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INTEGRATING LEARNING PROCESSES ACROSS BOUNDARIES OF MEDIA, TIME AND GROUP SCALE

H. ULRICH HOPPE

Institute for Computer Science and Interactive Systems
University of Duisburg-Essen, 47048 Duisburg, Germany
hoppe@collide.info

Recently, we have seen *integration* as a theme and purpose of educational media usage of its own right. The genuine value of integration is primarily characterized by improving the richness and directness of educational interactions. This article takes its starting point by looking at classroom activities. A good integration of interactive media in the classroom including groupware functions can already facilitate smooth "learning flows". Specific design principles can be extracted from the experience gathered in several recent projects, e.g. the "digital mimicry" principle refers to the extrapolation of expertise with conventional tools to similar computerized tools. The general issue of interoperability and connectivity includes aspects of software and hardware interfaces and even goes beyond technology in that it requires mental interfaces that allow users (teachers and learners) to realize and make use of the possible connections. These interfaces are conceived at design and provide implicit learning process support in the learning environment. In analogy to "business process modeling", there is also an explicit approach to integrating learning processes: The use of specific representations is to describe and potentially operationalize the orchestration of learning scenarios. In Computer-Supported Collaborative Learning (CSCL), the integration of media and group scales, e.g. between individual, classroom and community, relies essentially on mechanisms for handling emerging learning objects in terms of production, exchange, re-use and transformation. In the spirit of constructivist pedagogical approaches, we have to cope with "emerging learning objects" created by learners and learning groups in partly unanticipated ways. This assumption gives rise to specific new challenges for the indexing and retrieval of such learning objects (or products). Automatic indexing derived from the task-tool context and similarity based search allow for an asynchronous exchange of learning objects within larger anonymous learning communities. In this sense, objects of common interest may trigger social processes in learning communities.

Keywords: Integrated learning environments; ubiquitous computing; digital minicry; emerging learning objects; learning communities.

1. Introduction: Starting Point and First Orientation[1]

The understanding of the term "learning environment" (LE) is very significant for specific approaches in the area of technology enhanced learning. An LE is usually seen as a virtual or computational system that supports learning in a specific coherent way. There are domain oriented environments, sometimes called microworlds, which support specific semantic representations and processing mechanisms, but also general "learning platforms" that aim at organizational, communication and archiving support for learning communities. Despite the differences between these approaches, neither one challenges the conventional assumption of the LE residing on one or more computers. Particularly in the area of intelligent tutoring systems or ITS, we find a strong tendency to "understand" and control the ongoing learning processes to a maximum extent. This article is based on an alternative view of the learning environment.

The work of the COLLIDE group at the University of Duisburg-Essen (www.collide.info) was from its beginning in 1995 based on the assumption that the notion of "learning environment" should be given a much wider definition, including spatial and organizational surroundings, social constellations as well as external requirements on the learners beyond a singular learning experience. This implies that the system could never be in full control of the learning process. However, it can enable or facilitate certain learning activities by providing interactive tools and materials. In both pre-computerized and computerized learning settings, we have seen discontinuities (or "gaps") between media-based activities. We try to explore how technology can help to bridge such gaps.

In this more integral view of LEs, we also consider different roles. In a classroom-based learning environment, the teacher is a central actor. Hence, technology can also be used to support the teacher and the teaching in terms, e.g. of taking over routine work, providing supervision support or helping to manage group formation processes. Often, this kind of support is seen as improvement of efficiency: reaching more students in a shorter period of time. However, there is an important potential benefit of integrating learning processes which is not identical with the acceleration of learning processes and the multiplication of effects by reaching a higher number of learners. *The value of integration is primarily characterized by improving the richness, directness and cohesion of educational interactions.* We can distinguish several aspects of integration: (1) the integration of media and processes to support a smooth and seamless information flow in both virtual and face-to-face classroom scenarios, (2) the use of ICT to bridge between different conditions of learning, such as individual, small group or large community activities as well as between

[1]This article is based on a keynote speech given at the 8th *International Conference on Intelligent Tutoring Systems* 2006 in Jhongli, Taiwan. The original talk was conceived as a synthesis of more or less recent developments of group learning environments centered around the notion of *integration* in several ways. The article maintains this perspective in which the concrete examples described in more or less detail are meant to illustrate certain aspects of the general theme of integration.

synchronous and asynchronous settings, and recently (3) model-based integration using learning process modeling languages. All these aspects will be taken up on the following pages.

