CO-LAB: RESEARCH AND DEVELOPMENT OF
AN ONLINE LEARNING ENVIRONMENT FOR
COLLABORATIVE DISCOVERY LEARNING

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ABSTRACT
There are many design challenges which must be addressed in the development of
collaborative scientific discovery learning environments. This paper presents an overview
of how these challenges were addressed within Co-Lab, a web-based learning
environment in which groups of learners can experiment through simulations and remote
laboratories, and express acquired understanding in a runnable computer model. Co-Lab’s
architecture is introduced and explicated from the perspective of addressing typical
problem areas for students within collaborative discovery learning. From this view the
processes of collaboration, inquiry, and modeling are presented with a description of how
they have been supported in the past and how they are supported within Co-Lab’s design
and tools. Finally a research agenda is proposed for collaborative discovery learning with
the Co-Lab environment.

INTRODUCTION
Socio-constructivist learning theories perceive learning as a constructive, situated and
collaborative process. These theories converge on the notion that learners develop an
understanding of a domain by working on authentic tasks in realistic settings. Task performance
preferably occurs in collaboration with peers, and should be regulated by the learners (instead of
the teacher or the learning material).

In science education, these notions of learning can be implemented by letting learners "act
like scientists". That is, learners should perform experiments to discover relationships between
phenomena, and construct models to express their understanding. Clearly, these learning activities
are more constructive by nature than, for instance, listening to lectures or solving paper-and-pencil
physics problems. Experimentation and modeling are also authentic activities that reflect the way
scientists go about in studying unknown phenomena. Learners thus develop domain knowledge
and, at the same time, familiarize themselves with a scientist’s way of working and thinking (cf.
Brown, Collins & Duguid, 1989). Such enculturation can be further enhanced through
collaboration. Teamwork has long since been a common practice in science and many scientific
discoveries were a joint effort (Dunbar, in press).

Organizing science education around collaborative inquiry and modeling activities requires
innovative, student-centered forms of instructional support. Collaborative discovery learning
environments are a potentially powerful means to offer this type of support, provided that their
design meets certain criteria. One obvious demand concerns the presence of tools learners can use

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to explore a task domain through experimentation. Yet merely doing experiments does not capture the full range of a scientists’ activities. Nor will it develop deeply rooted, transferable knowledge and skills. Structural changes in domain knowledge require reflection in conjunction with modeling, and reflection is a natural component of the social interaction that occurs in collaboration (Penner, 2001). Collaborative discovery learning environments should therefore comprise tools that support inquiry through experimentation, domain modeling and student collaboration.

This paper exemplifies how this type of support might be brought about. It does so by articulating the design considerations for Co-Lab, a web-based learning environment in which groups of learners can experiment through simulations and remote laboratories, and express acquired understanding in a runnable computer model. The next section presents an overview of Co-Lab’s basic architecture. The sections that follow elucidate how the processes of inquiry, modeling and collaboration are supported within the environment and its tools. In the final section, a research agenda is proposed for collaborative discovery learning with the Co-Lab learning environment.

**CO-LAB’S BASIC ARCHITECTURE**

Co-Lab supports collaborative discovery learning in the natural sciences at the upper secondary level and the first years in university. Content is currently available for four domains: water management, greenhouse effect, mechanics and electricity. Water management and greenhouse effect are extensive courses that cover the richness of these interdisciplinary domains. Both courses comprise several modules of different levels of complexity.

A building metaphor was used to elucidate this multi-layered structure. Learners have access to one or more buildings symbolizing the courses in the various domains. Each building contains multiple floors (representing the modules) and each floor has multiple rooms to structure the learners’ activities. Experimenting and modeling are supported in the Lab and Theory room respectively. The Meeting room is intended for planning and monitoring; the Hall is where learners gather and collect their assignment. Buildings and floors thus organize the domain, rooms organize the learning activities.

![Figure 1: Annotated screenshot of Co-Lab’s interface](image)
Figure 1 shows the Co-Lab interface that appears upon entering a floor. The top-right part of the screen is the main working area. Here students can select various tools for experimentation and modeling. In keeping with the building metaphor, different tools are available in different rooms, so the content of this part of the screen depends on the learner’s current location.

