor to one that links the learner to others and involves him or her in social exchange and communication with both the tutor and other learners. For example, Thach and Murphy (1994) present a continuum of interactions that moves from collaboration by the designers, to student-to-student, class-to-class, and finally institution-to-institution. Along the same lines, Anderson and Garrison (1995) present the concept of a community of learners in which the emphasis is on developing, extracting, and refining existing knowledge from the group, rather than following a teacher transmission of knowledge model. This group interdependence does entail a loss of some of the flexibility and independence that distance education learners have typically enjoyed. However, Anderson and Garrison found that most of the students enrolled in courses requiring group interactions found the trade-off between reduced independence and increased interactivity one that was worthwhile. Similarly, Garrison (1993) highlights the potential for new technologies to sustain two-way communication and, therefore, facilitate the development of learning environments that move away from the traditional (distance education) behaviorist orientation to learning.

**Cooperative/Collaborative Learning.** According to the Oxford English Dictionary, the terms “cooperative” and “collaborative” share the same meaning and have equivalent etymologies. Nevertheless, one finds the words used both interchangeably and in opposition to each other, and the distinctions made in some fields contradict those made in others. We have chosen the term “collaborative” for our work based on Salomon’s (1992) view; however, in the following discussion, we respect and use the particular author’s choice of vocabulary.

The essential elements of traditional collaborative learning are face-to-face interaction, positive interdependence, individual accountability, cooperative social skills, and group processing (Johnson and Johnson 1976). (Obviously, the requirement for face-to-face interaction would have to be replaced if we are to create collaborative learning activities in a distance education environment.) Slavin (1983) concluded that the effects of cooperative learning are primarily motivational, since working
together toward a group goal creates peer support for individual learning, and that, in turn, increases individual motivation both to achieve and to help others. Abrami et al. (1995) also found that "there is little doubt that cooperative learning produces superior results when the objective is the promotion of positive attitudes and feelings toward learning, classmates, and self" (196). As anyone familiar with distance education knows, motivation is key. Therefore, the potential for cooperative learning to increase a student's motivation by adding to their sense of belonging and commitment makes it worth investigating. Although distance learners are already motivated enough to initiate their own learning activities, their high attrition rates could be decreased by improving the quality and quantity of interactions.

**Distribution and Collaborative Learning.** The concept of distribution refers to different kinds of distribution: across time, across space, and across individuals. In distance learning, learners are distributed geographically and temporally. To complicate this situation further, the resources needed for a given learning activity may also be at a distance from the student and/or the teacher. In addition to overcoming the traditional pedagogical challenges, distribution introduces additional challenges to supporting authentic collaborative work; it increases the complexity of coordination and communication and also introduces logistical hurdles such as working together on tasks, exchanging documents, and arranging meetings.

Collaborative learning may also be seen as different individual cognitive systems working together toward a common goal. For example, in a collaborative approach, each student working on a laboratory activity brings his or her own cognition to the activity. They not only bring their existing knowledge, belief systems, and cognitive abilities, but they also bring their own way of building new knowledge. Team cognition is thus distributed among its members, and team learning is, to some extent, dependent on the characteristics of this distribution. When different tasks are assigned to each member of a team, the interaction between each individual's cognition and the specific task assigned will influence the group outcome. The concept of distributed cognition has implications, therefore, not only for the way in which a group will work, but also for what the results of that work will be. Thus, depending on the composition of the team, the team may choose to work by dividing roles and/or tasks according to the competencies that particular individuals bring to the team. They should implement a strategy that either exploits an individual’s strengths or strengthens their weaknesses.
The Science Learning Laboratory. The science laboratory is seen as central to science teaching by those who believe that it promotes positive attitudes toward science, scientific inquiry, conceptual development, and technical skills (Collette and Chiappetta 1994). Constructivist views of science learning consider the laboratory to be the primary instructional environment for involving students in scientific inquiry. However, given the widespread use and importance of laboratory instruction in science education, it is surprising how little we know about the effects of lab work on learning (Gallagher 1987; Lazarowitz and Tamir 1994).

The laboratory is an environment that not only characterizes (in popular culture) science as a profession, but also sets it apart from most other disciplines, such as the humanities and social sciences (White 1988). As a learning environment and an instructional strategy, the science laboratory includes practical work within planned learning experiences that take place in a purposely assigned environment (Lazarowitz and Tamir 1994). While a physical space or an assigned, structured sequence of tasks often defines science laboratories, the science learning lab does not necessarily require either of these elements. The important aspect of a science learning lab is the controlled nature of both the actions and the environment that ultimately permits students to generalize beyond the specific instance under study. As such, a "laboratory" may be conducted in a traditional, controlled environment or out in the field with a teacher-provided protocol or a student-generated one.