Integrative types of technology potentially provide an added value also to grown learning scenarios such as the classroom. In a *computer-integrated classroom* (Hoppe, Baloian & Zhao, 1993), a mixture of traditional (or natural) forms of communication and media may co-exist with digital media serving different functions which may be partly identical to traditional media use and in other parts actually qualitatively new. We have used the term "digital mimicry" to characterize interactive digital media functions which mimic traditional forms such as the use of a pen-based big electronic display instead of a chalkboard (Hoppe, 2004). Interactive simulations are a typical example of a genuine new media function which is bound to the digital modality. However, there is a general added value that we expect from combining digitized traditional media (e.g. scanned-in paper notes) with digital mimicry applications and real new media into a new form of digital information flow with specific forms of recording, re-use, re-enactment and extension/modification.

2. Media Integration in the Classroom

Traditional classroom scenarios suffer from discontinuities caused by incompatibilities of media and representations ("media gaps"). Often, e.g. results developed in small groups using paper and pencil are copied to the chalkboard, which is a redundant activity. The chalkboard, on the other hand, allows for flexible and spontaneous note taking and visualization, but it has shortcomings in terms of persistence and re-use. Technology can help to bridge media breaks without introducing serious additional constraints. This is exemplified by the European project NIMIS (1998–2000) in primary school classrooms (Lingnau, Hoppe & Mannhaupt, 2003).

NIMIS has adopted ubiquitous computing technologies, particularly supporting pen and finger based interaction, for an early learning classroom and combined it with speech technology to support reading and writing. The NIMIS environment has been specially designed for the needs of learners who do not (yet) have full reading and writing skills by introducing a new visual desktop with very intuitive visual tools for archiving, sending messages and integration of peripherals (scanner, camera) to archiving. It has several groupware functions for synchronous and asynchronous cooperation.

The NIMIS software includes a special application for initial reading and writing ("Today's Talking Typewriter", see Tewissen *et al.*, 2000). This application was designed in a participatory way together with the teachers. It was conceived as a computerized version of an existing phonetic approach to acquiring reading and writing skills ("reading through writing"). The flow of information and ownership of data were the major challenges in designing a computer-integrated classroom or CiC for early learners. As a child-oriented metaphor for handling and visualizing

Fig. 1. Scenes from the NIMIS classroom.

data and different media we introduced the metaphor of a "companion" as a virtual representative of the child. The child logs in to the computer by *calling the companion*. The companion appears and shows the child's documents (results of previous learning episodes, multimedia messages from classmates etc.) in the form of small preview images. Data organization for young children is supported by means of automatic arrangement and distribution in folders marked with icons. Later, children may create their own folders and use drag and drop operations to arrange their documents. Different from standard operating system conventions, two children can log in at the same time on one machine and work together at their desktop. When the child logs out, the companion disappears and *goes to sleep*. The companion also disappears in its original place, when a child logs in on a different machine. This feature, together with action logging, also allows for tracing distributed activities in the classroom.

Studies of classroom procedures and "educational workflows" have guided the design of the NIMIS tools, especially with respect to interoperability. The underlying requirements were formulated on different levels: (1) technology should not get in the way (with respect to established classroom processes), (2) technology should unify representations and interactions on a digital basis, (3) new workflows should be facilitated. As for (3), we have seen the use of the big interactive screen in a way unprecedented by the chalkboard (that is indeed rarely used in current primary education in our region): In phases of group reflection and looking back, kids would gather around the board, sitting on the floor, and revise and compare their learning results using asynchronous groupware functions. This is an example of a media facilitated transition between small group work and a whole classroom activity.

Computer-integrated classrooms are a specific example of ubiquitous computing environments (Weiser, 1991) following the principle of functionally embedding interactive computerized devices with the physical environment. This embedment should be seamless and non-disruptive. One strategy to achieve this is the above mentioned principle of "digital mimicry" (Hoppe, 2004), i.e. the introduction of digital device as a surrogate of a traditional one. In the consumer area this is the case with digital cameras and musical instruments. In the classroom, it is the case with pen-based computing devices such as big interactive displays or tablets. Of course the digital device will provide added values, but, to start with, it can already be used in very much the same way as the analogue one. A very nice example of seamless integration is the usage of an analogue tool in conjunction with a digital device as shown in Fig. 2.

The scene shown in Fig. 2 stems from a computer-integrated classroom in Taiwan (Liu *et al.*, 2002). In this environment, tablet PCs are used as individual devices in combination with big interactive displays based on a wireless classroom network. The wireless platforms allows for more flexibility and portability of the whole environment.