The left-hand side of the screen houses generic tools for navigation and collaboration as well as a tool to move learning objects across rooms. As these tools are available in each room, this part of the screen remains unchanged when students switch rooms. The same goes for the bottom part of the screen where a synchronized chat tool supports communication.

**CO-LAB’S COLLABORATIVE DISCOVERY LEARNING ORIENTATION**

In collaborative discovery learning, groups of students examine scientific phenomena and express their shared understanding in a runnable computer model. Learners thus engage in three analytically distinct processes, namely inquiry, modeling and collaboration. In Co-Lab, however, the demarcation between these processes is less clear cut. Collaboration, for instance, runs like a continuous thread through the discovery learning process, affecting the way in which inquiry and modeling processes are performed and should be supported. Furthermore, modeling is considered an integral (but still special) part of the inquiry process. During the initial stages of the learning process, learners make model sketches to orient themselves to the learning task and use these sketches to formulate hypotheses. By testing their hypotheses with the simulation, learners gain knowledge which they can use to refine their model. At the end of the learning process, the model thus conveys the learners’ acquired understanding.

The sections below detail Co-Lab’s orientation to collaborative discovery learning. For clarity, the processes of inquiry, modeling, and collaboration are described in separate sections, despite the dynamic interplay between them.

**FACILITATING INQUIRY LEARNING**

Inquiry learning pertains to the acquisition of knowledge by a learner-regulated process of data collection and data interpretation. The inferential processes that build upon the data gathered by the learner should lead to the discovery of rules that govern the relations between variables in a given domain. In this sense, inquiry learning has shifted from the discovery of concepts (as it was originally conceived in Gestalt psychology and the work of Bruner (1961)) to discovery of rules (De Jong & Van Joolingen, 1998).

In Co-Lab, learners can collect data from either built-in simulations, remote laboratories or remote databases. Regardless of the data source, learners are to unravel the relations between input and output variables through systematic experimentation. This process proceeds through five phases: analysis, hypothesis generation, experiment design, data interpretation, and conclusion. Njoo and De Jong (1993) coined the term *transformative processes* to indicate that the learners’ activities in these phases are performed for the sole purpose of yielding knowledge. *Regulatory processes*, in contrast, serve to manage and control the inquiry learning process. Planning, monitoring and evaluation are typical instances of regulatory processes.

A review by De Jong and Van Joolingen (1998) has produced a comprehensive overview of the difficulties learners encounter in inquiry learning. How these problems were addressed in Co-Lab is discussed in the sections below.

**Support for transformative processes**

*Hypothesis generation*

Formulating syntactically correct (i.e., testable) hypotheses is among the most pertinent problems in inquiry learning. One solution is to provide learners with partly specified hypotheses. To this end, Van Joolingen and De Jong (1993) introduced a hypothesis scratchpad which contained templates to formulate syntactically correct predictions. Learners could select a statement from a pull-down menu and complete it by adding variables, relations and condition. Unfortunately, usability problems prevented learners from taking full advantage of this tool.
Bearing these problems in mind, Gijlers and De Jong (2004) converted the ideas of the hypotheses scratchpad into a proposition table. This tool comprised a list of fully specified hypotheses, the students’ beliefs about a hypothesis and their willingness to test it (the proposition table was used in a collaborative setting). Students using the proposition table outperformed both the hypotheses scratchpad and the control group on a test measuring intuitive knowledge. Protocol analysis revealed that these differences arose because students in the proposition table group produced more statements about hypothesis generation and discussed a larger number of hypotheses.

Despite these favorable results, offering fully specified hypotheses has the potential disadvantage of prompting the key variables and relations. This might instigate learners to skip the analysis phase and start experimenting on the basis of patchy knowledge. To restrain learners from jumping the gun, Co-Lab supports hypothesis formation in a graphical instead of a verbatim way. Learners use their model to express their prediction about a relation between two variables. During the initial stages, pre-specified, qualitative relations can be selected from a drop-down menu. Hypotheses can be tested by comparing the outcomes of the model and the simulation. During the later stages, qualitative relations can gradually be replaced by quantitative ones, using scientific formulas.

