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## **CIEL: setting the stage for integrated inquiry learning**

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### **Abstract**

*We present an integrated framework for the design, authoring, and evaluation of innovative learning scenarios for Collaborative Inquiry and Experiential Learning (CIEL). This framework has been designed to promote interoperability in environments for productive, open-ended learning, such as inquiry learning, but also learning by design and experiential learning.*

*The CIEL framework centers around a repository of learner generated learning objects that can be saved, and retrieved in standardized format and of which the collection can be queried for objects relevant for a given task. Issues are the ontology of learning objects needed for the support of inquiry learning, the generation of metadata and the semantic interoperability of tools.*

### **1. Introduction**

There are several environments that are designed to support different forms of inquiry learning, such as SimQuest for designing computer simulations (van Joolingen & de Jong, 2003), environments for structuring inquiry processes, such as WISE (Slotta, 2004) and ThinkerTools (White, 1993), modelling tools such as STELLA (Steed, 1992) and Cool Modes (Pinkwart, Hoppe, Bollen, & Fuhlrott, 2002), and tools trying to integrate collaboration, modelling and discovery learning, such as Co-Lab (van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005). CIEL scenarios aim to combine the strong points of different environments maintaining conceptual consistency. For instance, learners may gather data in one environment, process the data in another, and create a model describing the data in a third.

A number of these encompassive learning environments that include one or more of the above mentioned design guidelines on different domains have been created in various places. Examples are: CoolModes/FreeStyler (Hoppe, 1999) providing generic worksheets for a variety of symbolic languages, SimQuest (van Joolingen & de Jong, 2003) for authoring simulation-based learning environments, Co-Lab for collaborative inquiry learning, FLE (Leinonen, 2004; Mørch, Dolonen, & Omdahl, 2003) for progressive, collaborative inquiry, JEMUE (Baggetun & Dragsnes, 2003), providing pedagogical agents in collaborative knowledge building, and more domain specific environments such as ARI-LAB (Bottino & Chiappini, 2002) for mathematics learning and Tangibles (Cerulli, Chiocciariello, Fernaeus, Lemut, & Tholander, 2005) for learning basic concepts on statistics and randomness.

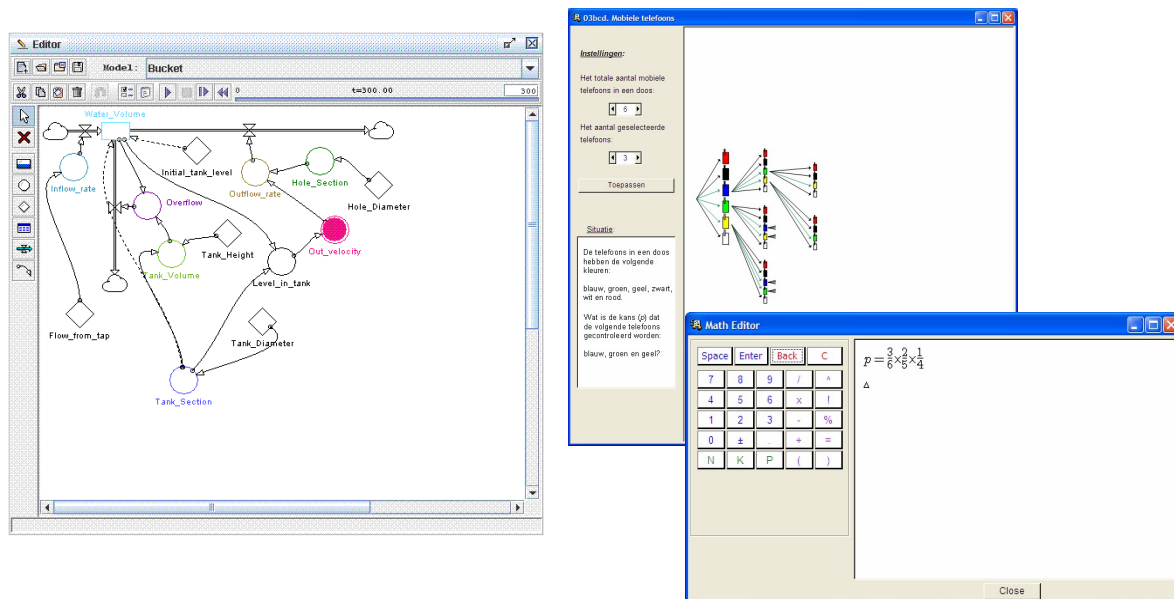
### **2. Supporting advanced pedagogical scenarios**