In the context of the EU project SEED (2001–2004), following up on NIMIS, the COLLIDE group has tried to create classroom innovation using interactive media together with a group of secondary school teachers. These teachers were introduced

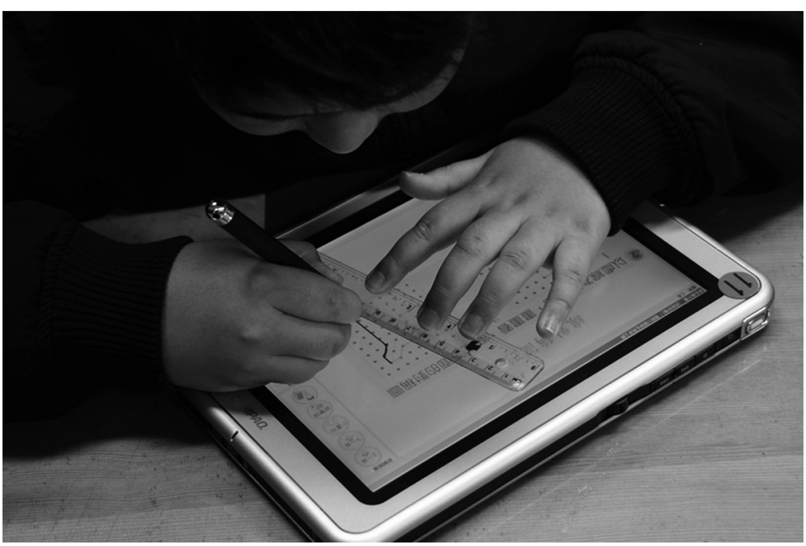


Fig. 2. Digital-physical media integration in a Taiwanese classroom.

to the new types of hardware and software (mainly annotation and modelling tools) and were invited and supported in appropriating these for their own teaching. This has led to interesting software extensions and blueprints for teaching in areas as diverse as biology, mathematics and language studies (Kuhn *et al.*, 2004). The focus of these activities was clearly on representational tools, not so much on a general communication infrastructure. Indeed, we found that existing school intranets are still too poorly developed in terms of availability, maintenance and coherence to get the full added value out of the digital enrichment of the classroom in terms of organizational memory functions. Yet, we have explored the general feasibility of using new devices such as low cost graphics tablets for handwriting as well as big interactive displays, tablet PCs as well as PDAs in domain specific applications with a special focus on collaborative use.

We have also explored face-to-face learning scenarios integrating mobile devices. Our “Mobile Notes” (Bollen *et al.*, 2006) system supports classroom discussions by integrating PDAs with a big interactive screen. Following Liu and Kao (2005), public interactive displays complement the lack of shared visual focus with smaller personal devices. In “Mobile Notes”, the PDA is essentially only used as an input device to initially prepare and enter discussion contributions. When a contribution (either text based or a hand written sketch) is completed, it is sent to a database from which it can be retrieved and transferred to the public display application. This transfer can be controlled by a moderator. All plenary classroom discussions would be supported by and centered around the public display. This has turned out to be a very generally usable scenario. As opposed to scenarios with mobile devices only, this is an example of the “functional differentiation” principle: Based on an assessment of the strengths and weaknesses of available devices, specific functions are assigned to the adequate type of device in a blended scenario.

3. Process Integration and Explicit Learning Process Modeling

The NIMIS example demonstrates that a well designed integration of interactive media including groupware functions can already facilitate smooth “learning flows”. This kind of implicit process integration comes as a result of the overall design. Tool interoperability is an important issue to achieve it.

In an analogy to “business process modeling”, explicit approaches to integrating learning processes have been suggested: They are based on the provision and use of so-called “educational modeling languages” to specify and potentially operationalize the orchestration of learning scenarios. The most prominent representative of this line of research and development is the educational modeling language EML, developed at the Dutch Open University, and its successor IMS Learning Design supported by the IMS Global Learning Consortium (Koper & Tattersall, 2005).

IMS LD is typically used for to design and develop web-based learning environments. In this context, it allows for dynamically arranging predefined learning materials and adapting these to some extent to individual user characteristics. IMS LD is specified as an XML-based language. The top level structure reflects the metaphore of a theatrical play composed of acts. On lower levels it allows for specifying roles and activities, also the interaction between roles and activities. A general problem with IMS LD is that this quite complex definition is only precisely defined on a syntactic level. From a user perspective, a standardized diagrammatic representation would be desirable. Often UML diagrams are used to translate LD models into something easier to grasp and understand. However, these mappings are based on intuitive transformations which are not standardized.

From a CSCL perspective, we are e.g. interested in formulating "collaboration scripts" as learning process models (Kollar, Fischer & Slotta, 2005). These scripts are typically rich in role changes and in exchanging and re-using results (objects) generated on the fly between learning groups. The adaptation of IMS LD to these needs is not straightforward and leads to some additional requirements (Miao *et al.*, 2005). Hernandez *et al.* (2004) showed that some aspects of complex collaborative designs (also called "collaborative learning patterns") are not represented properly in IMS/LD and extensions are necessary.