**Experiment design**

Another class of problems pertains to the design of experiments. These include the design of inconclusive experiments, inefficient experimentation behavior, and the design of experiments that are not intended to test a hypothesis.

Inconclusive experiments often arise because learners vary too many variables at once. Experimentation hints such as “vary only one variable at a time” can improve learners’ experimentation abilities in this respect (De Jong & Van Joolingen, 1998). In Co-Lab, these hints are offered in the Process Coordinator and in help files.

Inefficient experimentation occurs when learners fail to design informative experiments or repeat previous experiment. The former instance may be difficult to overcome because inquiry learning essentially is a learner-directed process. Repetitions on the other hand might be avoided by providing insight into the experiments a learner has performed. To this end, SimQuest simulations contain a monitoring tool that shows for each experiment the initial values of input variables and end values of output variables (Veermans, 2002). Learners can reveal the progress of output variables through time by selecting a given experiment from the tool and clicking the ‘replay’ button. The simulation is then run using the exact same settings as in the original experiment. Experimentation support in Co-Lab is more output-oriented in that learners can save experimental results instead of experimental settings. Learners can save tables and graphs in the Object Repository and annotate these to identify the settings used in the experiment. Tables and graphs can be retrieved by clicking the ‘restore’ button (see Figure 1).

Designing experiments that are not intended to test hypotheses is often indicative of an engineering approach. Schauble, Klobfer and Raghaven (1991) characterize this approach as one in which learners attempt to create a desirable outcome instead of trying to understand the model. Co-Lab seeks to resolve this problem by requiring learners to produce a comprehensive model. Assignments in Co-Lab are therefore open-ended, merely instructing learners to come to grips with a phenomenon and model it. However, research suggests that additional experimentation hints are needed. An exploratory study with Co-Lab revealed that experimentation in absence of any further support to the contrary shows learners engaging in an engineering approach (Manlove & Lazonder, 2004). Learners merely used the water tank simulation (displayed in Figure 1) to reach equilibrium through trial-and-error. Once they succeeded, they did not try to discover the simulation’s underlying model by reaching equilibrium using different settings (as indicated by the assignment).

**Data interpretation**

Learners often experience difficulties in drawing conclusions from their data. Visualizing data is a well-tried solution. A linear relationship between two variables can, for instance, more easily be identified from a graph than from numerical values in a table. Nevertheless the construction and interpretation of graphs appears to be both time consuming and error prone. Co-Lab’s graph tool
therefore automatically generates a graph when the simulation is run. Learners can thus readily interpret the results without having to convert raw data into a graph.

Co-Lab does not yet support across-experiment comparison of data. But it might be interesting to add the extended version of Veermans’ (2002) monitoring tool to the Co-Lab environment. This tool allows learners to arrange stored experiments according to one of the variables to compare various experiments. Across-experiment comparison is further supported by a graphing option that allows learners to plot the end value of an output variable obtained in a series of experiments in a single graph. This option supports learners in performing a meta-analysis of their own data to extrapolate relations between variables.

Support for regulatory processes

Regulatory processes are pivotal to successful inquiry learning. While constructivists advocate that learners should engage on their own in regulatory activities such as planning, monitoring and evaluation, research has consistently shown that additional support is needed for learners to become “active agents of their own inquiry learning” (Kluwe, 1982).

Task complexity can get in the way of learners’ spontaneous use of self-regulatory skills (Elshout, 1987). This problem might be overcome by scaffolding the inquiry process along a spectrum of progression. This so-called model progression allows learners to start with a simplified version of the simulation; complexity is gradually increased by introducing new variables or features during the course of the learning process (De Jong & Van Joolingen, 1998). In Co-Lab, the floors within a building represent the various levels of complexity. To illustrate, model progression in the water management building develops from a simulation of a water tank, through a real water tank (accessible via a remote lab), to an advanced simulation of polders and rivers that includes tidal movement, rainfall, and pumping stations.