For those who see the laboratory as practical work that leads to concept formation and the formulation of theories, each experiment should begin with an existing theory and knowledge base and the identification of a problem that then leads to a hypothesis, a plan, and finally, the execution of an experiment (Arons 1993; Lazarowitz and Tamir 1994). Accordingly, science laboratories should provide concrete experiences, ways to help students confront their misconceptions, opportunities for developing process and technical skills, and opportunities to construct knowledge. Even though these objectives are aimed at the individual, concerns related to the role of social interaction in knowledge construction and motivation make it worthwhile to look at what cooperative learning can contribute to instructional models of laboratories.

Cooperative Learning in Science. A large-scale survey of student results in introductory physics courses found that the use of interactive engagement methods in the classroom can significantly improve course effectiveness (Hake 1998). In chemistry, Nurrenbern (1995) states that
tasks in a cooperative learning activity must require students to make independent contributions toward task completion, as well as requiring some group decision making on the process itself. These are presumably the main characteristics to consider when designing an activity.

While noting the scarcity of research on cooperative science laboratory learning, Lazarowitz and Tamir (1994) report on studies that show cooperative work to be superior to competitive and individual work in terms of cognitive achievement but inferior in terms of process skills. However, when learner abilities were taken into account, no conclusive statements could be generated from the results of the different studies. Not surprisingly, cooperative learning is superior to competitive approaches when there are cooperative tasks to be carried out, while competitive groups are superior for tasks emphasizing individual achievement.

In science education, the concept of cooperative learning is often viewed as being essentially synonymous with group learning. The advantages of cooperative learning are seen in its elimination (or at least reduction) of competitiveness between students and/or of student isolation by including team-building and team-learning activities (Collette and Chiappetta 1994; Jones 1989). This makes it an approach that is appropriate and effective for teaching and learning science (Hassard 1992).

The Challenge: Setting up a Distributed Collaborative Science Learning Laboratory through the Internet

**Goal.** Our project focused on exploring new applications of information and communication technologies in distance science learning. Our overall goal was to create principles for designing technological and teaching environments that would support distance learners in the collaborative learning of scientific concepts. Our educational partner was the CCFD (Centre collégial de formation à distance/Center for College Distance Education), based in Montreal. The center’s mandate is to provide college-level (postsecondary, pre-university) distance teaching for the province of Quebec. In conjunction with the RECTO (Réseau de chercheurs pour la téléformation opérationnalisée/Network of Researchers for Operational Teleteaching) project and funded by the Fonds de l’autoroute de l’information (Information Highway Fund), the center has created a new course designed to take advantage of the information highway (Potvin, Chomienne, and Boutin 1996).
The CCFD chose a new introductory course on the scientific method for the project. The course objective was to familiarize non-science majors with the fundamentals of the scientific method so that they would be able to apply it in simple problem-solving contexts, specifically those involving concrete physical phenomena. A key element in the course's learning activities was the distribution (in both time and space) of the virtual laboratory experiences. Because this was a new course, it provided an opportunity to incorporate information and communication technologies as an integral part of the design. The course material was designed for a hypermedia Web site and required both synchronous and asynchronous inter- and intra-team communication using tools such as electronic mail, chat rooms, teleconferences, and computer audioconferences.

The course designers chose physics as the content area from which to teach the scientific method, and they developed a modular course with a common starting point—a chapter on the history of the scientific method. Students then completed three modules consisting of mechanics, optics and sound waves, and electricity. The course materials contained embedded exercises and hypertext links. The module on electricity was chosen to be the testbed for the design of a prototype DCSLL.

Description of the Prototype

In designing the electricity laboratory, we created three experiments for the learners to conduct. These experiments were not designed for deductive verification of laws and principles. To produce individual syntheses, some of the activities within the DCSLL component of the course covered concepts through concrete manipulation; these then served as a basis for negotiating a collective synthesis. Other activities reviewed a concept so that the learners could gain a better understanding of it on both a qualitative and quantitative level. Still others used the concepts discussed to gain new knowledge through teamwork. The specific instances where collaboration came into play are identified in Figure 1.

In the first experiment, experimentation was conducted with real artifacts, and measurements were taken using real instruments. In the other two, experimentation was carried out by simulation, and the measurements were computerized. Collaboration began only during the interpretation/conclusion phases of the first two experiments. The third experiment required the learners to plan their experimentation from the beginning, and then collaborate during both the analysis and interpretation/conclusion phases.
The principles applied in the design of the DCSLL came from four contributing areas: instructional design for distance education, science learning laboratories, information and communications technology, and collaborative learning. The design principles are presented in a tabular format in the results section.