In our understanding, explicit learning process modeling has a great potential that goes much beyond the orchestration of web-based learning environments. If it had a clear conceptual basis and a representation readable also by teachers, it could be used as a tool for pedagogical design and engineering not only directly related to computerized learning environments but also, e.g. for lesson planning. To exploit the potential benefits of machine interpretable learning process specifications also in computer-integrated classroom environments, loosely coupled architectures for the interdependence of the learning environment and a process monitoring engine are needed. The COLLIDE group is working towards such an extended perspective on learning process modeling. The following section will elaborate on an approach to specify and capture specific classroom constellations from a CSCL perspective.

4. "Learning-Design by Example"

In the context of the SEED project, teachers had used our collaborative learning and modeling environment Cool Modes (Pinkwart, 2003) to set up different group scenarios in their classrooms. These sessions involved several computers and required the setting up of a communication environment based on our MatchMaker communication server which allows for flexible workspace sharing and coupling. The setting up of the environment was time consuming and only the more experienced were able to do it on their own. Thus, there was a general demand for setting up classroom networks with flexible grouping and archiving/recording mechanisms with less additional time effort to be justified for a 45 or 90 minute lesson. This gave rise to the implementation of an "ad hoc session manager" (Kuhn *et al.*, 2005).

Since we already used the collaborative modeling platform Cool Modes in schools for mathematical modeling, computer science lessons and graphical argumentation, it was an obvious option for us to implement the session manager on this basis. So, the Cool Modes framework is used with two different intentions in our scenario: On the one hand, it is used by the students to perform their collaborative modeling task, and on the other hand, it is used by the teacher in order to specify and orchestrate the group work.

The graph based visual language (*"session manager"*) for the representation of the classroom networks was developed as an additional plug-in to the Cool Modes framework. The language consists of a specific set of nodes and edges: *User nodes* represent participants or *clients*. Visible indications on this type of node are the name of the user (or the partners, if students share one computer), the login name, the local host computer and the IP address of the host. Shared collaborative sessions are indicated by *session nodes.* At run time, the teacher has the possibility to model and control (start/stop) sessions, see how many clients currently are connected with the session and the unique name of the session. A *database node* allows the teacher to store the data of a connected session at a previously defined place. A *slot node* acts as a wildcard for clients which are not yet instantiated. This type of node allows the teacher to pre-define the different working groups before the students enter the classroom and log into the system. A *slot node* can be pre-configured in such a way as to automatically identify a specific student when he or she logs in. Then this slot node would be replaced by the client node representing the student. Alternatively, student names can be dragged on to the slot node.

Furthermore, the visual language provides three different types of edges. There are two types of edges that allow for connecting a slot node or a client node to a session. A *force edge* between a client and a session node results in an automatic join of the client to a session, whereas an *is allowed edge* just permits that a user might join a certain session. Another edge type connects sessions to database in order to store the session data in the previously defined place.

The only precondition to set up a classroom session from such a specification is that all machines have to be equipped with the Cool Modes software including a session manager client. The teacher's machine initiates the session and establishes the communication with the participant machines. The initial phase of setting up the topology as described in the session diagram relies on multicasting. Once the communication topology is set up, MatchMaker and Java RMI are used for workspace sharing and data transfer.

So far, the group management tool has been tested in a secondary school computer science courses with 12th graders in the area of modeling with UML. Our tool was not only used to administrate the group work but also to evaluate the work process and the results of different forms of group work. Each group work scenario can be classified by the degrees of freedom it offers students to structure their collaboration and their work on the task. Our ongoing research work will have a closer look on the influences of these two dimensions on the learning process of students and its outcomes. Figure 3 shows an example configuration. In this setting, two different groups worked on a UML class diagram. Whereas the second group was working on a common task, the first one was divided into two subgroups (1a

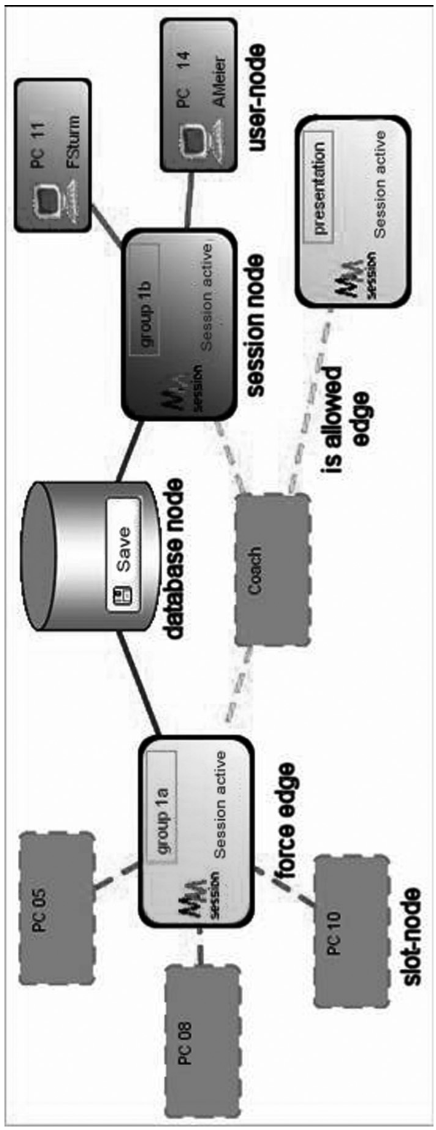


Fig. 3. Model representing the arrangement of computer based group work.