While model progression enables learners to employ existing self-regulatory skills, it does not cater for the use of unmastered skills. To provide the latter type of support, specific features or tools should be implemented in the learning environment. The sections below discuss measures for promoting planning, monitoring and evaluation.

Planning

Planning can be facilitated by directing learners to the important aspects of a simulation. Assignments are an unobtrusive way to provide such prompts (De Jong & Van Joolingen, 1998). Co-Lab uses so-called explication assignments that ask students to explain a certain phenomena and to model it. Prins (2002) showed that such assignments can increase the time on orientation activities during the planning phase.

Planning can also be supported by outlining the steps learners should take during each phase of the inquiry process. This type of support is particularly useful for learners with lower levels of self-regulation (Vermunt, 1998), and research suggests that Co-Lab’s target audience matches this profile. Manlove and Lazonder (2004) report that Co-Lab users between the ages of 15 and 17 hardly engaged in planning and frequently expressed their ignorance of the general approach to the learning task. This observation prompted the development of a fully specified planning tool called the Process Coordinator (see Figure 2). It contains a series of goals and subgoals that guide learners through the stages of the inquiry process. Each goal statement comes with a description stating what learners should do to accomplish that goal, and one or more hints that answer frequently asked questions. This design is assumed to promote self-regulation which in turn will yield higher knowledge gains. Attempts to validate this assumption are in progress.

As learners’ self-regulatory skills are expected to improve, planning support is gradually faded. In keeping with the building metaphor, the Process Coordinator contains fewer and less explicit directions on higher floors. Fading may occur by first removing the subgoals, then the descriptions, then the hints, and finally the top level goals. The Process Coordinator thus provides a temporary support structure which can be considered another instance of model progression.
Monitoring
In the monitoring phase, learners engage in control and observation of both their comprehension, attention, and performance in relation to the goals set during the analysis phase. Monitoring can be triggered internally (e.g., learners spontaneously consider their approach to the inquiry task) and externally (e.g., inconsistent results prompt learners to check the simulation’s settings). It is therefore somewhat difficult to anticipate when exactly monitoring will (or should) occur. This in turn complicates the design of specific monitoring support—at least, without an intelligent tutoring system (cf. Veermans, 2002).

Monitoring can be supported by giving overviews of the learner’s actions in the environment (De Jong & Van Joolingen, 1998). While Co-Lab does not provide ready-made overviews, it does facilitate learners in compiling overviews themselves. In the Process Coordinator, learners can tick off goals they consider completed and review their own notes via the History tab. Learners can also extrapolate an overview from the data stored in the Object Repository (see Figure 1).

Evaluation
Evaluation pertains to a judgment of learning outcome as well as the learning process. While often there is no clear-cut distinction between evaluation and monitoring, Schön (1991) differentiates reflection on action from reflection in-action. Reflection in action pertains to monitoring activities, whereas reflection on action can be likened to evaluation activities which occur at “certain stopping points” during an activity, often at the end of the learning process.

Process displays and process prompts have been used to promote evaluation of learners engaged in discovery learning (Lin, Hmelo, Kinzer & Secules, 1999). A process display shows the learners explicitly what they are doing to solve a task. In learning environments this is often a trace or history of student actions. Process prompts give learners the opportunity “… to explain and evaluate what they do before during and after problem solving acts” (Lin et al., 1999). These prompts are usually in the form of questions posed to the student by the learning environment. Lin and Lehan’s (1999) study of different prompt types found that prompting learners to justify their reasoning directed learner’s attention more to understanding “when, why, and how to employ experiment design principles and strategies” (p. 837). This in turn enabled better transfer of their understanding to novel problems.

Co-Lab utilizes both process displays and process prompts via the multiple views within the Process Coordinator. In the goal view, a process model is supplied to the learners in the form of goals and subgoals which gives learners an overview of the process they should engage in. The process prompts are supplied in the form of hints per sub-goal and take a question and answer format. The history view within the process coordinator shows all learner actions organized under the goals provided. Finally both the history and the goal views are combined within the report view. It enables learners to see their goal progress within the goal view, along with the notes and products they have made in the history view. The report view also provides a template structure
where learners write a report of their findings. The template specifies report sections along with descriptions which assist learners in writing out what they have learned from their inquiries and what they have learned about the process of inquiry.