The Three Electrical Circuit Simulator Experiments. Experiment 1 consisted of a qualitative exploration of the behavior of simple circuits and involved concrete manipulation of common electrical equipment—light bulbs, batteries, electrical wiring, etc. The experiment was carried out with real (as opposed to simulated) objects, and measurements were taken using real instruments. The learners analyzed their data individually, while the interpretation of results and the development of conclusions were conducted as a team.
Experiment 2 examined the relationship between current, potential, and resistance in a simple electric circuit (Ohm’s law). Experimentation involved a number of activities using a simulator. The data measurement phase was done automatically by the computer. The learners analyzed their results individually, and again, both the interpretation and conclusions were the result of a team effort.

Experiment 3 studied the distribution of current and potential in a circuit (Kirchhoff’s laws). Experimentation consisted of a number of activities using a simulator. The team planned the experiment before collecting the data. Although data measurement was automated, the data analysis, interpretation, and conclusion phases were all conducted as a team.

Pilot-Testing the Science Learning Laboratory

The prototype DCSLL on basic concepts of electricity was pilot-tested at the CCFD in July 1997 using a team of three participants who were representative of the target population. Results indicate that distance collaboration in the context of a distributed science learning laboratory is possible. During the pilot test, the participants showed their commitment and interdependency in the learning process.

Method. Data were gathered using the following means: group interviews with the three participants (both before and after the pilot project), students’ assignments, and participant observation by the three research team members. Interview questions examined content and also probed the participants’ ideas about science labs, collaborative work, and computer-based learning activities. Observations focused on the interactions as well as on the technical and conceptual areas that posed difficulties.

Logistics and Computer Platform. To simulate distance, the three participants worked in different rooms, each equipped with a workstation and telephone that enabled telephone conferencing. The workstations themselves were PCs with Windows 95 and Internet access. Using a browser (either Explorer® or Netscape®), the participants accessed the laboratory site with a user name and password. By clicking on a desktop shortcut, they loaded NetMeeting™, through which they could share a whiteboard, use the annotation tools (the hand, the highlighter, etc.), type in comments and information, and use the screen capture tool. When necessary, the research team provided on-the-spot technical support.
Results

The pilot test provided feedback on the success and appropriateness of the different design principles used to create the DCSLL. Each set of principles is presented below with the principle articulated in the left column and the results observed during the pilot test in the right column. Of course, since these results are based on a very limited number of participants, the significance of the results should be viewed with circumspection. The results of the pilot test were used to define new technical specifications for the revised version of the laboratory that has been implemented in the CCFD course.

Table 1. Distance Education

<table>
<thead>
<tr>
<th>Prototype Design Principles</th>
<th>Results</th>
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<tbody>
<tr>
<td>1. Begin with an individual task, and then provide a personal workspace accessible at all times to respect different cognitive and affective profiles.</td>
<td>This proved important. Participants made frequent recourse to the personal workspace to work at their own speed and to try things out for themselves.</td>
</tr>
<tr>
<td>2. Develop readable, comprehensible learning materials that are easily followed.</td>
<td>The collaborative aspects made this both more important and more difficult because shared, not just individual, understanding was a factor.</td>
</tr>
<tr>
<td>3. Develop a variety of learning activities.</td>
<td>This proved entirely feasible.</td>
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<tr>
<td>4. Anticipate errors and prevent them when appropriate.</td>
<td>Conceptual errors were anticipated during the design phase. Nonproductive technical errors were prevented. Productive errors, which we did not seek to prevent, did not occur with this group.</td>
</tr>
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Table 2. The Science Learning Laboratory

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<th>Prototype Design Principles</th>
<th>Results</th>
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<tbody>
<tr>
<td>1. Practical exercises within planned learning experiments carried out in an appropriate environment.</td>
<td>This proved feasible. Collaborative work raised the participants’ awareness that scientists generally work as a team.</td>
</tr>
<tr>
<td>2. Inductive approach: discovery of laws based on a prediction followed by experimentation and comparison of the prediction with the experimental results in order to foster cognitive conflict.</td>
<td>The approach based on cognitive conflict did not suit all participants; this has implications for the tutor. Participants were not always comfortable making predictions and had to be convinced of the importance of their “lay” predictions.</td>
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<tr>
<td>3. Allow learners to design and conduct their own experiments.</td>
<td>The participants specifically asked to go further (i.e., designing their own circuits on the computer).</td>
</tr>
<tr>
<td>4. Progression from qualitative data to quantitative data to graphic representation to formal representation by mathematical equations.</td>
<td>The progression was effective, and the participants established their own mathematical equations. They grasped the relationship between the various representation systems.</td>
</tr>
<tr>
<td>5. Free the learners from nonauthentic or nonproductive work by using the computer in “emancipatory” mode. The learner should remain an active participant; do not automate too many of the tasks.</td>
<td>The procedures were not too difficult, so the participants had no trouble following the steps.</td>
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Table 3. Information and Communication Technologies