Each of the learning environments mentioned in the previous section offers specific kinds of support, usually for one or a limited amount of *pedagogical scenarios*. A pedagogical scenario is defined as an orchestrated set of activities that learners undertake to learn. Scenarios can represent episodes of scientific inquiry, technological design, engineering or others. The basic idea of these scenarios is to engage learners in a constructive, realistic context in which knowledge is created and used at the same time.

In the example learning environments presented above the scenarios are supported by offering specific (cognitive) tools (Lajoie & Derry, 1993; van Joolingen, 1999) to learners. These tools have a role within the environment they were created for, but also may have broader application. The CIEL project aims at integrating such tools into a framework that supports a multitude of advanced pedagogical scenarios that support the building of scientific knowledge by learners. The main reasons for starting this undertaking are:

- *Combining specializations.* Each tool has its merits of supporting specific parts of advanced pedagogical scenarios such as a collaborative inquiry learning process, including support for collecting data, modeling and specific means of collaboration. Instead of trying to create a single tool that can do it all CIEL strives to enable *semantic interoperability* (Koedinger, Suthers, & Forbus, 1999), between tools.
- *Support of longer term learning scenarios.* Most learning environments support a specific type of activity, such as doing research on the greenhouse effect, or create a model of volcanic activity. This means that the typical duration of use will be limited. CIEL strives to design scenarios that extend over longer time periods, involving multiple activities and tools.

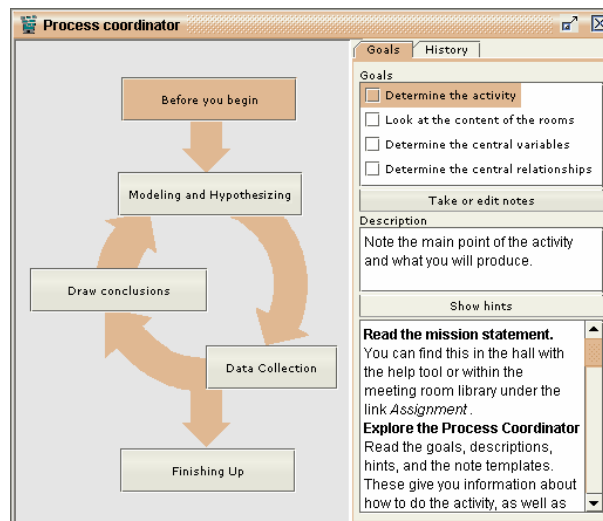
In a typical pedagogical scenario that takes more than a few lesson periods, learners will perform diverse activities. Each of these activities will represent steps in the process of scientific knowledge building, and the whole scenario may therefore be supported by a variety of tools. CIEL aims to create an architecture in which many tools can interoperate to construct many different inquiry learning scenarios.