**FACILITATING MODELING**

Mental models are the internal representations we hold of our world. We use them to provide insight into how to reason over a particular problem, domain or situation (Jonassen, 1995). Assisting learners in acquiring appropriate mental models of physical systems is one of the main purposes of scientific discovery learning. Computer modeling has been recognized as an effective method to facilitate mental model development. By building an executable domain model, learners externalize and test their conceptions of the variables in the simulation. The role of the model thus is to house domain knowledge and to be a vehicle for students understanding and conceptual change (Jonassen, Strobel & Gottdenker, in press).

There are many types of modeling formalisms, from concept map notations to text based modeling found, for example, in goal tree structures. When reasoning about the continuous physical systems found in water management and green house gasses however, systems dynamics modeling appears to be the most appropriate to represent these systems (Frederiksen & White 1998, Jackson, Stratford, Krajcik & Soloway, 1996). It reflects the nature of physical systems in that it allows learners to construct models which change over time, has multiple variables with both direct and indirect relationships. The use of generic variable types such as stocks, constants and auxiliaries provide learners with “mini” mental models of how to think about variables and their relationships in the system. The Co-Lab environment then utilizes a Model Editor tool which allows learners to construct systems dynamic models of the phenomena displayed in the simulation.

When learners construct a model, they tend to go through four stages: (1) model sketching, (2) model specification, (3) data interpretation, and (4) model revision (cf. Hogan & Thomas, 2001). As Co-Lab perceives modeling as an integral part of scientific inquiry, the stages in the modeling process are closely related to the phases of the inquiry learning process identified by Njoo and De Jong (1993). In the analysis phase, learners sketch a model outline to express their initial understanding of the phenomena from the simulation. In the hypothesis phase this sketch is transformed into a runnable model by specifying the relations between the variables in the model. During data interpretation, learners compare their model to data from the simulation which, during the conclusion phase, feeds their decision to revise the model.

Given the intertwined nature of inquiry and modeling, much of the support which has been explained in the previous sections also applies to supporting modeling activities. The sections below therefore present the support learners can use for model building per se.

**Support for model sketching**

During problem analysis, learners can make a situation drawing to express their initial mental model and understanding of a domain (Forbus, Carney, Harris & Sherin, 2001; Oliver & Hannafin, 2001). The sketch often serves to scaffold the complexities found in simulation-based inquiry learning, where learners have to unravel various, simultaneously interacting cause/effect relationships (Jackson et al., 1996). Co-Lab’s supports model sketching through a graphical modeling tool which allows learners to build an icon-based model structure (see Figure 3). Additionally learners are supported within Co-Lab in learning systems dynamic modeling via a tutorial and model editor help files.

**Support for model specification**

In model specification, learners define the relations between variables in their model. These relations initially represent a learner’s assumptions of how variables interact; later the relations represent the learner’s insights derived from the simulation. According to Löhner, Van Joollingen and Savelsbergh (2003), qualitative specifications are appropriate during the initial stages of the
he modeling process when learners still lack a clear understanding of the model they are building. In fact scientists in practice often start with a qualitatively expressed model (White & Frederiksen, 1990). By qualitatively expressing relationships, learners begin to construct a bridge between their initial mental model of the system (as found in the model sketch) and the target model (Jackson et al., 1996). Quantitative, formula-based specifications are more useful for the later part of the modeling process, when the model is finalized. As both forms of representation play a distinct role in the modeling process, learners are best supported by a modeling tool that accommodates a mixed representation.

Co-Lab’s Model Editor was designed according to these guidelines. It allows learners to specify their model by selecting pre-defined qualitative relations, drawing graphs, or entering mathematical formulas (see Figure 4). As variable and property identification progresses across a qualitative to quantitative spectrum (Njoo & De Jong, 1993), learners are prompted to specify their model accordingly, using qualitative relations to specify their hypotheses and quantitative relations to express insights derived from the simulation.