and 1b) with a predefined division of labor. Additionally, in this group one student acted as a coach to merge and present the two component solutions. Figure 3 shows the two sessions for group 1 with four respectively two students. Another student acting as a coach *is allowed* to join both sessions of group 1 and the final presentation session. The other students are *forced* to join the session of group 2. These different modes are indicated by differently colored edges.

The session manager diagrams capture the more static, structural elements of a specific group learning setting. Diagrams can be directly re-used on the basis of slot nodes (otherwise user nodes would have to be modified), and they can also be exchanged (e.g. between teachers) for documentation or replication purposes. Elaborating on the exchange idea, the session manager tool has been extended to serve as an editor for collaborative learning designs with IMS/LD as output format. The teacher can specify the learning design "*by example*" creating a concrete visual model, instead of using the machine-level textual format of IMS/LD. We have defined the following mapping from our scenarios to an IMS/LD document:

- Each session within the classroom scenario is mapped onto an IMS/LD *learning-activity* (in our example "group 1a", "group 1b", "presentation", using the session's textual description for title and description of the activity).
- Each client node or slot node is mapped to an IMS/LD role of type *imsld:learner* (in our example "coach", "FSturm"). Since roles of a learning design are instantiated at runtime and not on beforehand, the client nodes are also abstracted to roles.
- The teacher who is implicitly present in the scenario (but not in the model) is represented in the learning design as a role of type *imsld:staff*.
- The whole classroom scenario graph of our visual language format is mapped onto an IMS/LD *act*.
- For each learner (client or slot node) an IMS/LD *role-part* is created within the act with the respective reference *role-ref*; this role-part includes a *learning-activity-ref* to the respective learning activity (a "session node" in the session manager specification) for each edge connecting the learner with the session node. In case of a "force edge", there is only one session available as *learning-activity-ref*. The *role-part* of the teacher includes every learning-activity to show the potential participation in every session.

Currently, we can only define single act scenarios directly using our MatchMaker/Cool Modes environment. More complex learning designs with sequences of acts are obviously desirable to enable richer classroom scenarios to be defined and conducted. We plan to extend our IMS/LD export in such a way as to allow for combining multiple models in the form of temporally ordered sequences of acts corresponding to a complete IMS LD "play". The teacher just specifies the configurations separately and connects them with a specific sequencing operation. Even more convenient is the "specification by example" in which a complete learning process model is derived from an enacted and recorded example sequence. The exported IMS/LD-format could additionally include a "learning objectives" element to enrich the design with more pedagogically oriented information.

5. Learning Objects and Learning Communities

The integration of media use across group scales in CSCL relies essentially on mechanisms for handling emerging learning objects in terms of production, exchange, re-use and transformation. In the spirit of constructivist pedagogical approaches and in contrast to standardized activities around pre-fabricated objects or materials, we assume that "emerging learning objects" be created by learners and learning groups in partly unanticipated ways. This assumption gives rise to specific new challenges for the indexing and retrieval of such learning objects (or products). In the absence of indexing through experts, learning object descriptions have to be derived from the learning situation with minimal input from the learners themselves. This constitutes a new challenge for intelligent support techniques, namely for the dynamic recognition and modeling of learning contexts on a semantic level. Contextualized indexing allows for an asynchronous exchange of learning objects within larger anonymous learning communities based on semantic similarities. In this sense, objects of common interest may trigger social processes in learning communities (Hoppe *et al.*, 2005).

Retrieval support for learning objects is usually associated with metadata standards like LOM or SCORM. However, the use of metadata to facilitate the archiving and re-use of learning objects has not yet been widely discussed from a Computer-Supported Collaborative Learning (CSCL) perspective. The proceedings of CSCL 2003 contain just one article related to metadata issues (Allert, Richter & Nejdl, 2003), and also this contribution shows an early stage of conceptualization. Given the relevance of metadata approaches in other fields of technology enhanced learning this may be surprising. A possible explanation is that learning objects in CSCL are typically conceived as emerging entities, i.e. as being created by the co-learners in the learning process. In contrast, most metadata approaches deal with predefined static learning objects, e.g. course materials. In the sequel, it will be explored how the CSCL perspective can be opened towards metadata, and vice versa how metadata techniques can be adapted to dealing with emerging learning objects.