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<th>Prototype Design Principles</th>
<th>Results</th>
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<tbody>
<tr>
<td>1. Written, audio, and visual communication.</td>
<td>Both audio communication by telephone and shared visualization of individual results enhanced the learning experience.</td>
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<tr>
<td>2. Common work and visualization screen shared by all participants.</td>
<td>Having a shared work and visualization screen proved essential.</td>
</tr>
<tr>
<td>3. Preservation of autonomy and balance by carefully limiting application sharing.</td>
<td>Care must be taken in sharing applications, such as the simulator. This is related to the importance of a personal workspace; a shared simulator would have encroached on this.</td>
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Table 4. Collaborative Learning

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<th>Prototype Design Principles</th>
<th>Results</th>
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<tr>
<td>1. Positive interdependency without face-to-face interaction.</td>
<td>The learning environment enabled the development of positive interdependency; the audio communication successfully replaced face-to-face interaction.</td>
</tr>
<tr>
<td>2. Develop competencies (related to content and the collaborative method) and individual accountability.</td>
<td>Individuals became accountable for their own learning and that of the team as a whole.</td>
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<tr>
<td>3. Include sharing of the analysis and data interpretation.</td>
<td>The participants arrived at the planned learning outcomes.</td>
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Guidelines for the Design of a DCSLL

The results of the pilot test from the DCSLL on electricity enabled us to make a number of recommendations to instructional designers wishing to develop distance science learning laboratories. A DCSLL, such as the one we envisaged and realized, is a complex learning environment integrating contributions from different fields. The instructional design recommendations particular to this environment reflect the integration of the different contributing areas and address the complexity and challenges of their design. Some of these recommendations are equally applicable to learning environments that involve only some of the contributing areas, but in an environment as complex as a DCSLL, each of the following recommendations are essential.

1. Provide both a separate workspace for the individual and a common space for the team. Even in collaborative learning situations where the team is the functional unit, the individual learner should retain his or her autonomy. An individual workspace permits each learner to proceed at his or her own pace, to confront common misconceptions individually and not just be "pulled along with the crowd," and to confront idiosyncratic interpretations or conceptions about the concepts under study. The common space is necessary to allow the team to pool their findings and work together to accomplish the learning tasks.
2. Conduct formative evaluations of the learning materials with groups of learners to ensure that the instructions and vocabulary are not only internally consistent, but also subject to the same interpretation.

3. Offer a variety of learning activities. When feasible and appropriate, hands-on activities should be included to provide students with the opportunity to engage in concrete manipulation. Learners should be able to initiate experiments in addition to following predetermined protocols. Learning activities should progress from active to symbolic, and data generated should progress from qualitative to quantitative.

4. Error analysis must distinguish between productive and nonproductive errors, so as to permit the former and prevent the latter.

5. Technology should enhance the learning experience by providing experimental opportunities that would be otherwise unavailable, by facilitating data manipulation and analysis, and by supporting communication (written, video, and audio) among team members and with the tutor.

6. Each learner’s contribution must be necessary but not sufficient for both the individual and the group to succeed in the learning activity. No one student should be able to complete the learning activities individually.

Conclusion

The test results of the prototype’s pilot project, the “Electrical Circuit Simulator,” demonstrated the feasibility of a Distributed Collaborative Science Learning Laboratory. However, due to the somewhat artificial setting of the pilot project, certain questions remain unanswered. For example, do the increased sources of feedback in a peer collaboration context improve the quality and nature of the interaction between students and tutors? Should opportunities for constructive technical errors be created? What are the implications for the tutor’s role in an approach based on cognitive conflict? Under what conditions and in what form is asynchronous communication appropriate? What are the various roles played by the learners in a DCSLL? Many of these issues may be addressed in a real delivery of this Internet-based course to clients of the CCFD.
In conclusion, the Distributed Collaborative Science Learning Laboratory appears to be a practical way to provide authentic lab experiences and reduce student isolation while respecting the fundamental constraints of distance education. Careful attention must be paid to design and management issues raised by this new instructional approach, and the increased technical complexity of the learning environment must be taken into account when designing the instructional activities. Overall, it seems that the DCSLL approach is a way to support learning within a distance context that allows distance education students to engage in collaboration in action as well as collaboration in discourse.

Notes

1. Technological limitations prevent multipoint, Internet-based audio conferencing from offering satisfactory results. Therefore, in order to test the design principles without being limited by current technology, conventional telephone conferencing was substituted.

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