**Support for data interpretation and model revision**

Using a model to run is the primary means of model testing and revising (Forbus et al., 2001; Frederiksen & White, 1998). Running a model produces results to be interpreted by the learner. That is, learners have to establish how well the data from their model match with the results from the simulation. The immediate feedback a model can give is an important factor also in assisting students in evaluating their domain understanding (Jackson et al., 1996).
To facilitate the comparison of data between simulation runs and model runs, Co-Lab’s Graph tool is equipped with a curve fitting option. This feature allows students to display the output of the simulation and their model in a single graph (see Figure 1). As the settings of simulation and student model may differ (which is often the case with qualitative modeling), the graph tool also contains an normalization feature that adjusts the scales of both graphs in order to allow for a valid comparison.

In curve fitting, learners judge the equivalence between simulation and model at face value. While this is definitely helpful during the initial stages, a more accurate measure is needed in fine-tuning a model. Co-Lab therefore offers a fitting option in the Graph tool. When learners select this option, the system calculates the goodness of fit between the model output (as shown in the graph) and a given theoretical distribution (e.g., a curvilinear relationship).

Examining and interpreting model output is essential for understanding scientific phenomena. Yet research shows that students use model output sparingly, usually only at the end of a modeling session to check if obtained results match their initial expectations (Hogan & Thomas, 2001; Stratford, Krajcik & Soloway, 1997). Modeling should involve dynamic iterations between examining output and revising models. As learners generally fail to spontaneously adopt such an iterative approach, the learning environment should prompt them to do so. In Co-Lab, these prompts are offered in the Process Coordinator, fully integrated with the directions for systematic experimentation.

**FACILITATING COLLABORATION**

Discovery through collaboration is a common practice in science. In order for students to “act like scientists”, discovery learning should occur in groups. An additional advantage of collaboration is that it promotes higher achievement than individual learning strategies (e.g., Lou et al., 1996). Other studies have shown that this effect transfers to discovery learning. Paired students generally are more successful in discovering scientific mechanisms than single students (e.g., Okada & Simon, 1997; Teasley, 1995). These studies further demonstrate that the superiority of student pairs is attributable to peer interaction. Collaboration increases the likelihood that learners engage in the type of talk that supports learning, such as asking and answering of questions, reasoning and conflict resolution.

Collaboration also promotes regulation of the learning task. In a study by Lazonder (submitted), pairs of students showed relatively higher proportions of self-regulatory activities than single students. More specifically, dyads exhibited a richer repertoire of strategies to solve problem solving tasks. They were also more proficient in monitoring each other’s actions which facilitated early detection and correction of errors. The results for evaluation also differed in favor of the dyads. They crosschecked initial answers more frequently and modified initially incorrect responses more than twice as often. Further research is needed to determine if these effects generalize to discovery learning.

The studies reviewed above, however, focused on face-to-face collaboration. Comparisons of computer-mediated and face-to-face collaboration suggest that computer-mediated collaboration is characterized by some deficiencies A number of studies have, for instance, found that face-to-face dyads attain higher performance scores than students who collaborate online (e.g., Salminen, Marttunen & Laurinen, 2003; Van der Meijden & Veenman, in press). Face-to-face dyads also have more prolonged discussions on the learning task; communication in the computer-mediated dyads is more directed at coordinating efforts, operating the communication tool, and expressing emotions.

Together, these findings indicate that computer-mediated collaboration can promote scientific discovery learning, but that collaboration itself should be promoted for learners to take full advantage of each others presence. This implication is relevant to Co-Lab, as this environment is designed for synchronous online collaboration, permitting learners to work together in real time while being geographically dispersed. Co-Lab allows for this type of collaboration by providing a communication channel, shared workspaces to visualize and manipulate joint products, and functions which increase social presence.