6. Extending the Notion of "Communication Through Artefacts" to Asynchronous Settings

"Communication through the artefact" is an essential principle used in a variety of shared workspace environments in CSCW and CSCL. Its basic function consists in complementing natural language communication through the creation and manipulation of shared objects. The typical shared activities are editing, brainstorming, co-construction and co-design. Several authors such as Hoppe and Plötzner (1999) or Suthers and Hundhausen (2003) have characterized communicative and cognitive functions of interactively co-constructing and using shared representations. The latter distinguish the following support functions of interactively co-constructing and using shared representations: (1) initiation of negotiations of meaning, (2) provision of a representational proxy for gestural deixis and (3) basic support for implicitly shared awareness (external group memory).

The type of information communicated through a shared object or artefact depends on the nature of this object: It can be symbolic as in shared concept maps or argumentation graphs with textual nodes. Here, the semantic decoding relies essentially on the users' interpretation(s). Other representations such as Petri Nets or System Dynamics models come with an inherent operational interpretation on the machine which allows for dynamic simulation as well as for checking certain properties (e.g. deadlock detection in a Petri Net). Our experience with collaborative problem solving and model building is based on the multi-representational tool Cool Modes (Pinkwart, 2003) which supports a spectrum of representations including hand written annotation, symbolic representations without machine semantics as well as representations with machine semantics and simulation capabilities. These tools are typically used in learning activities or "sessions" with smaller groups of 2–5 members over a time span of 30 to 90 minutes. A new challenge consists in relaxing these constraints in terms of time and group size while still maintaining essential features of "communication through the artefact".

The question is which of the support functions can be transferred to a situation of asynchronous use, and how this could be facilitated. Of course, we cannot expect a transfer of deictic reference support to the asynchronous case. Yet, negotiations of meaning may arise from exchanging variants and annotations. Also the external memory function can be redefined from — metaphorically speaking — short term to long term memory support. When using collaborative modeling environments such as Cool Modes in the classroom, we have experienced situations in which the sharing mechanism has been used to transfer information from small groups to the whole class, e.g. to display and discuss group results in the public. This is typically not a kind of "late re-use" but "immediate re-use". In a comparative study with a number of collaborative discussion and argumentation environments, we found a clear deficit with respect to their support for later re-use. This brought us to considering (and implementing) combinations of synchronous co-constructive environments with indexing and retrieval mechanisms (Hoppe & Gassner, 2002). Although this implied a relaxation of time constraints, it was not explicitly related to differences in group scale.

With respect to group size, there is a qualitative difference between groups in which members know each other and share context in terms of location, curricular content and institutional features (staff, teachers) and anonymous groups which may share an interest on the content level without sharing much context.

Content oriented social relationships have been supported and studied with anonymous groups under the notion of "social navigation" (see Höök, Munro & Benyon, 2002). Whereas social navigation relies mainly on process information in the form of "traces" left by other users or actors, we focus on the re-use of artefacts. We have recently described these objects used to exchange information in a larger learner community as "thematic objects" (Hoppe *et al.*, 2005). Asynchronous communication through thematic objects is, in first order, also asymmetric in the sense that the originator is not necessarily aware of the object's re-use. Yet, if a learning community is driven by common interests and disposes of rich means of communication, it is likely that object re-use can lead to social contact and interaction.

As with other predefined learning objects, semantic indexing and retrieval techniques are crucial to support the access to and re-use of emerging thematic objects. Given the fact, that learners are primarily motivated by the problems at hand, we cannot expect them to engage in time consuming indexing activities. To avoid this, we extract as much contextual information as possible from the task/tool environment for the purpose of semantic indexing.

In the following section, the practical implementation of this approach in a European project will be described.

7. The COLDEX Project

The European project COLDEX ("Collaborative Learning and Distributed Experimentation", 2002–2005) has taken up issues and current challenges in the area of technology support for collaborative learning in science and technology with a special focus on learning based on both local and remote experimentation. The COLDEX user/learner community was conceived as being built up in a bottom-up way: Local teams in schools or a science center have face-to-face interaction and a blend of hands-on and remote experiences in the general thematic area of "exploring space" with sub-themes such as "lunar cartography", "growing plants in space" (using small biospheres) and "robot vehicles". These local teams located in Sweden, Germany, Portugal, Chile and Colombia were encouraged to contribute to a global COLDEX Learning Object Repository (LOR). The LOR provided both group and community navigation tools as well as mechanisms to detect similarities of interests in terms of the produced objects or artefacts. The aim was to provide and explore exchange mechanisms between local communities in Europe and Latin America. In accordance with the general goals described above, the primary focus was on electronic support for the exchange of learning results and not on direct communication channels, e.g. via email contacts.

COLDEX relied on the already mentioned Cool Modes system as a general tool for model building and for the structured representation of scientific arguments. The tool supports synchronous cooperation by a shared workspace environment with full replication of the coupled objects. For the COLDEX purposes, Cool Modes has been equipped with an embedded interface to the LOR in two directions, (1) for uploading (with indexing support) and (2) for retrieval (exploiting similarities to the currently active workspace in the Cool Modes environment). These mechanisms will be explained in more detail.