**Figure 1** Two examples of tools to support transformative learning processes.

In several empirical studies, data has been collected to inform the design of an architecture of interoperating tools that support the scenarios we aim at within CIEL. Most of these studies compare different versions of *cognitive scaffolds* or tools for the processes of inquiry learning (van Joolingen, de Jong, & Dimitracopoulou, 2007). Scaffolds can support both the transformative processes of learning, such as the generation of hypotheses (Njoo & de Jong, 1993; van Joolingen & de Jong, 1991) or the creation of models (Löhner, van Joolingen, & Savelsbergh, 2003) as well as regulative processes of inquiry learning. For the latter we conducted an empirical study with a cognitive tool which assisted students to plan, monitor, and evaluate their inquiry activity. 86 students participated from three international high schools in the Netherlands. We compared a full support version of the process coordinator (PC+) with a lean support version (PC-). The full support version (See Figure 2) included an inquiry cycle (White & Frederiksen, 1998) goal list, hints, note cueing, and prompts within note templates. In addition the PC+ condition received a lab report template to support student evaluation work. The PC- enabled students only to make their own goals and take notes. Learner generated objects, such as models, lab reports, and notes were utilized to determine the extent to which the PC assisted students in achieving higher quality models and lab

reports. Log file analysis of student actions with the PC was also conducted. Findings indicate that, while use of the PC was significantly higher by PC+ groups, and they had significantly higher lab report scores than their PC- counterparts, it was the PC- group who achieved significantly higher model quality scores. Further analysis revealed that PC- groups consulted help files more often than PC+ groups which may explain this unexpected finding. The help files contained more domain specific information related to modeling. So while regulative support did effect evaluation type work, further research is needed to see how it can better support domain constructing type activities.



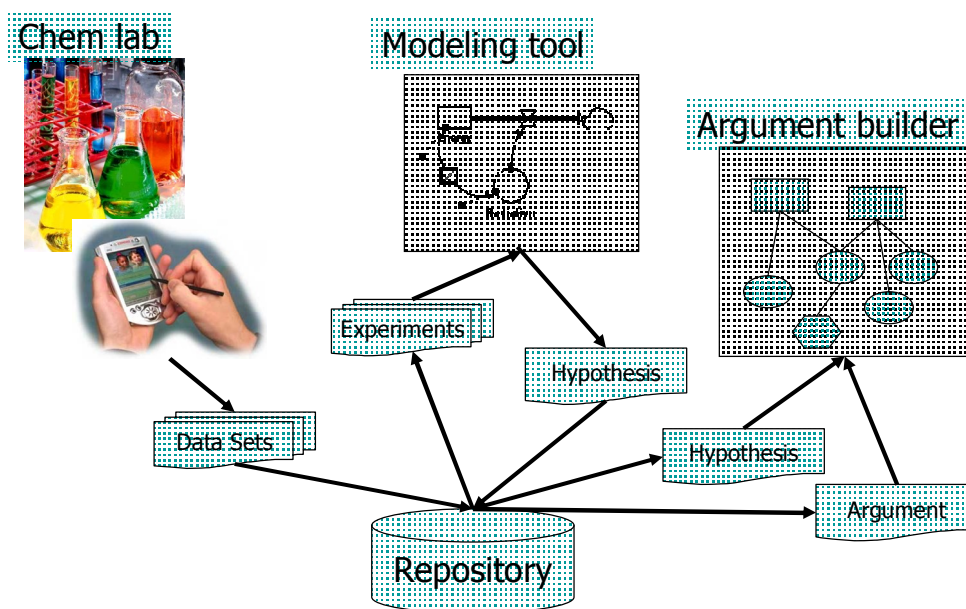
**Figure 2** Process Coordinator used by the PC+ groups, as an example of regulative support

The resulting insights from this and other studies are that (1) supportive tools can have an effect on the process of inquiry learning and (2) that the process as well as the scaffolds that support this can be modelled in terms of objects created by learners using the scaffolds and tools within the environment. The latter insight is important because it allows us to define what we mean by interoperability of tools and scaffolds, viz. that tools are interoperable when they can consume and produce objects that can be interpreted within a shared ontology of learning objects. In other words, tools are interoperable when the objects they can operate upon can be exchanged on both a technical and conceptual level. The meaning an object has for a learner should not change when it is transferred from one tool to another.