Co-Lab does not include additional support for collaboration. Although such supportive features are available (e.g., reflective notebooks, collaborative concept maps, communication
widgets), their efficacy in synchronous online collaboration has not been assessed. Yet empirical validation is needed because Co-Lab’s target audience is familiar with online communication technologies. To illustrate, Lazonder, Wilhelm and Ootes (2003) examined the efficacy of sentence openers to foster peer interaction. Sentence openers are pre-defined opening phrases students can readily select from a menu in their chat tool. The students in this study hardly used sentence openers, a result that was attributable to their chat experience. Students were accustomed to typing chat messages and maintained in this chat style, being unwilling or unable to adopt an alternative way to create messages.

**Support for student interaction**

Peer-to-peer collaboration encourages students to articulate their thoughts, which in turn has a facilitative effect on achievement and regulation. While such verbalizations occur naturally in face-to-face collaboration, designated tools are needed for learners to interact online. Co-Lab enables social interaction through a synchronized chat tool. Consistent with the building metaphor, the chat is room-specific, which means that by default messages can only be read in the room in which they were sent.

Usability tests revealed that this division was too strict as it impeded the learning discourse. Learners specifically asked for an “intercom” to contact group member in different rooms. This functionality was implemented in the form of the “Send to floor” button. By pressing this button, the unsent chat message becomes visible in every room.

**Support for shared knowledge building**

Constructing shared knowledge is the ultimate goal of collaborative learning. This goal has two important consequences for the tools in collaborative discovery learning environments. One is that shared knowledge must be represented explicitly so learners can see the objects they are working on and talking about. Learners should thus be offered a joint space to post their ideas, hypotheses, models and so on. The second implication reads that the learners’ multiple perspectives should be integrated. This means that the tools should allow learners to manipulate the objects represented in the joint space.

The notion of shared workspaces was central to the design of Co-Lab. In a way, Co-Lab itself is one shared workspace: the environment holds no private tools or spaces, so everything a learner does is readily visible to and editable by his/her group members.

**Support for social presence**

Face-to-face collaboration is dominated by social presence (a sense of being together) where individuals can interact effortlessly. As online collaboration is weak in social presence, designated tools are needed to increase learner’s sense of being together (Kirschner, 2002). Co-Lab’s Locator tool allows learners to check which group members are online and which room they are in. Manlove and Lazonder (2004) showed that learners use this tool frequently to see when if group members have entered the environment or joined them when changing rooms. The Locator also served to trace group members who did not contribute to the ongoing chat discussion.

A related issue pertains to the control over tools in the environment. Due to weak social presence, one learner can accidentally change or undo another learner’s actions. As chat communication proved insufficient to settle control, most tools in the Co-Lab environment can be operated by one learner at a time. By default, the learner who enters a room first gets control over all tools, and can pass it on upon another learner’s request.
CONCLUSION

In this paper, the Co-Lab learning environment served as a vehicle to express our views on collaborative discovery learning. Co-Lab’s initial design was based on insights gleaned from instructional theory and empirical research. Usability tests have been conducted to improve the user-friendliness of the environment and the intuitiveness of its tools. Once the implications of these studies are fully implemented, Co-Lab can be utilized as means to further our understanding of collaborative discovery learning through educational research.

Our research agenda currently contains two major topics, namely regulation and modeling. Studies into student regulation focus on the use of the Process Coordinator tool. We are currently investigating if this tool yields increased instances of planning, monitoring and evaluation as well as better modeling quality. This study compares a fully specified Process Coordinator containing a hierarchy of process goals and subgoals, hints and a report function to a Process Coordinator which has no content, but has full functionality. The outcomes of this study will shed light on the functionality of the Process Coordinator. The results will also provide insight into how groups of students (as opposed to single students) use regulation prompts to organize their discovery learning process.

Research into modeling seeks to determine when and how learners change from qualitative to quantitative modeling. While the Model Editor allows for a smooth transition between these model representations, it is yet unknown whether learners can make this switch with the available support. This study also examines the differences between face-to-face and online modeling. Being a highly complex task, modeling is likely to suffer from the problems that are typical of computer-mediated collaboration. Analyses of student interaction might therefore prompt the development of additional support for online collaboration.

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