In addition to the tool embedded LOR access, there is also a general web interface (for details, see Hoppe *et al.*, 2005). Users of the LOR system can take multiple different roles which represent the different group scale they work in: *local group members* belong to the same (local) face-to-face learning group; *Cool Modes users* create models within the tool environment and upload them to the repository. *Community members* of a certain scientific domain may be interested in Cool Modes models. *Individual learners* can be members of all these groups, but also external visitors who are interested in the thematic content.

8. Challenge-Based Learning

The pedagogical approach of COLDEX is *challenge-based learning* (ChBL; Baloian *et al.*, 2006) — a concept which is closely related to problem-based learning in that it implies solving realistic, open ended problems in authentic contexts. Challenge-based learning has common aspects also with experiential, project-based and discovery-based learning. The cognitive focus of ChBL lies in knowledge interpretation, inquiry, and knowledge construction. In a typical ChBL scenario, a student would act as an active constructor, designer and researcher, usually supported by a teacher as a coach, co-experimenter and co-designer in the creation of learning objects. The initial challenges are selected in such a way so as to stimulate curiosity and to be a source of rich experience. We assume challenges to be extra-curricular problems which cannot be solved using routine skills or standard problem solving strategies. Despite the non-standard nature of the challenges COLDEX offers packaged digital materials ("Digital Experimentation Toolkits" or DexTs) which represent the initial challenge and computational tools for the tackling the central problems.

The contextualized indexing and retrieval mechanisms provided in the Cool Modes tool environment relieve the learners to some extent from entering detailed specifications including formal parameters, yet some "manual" assignment of keywords is still useful to support later re-use. Thus we are confronted with the known "cold start problem": Before a critical mass of interesting thematic objects is reached, there is no direct benefit in return of the effort. Similar trade-off situations have been discussed for information pooling scenarios with database tasks (Cress & Hesse, 2004). At the end of the project, the COLDEX repository had about 400 learning objects (models, diagrams, calculation sheets) so that the break even point is passed. Initially, we have tried to provide some useful examples on beforehand and to motivate students to work for future benefit.

The focus on extra-curricular non-standard problems is important to create an incentive for sharing concrete learning results. As known from other CSCL and CSCW scenarios, the use of group or community oriented tools comes with an additional cost (in terms of additional coordination and interaction efforts). Thus, from a motivational point of view, a clear benefit from using these tools should be expected. If, e.g., the explanation of an experiment could be found in standard textbooks, it would be quite unlikely that learners would engage in time consuming communications with people around the world to better understand this experiment. In contrast, with problems of non-standard and open ended nature, there is an obvious incentive to engage in such an exchange.

9. Contextualized Indexing and Retrieval

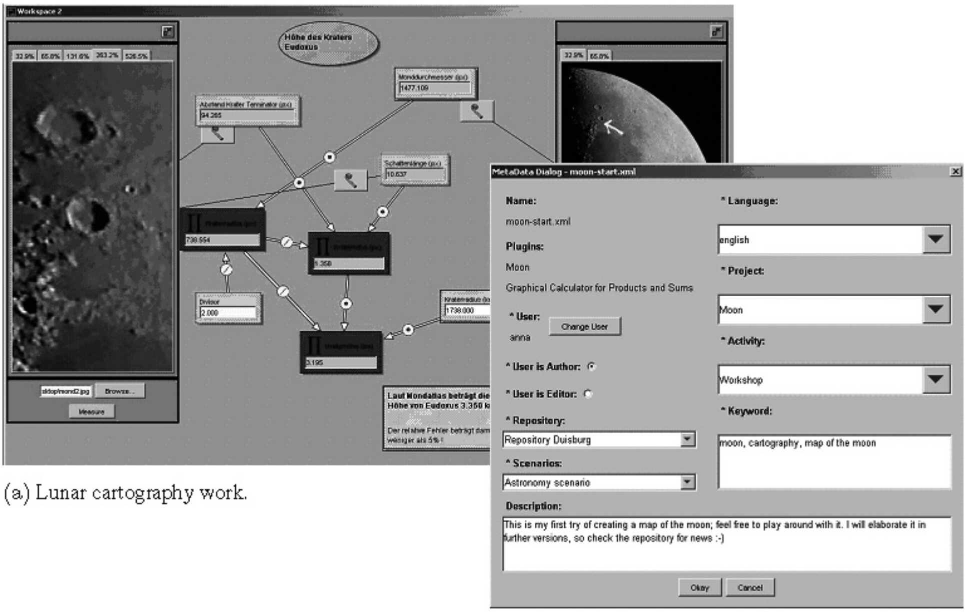
This section will describe the interface to the COLDEX Learning Object Repository (LOR) embedded in the Cool Modes tool environment. The basic idea is to maximize the use of contextual information to relieve the learner from the burden of generating metadata "by hand". The following relevant parameters are directly available in the tool environment:

- date/time of the activity;
- user id and potentially a user profile;
- potentially a reference to the original course material (e.g. from the metadata of a worksheet) and thus a reference to the course unit and theme;
- the set of visual languages used in the active workspace (i.e. the Cool Modes palettes used) as an indication of the problem type.