### 3. An example pedagogical scenario

Figure 3 presents an example of an advanced pedagogical scenario for scientific inquiry learning. Learners working within this scenario mix solo work with collaborative work possibly in different groups. For instance, as depicted in Figure 3, learners may first collect data in a laboratory, using a mobile device. During data collection they probably work alone or in a small group (pairs or triads). These data can then be used to construct a model of the domain they are investigating using a modeling tool. In the modeling process they may use the data they collected themselves, but the scenario may also allow using other students' data. For instance comparing two data sets may help them to obtain a deeper understanding of the influence of experimental conditions on the results obtained. Comparing data and – at a later stage – models requires a collaboration at the level of larger groups. Part of this collaboration can be a debate, supported by the construction of an argument, using a dedicated argumentation builder such as Belvedere (Suthers, Weiner, Connelly, & Paolucci, 1995). Finally (not visible in Figure 3) individual learners may complete the activity by writing a report and submitting this to their teacher.

Figure 3 depicts how this whole scenario is integrated around a common repository through which the different tools exchange information (e.g., data or models). On the one hand such a scenario should be *semantically integrated*, meaning that the learning process as a whole, including the transitions from tool to tool take place in a



**Figure 3** A multi-tool scenario supported by CIEL.

smooth and meaningful way. On the other hand integration should also take place at a *technical level*, ensuring smooth data exchange between tools.

On the semantic level, it is important to support the flow of information and activity in the task context. This can be facilitated and implemented in different ways. One possibility is to map data onto specific objects that can be physically transferred (e.g., data can be captured on a PDA and thus be transferred). Another possibility is to transfer information between places and different environments by real time synchronization. Milrad et al. (Milrad, Hoppe, Gottdenker, & Jansen, 2004) discuss several of such interoperability patterns from both an engineering and an educational design view.

Here the environments can possibly be heterogeneous. This second option requires a tight coupling in terms of processing and time constraints. A loose coupling which implies much less restrictions is often facilitated through a common repository, although a real time synchronization is not supported in a loose coupling model. It needs a common data format which can be 'understood' and generated by the different tools. In CIEL, we have first adopted the loosely coupled model for our technical approach.

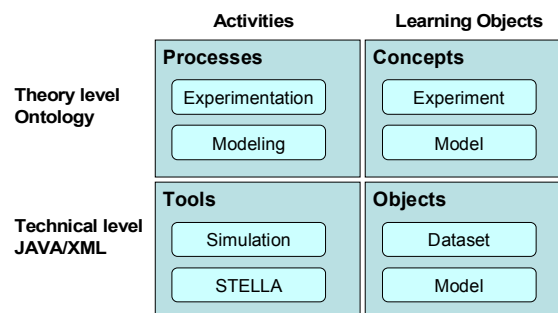
#### 4. The CIEL ontology

CIEL aims to support both levels of integration by bringing together several systems that support collaborative inquiry learning and make them interoperate at the two indicated levels. At the semantic level CIEL works on integration of concepts such as learning processes, learning objects and learning tools. The basic assumption behind CIELs conceptualization is that all activities of learners leave traces in the learning environment in the form of products created or, for instance, as communication with other students or with a teacher. In the example presented in Figure 3, the products that are created are the data sets collected, the hypotheses and models made and the arguments exchanged between learners. In order to appreciate this role of products generated by learners we extended the concept of *learning objects* (Friesen, 2004), to include objects created by learners during the activity in the pedagogical scenario. *Learning tools* can then be defined in terms of the learning objects they consume and produce. *Learning processes* are the mental activities that are reflected in working with the tool. So, in defining tools and processes learning objects take a pivotal role.

For each of the types of learning objects, shared definitions are created that provide meaning to data that are stored. Examples of these definitions include "data set", "experimental setup", "phenomenon", "experiment", and "model". Such definitions allow consistent support of learning processes across learning environment. If two systems treat the same object, for instance an "experiment" in a semantically consistent way, continuity of the learning scenario can be reached. The shared definitions in CIEL are created within the CIEL *ontology*.

The main functions of the CIEL ontology are:

- To create a shared framework of understanding for learning processes and objects that are supported by existing open learning environments. That is to support the *semantic* level of integration, in such a way that learner activities have a meaning with respect to the status of other tools and environments that have a place within the same scenario.
- To provide a context for a *technical* level of integration between various platforms. The definitions provided in the ontology form the starting point for formalization in terms of data formats. In order to exchange data between tools, XML definitions are given of the terms in the ontology. This leads to a common data format shared by a set of tools that each can play a part in scenarios for collaborative inquiry and experiential learning. This approach is depicted in Figure 4.



**Figure 4** Structure of the CIEL work, depicted as two layers: theoretical and technical. The contents of the four cells are examples of a wider range of possible content.

Currently the CIEL ontology contains about 50 definitions of learning objects and about the same number of definitions of processes and tools.

## 5. CIEL architecture and implementation

The CIEL architecture is created to provide technical support for the advanced pedagogical scenarios. As will be clear from Figure 3, the central service is a repository, called the *CIEL broker*. The CIEL broker offers functionality and interfaces for storing and retrieving learning objects, as well for searching and notification of changes in the repository.

The basis of the architecture is an XML database, with XML schemata based on CIEL glossary definitions. Searching learning objects is facilitated by tagging with metadata, using the IMS-LOM metadata model (IMS global consortium, 2006). Searches are specified as LOM templates, and tools can register to receive notification when changes in search results appear.

The repository is independent of the tools that connect to it. This opens up the road for scenarios that combine tools from different origins, and even scenarios in which learners diverge in the tools they use. For instance, it is possible in one scenario to combine data from different data sources, collected with different tools, or to compare models created using different modeling tools. This is enabled by the combined semantic and technical integration implemented in the CIEL architecture.

An actual first implementation of an integrated scenario along the lines described above has been created. For the topic of “sampling” in the domain of statistics, a scenario has been designed and implemented that involves multiple activities and tools. The learner is placed in the role of an employee of a forest agency that is involved in the production of wood. For a certain forest area it must be determined whether the trees are tall and wide enough to harvest the wood. In doing so a sample of trees has to be taken. The task for the learner is to determine the best sampling strategy, so that a reliable decision can be made based upon the sample.

The scenario is supported by two simulations, one in Flash™ and one made in Co-Lab [6]. Both allow creating samples and computing parameters such as the average and standard deviations of each of the samples. The data from the samples are stored as learning objects in the CIEL XML format can be imported in Freestyler, which are modeling tools that allow for modeling a variety of domains, including statistics. The sampling strategy can be modeled in FreeStyler.



## 6. Discussion

The sampling scenario is a proof of concept of the CIEL ideas. It demonstrates the interoperability between previously unconnected tools in a single, realistic scenario. It is the beginning of a process of deeper integration. Interesting problems that are identified and currently addressed are:

- *Adding content intelligence to the broker.* In order to allow better facilities for supporting the learning processes, it is necessary that search in the database becomes dependent on the content of the learning objects: what is the domain, subdomain and topic for which the learning object was created, and in what context did a learner construct the object. The idea is that such metadata will be added automatically to the learning objects. A challenge is to combine the CIEL ontology with an appropriate domain ontology to realize such content intelligence.
- *Structuring the repository.* Instead of just being a searchable collection, the repository is able to show a trace of learning activity. For instance it is of interest to extract the developing objects created by a single learner and to that objects of one type (e.g. datasets) relate in some way to other type (e.g. models) created by the same learner (e.g. the dataset contradicts the model). This would enable the CIEL architecture to be used not only for the design of scenarios that combine tools of different origins, but also become more than the sum of the parts, and use the inter-tool and inter-object relations as the basis for generating new kinds of instructional support.

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