This information can be used during an upload to automatically instantiate some fields of the upload form (see Fig. 4). The user is then asked to add a semantic description in terms of keywords and potentially further comments.

The same type of description can also be used to generate a search query that would take the content of the currently active workspace as an example. Of course, in a query certain description parameters such as the user/author or the date would not make sense; usually we would expect that a learner is interested in similar learning objects created by *other users* at *any time*. Based on this idea, we have added tool embedded support for task contextualized queries: A user working within the Cool Modes environment has a menue option for asking "is there something in the LOR similar to what I am working on", without necessarily providing additional manual information. The generated query form corresponds to the upload format in Fig. 4, but it would not contain the attributes irrelevant to such a s*imilarity oriented query*. This query form can still be modified. The result is a list of similar documents found in the LOR, ranked according to the number of attribute values shared with the example.

The same approach allows for a further step: Learners can take their current document as a query template, search for related content in the archive and not just the documents found but a ranked list of other users that created these documents. More technical details can be found in Pinkwart *et al.* (2004).



(a) Lunar cartography work.

(b) Contextualised generation of metadata (for upload).

Fig. 4. Archiving (uploading) lunar cartography work from COLDEX.

The mechanism of generating contextual queries to find peers working on similar problems may lead to social interaction, e.g. to forming groups of similar interest. This links in with other current research on "communities of interest" (Francq & Delchambre, 2005) based on the usage of document repositories. The specialty of our approach is the use of tool knowledge.

The similarity oriented retrieval strategies can be used to personalize systems by a "*what's interesting?*" feature. Similarity queries could be used as a source of continuous information on themes of personal interest, considering additional constraints like language, time, and organisational proximity of persons. Similar functions are served by *recommender systems* (Konstan & Riedl, 2002), but these are rather based on information about usage processes and "traces" than on attributes of the objects themselves.

10. Summary and Perspectives

We have seen integration as a theme spanning over a wide range of topics in technology enhanced learning. The guiding goal is enrichment rather than increasing efficiency. Integration is more than technical interoperability, but it may require certain types of technical connectivity. A first principle for *facilitating educational workflows* is to *eliminate discontinuities* in using different media and tools and thus support a *seamless integration* of media and processes. Unnecessary copying and re-coding of previous results should be avoided. *Digital mimicry* allows for a conceptual connection to existing expertise with conventional devices or tools. The added value of interactive and cooperative media, which comprises flexible re-use and sharing of results, can thus be gradually explored and appropriated in practical usage.

The *explicit representation and modeling of learning processes* allows for constraining interaction in a pedagogically purposeful way (e.g. with collaboration scripts) and can additionally support reflection and re-use on a process level. However, there is a still a big challenge in providing learning process modeling tools which are both expressive enough as well as understandable and usable by the practitioner.

Bridging the gaps between small group and individual learning on the one side and learning communities on the other is another integration challenge. An important ingredient to achieve this is the provision of indexing and retrieval mechanisms for *emerging learning objects*. Typically, these emerging learning objects are constructed by learners in phases of individual or small group work. They are potentially discussed, compared or merged in whole classroom scenarios or even shared in broader anonymous learning communities. To support the sharing and re-use of emerging learning objects, it is important to provide powerful *semi-automatic indexing techniques* as well as *similarity measures*. This draws on context information relating to user characteristics or to the task environment and goes beyond current applications of metadata standards in typical e-learning scenarios with predefined materials.

The principles and ideas gathered so far are meant to be both a starting point and a signpost for further work. A research agenda to elaborate on the "integration challenge" for technology-enhanced learning would currently comprise the following goals:

- designing and providing conceptual/visual models and corresponding tools for learning process modeling on different levels of description and for a variety of purposes;
- developing "model-based classroom management tools" which would allow tracking classroom activities according to predefined models and/or recording activities in structured form to generate models ("learning design by example");
- extending conventional metadata methodologies and tools (e.g. existing platforms for learning object repositories) to allow for handling emerging learning objects and for serving different levels of scale between individual learning and exchange in a large and growing learning community.

In all these endeavors, we should not only aim at serving the learners but also at enabling teachers and tutors to appropriate these technologies in their own professional practices. This will be an important factor to spread and disseminate new value-added technologies in the educational field.

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