Building Bridges within Learning Communities through Ontologies and "Thematic Objects"

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Abstract. Communication through artefacts, in the sense of objects (co-)constructed by learners, is a well known mechanism in synchronous shared workspace environments. In this article, we explore the potential of extending this principle to heterogeneous, anonymous and asynchronous learner communities by drawing on existing work, e.g. in the areas of "social navigation" and recommender systems. A new ingredient is the description and provision of "thematic objects" embedded in a task/activity context. Design principles and available technologies are discussed and an example implementation in a European project is presented from the perspective of technology design and development.

Keywords: Artefact-centred community support, social navigation, content-awareness

INTRODUCTION

Shared workspaces with visual objects enrich human-human communication by opening a new channel: *communication through the artefact*. When jointly creating and manipulating artefacts, the co-learners' language based interaction is complemented by an external medium providing inherent constraints. Whereas language utterances rely on individual interpretation "in the head", actions on the object level have directly observable results and consequences that may constraint future actions. Communication through the artefact is a basic principle used in a variety of shared workspace environments in CSCW and CSCL. The typical activities are editing, brainstorming, (co-)construction and (co-)design. Several authors such as Hoppe and Plötzner (1999) or Suthers and Hundhausen (2003) have characterised communicative and cognitive functions of interactively co-constructing and using shared representations. The latter distinguish the following three functions: initiating negotiations of meaning, serving as a representational proxy for purposes of gestural deixis and providing a foundation for implicitly shared awareness (group memory).

A shared workspace environment may support domain unspecific representations such as concept maps and/or hand written notes, but it may also support more specific, semantically enriched representations such as system dynamics or Petri Nets. Our experience is based on a multi-representational tool called Cool Modes (Pinkwart, 2003) in which a whole spectrum of representations is supported. In spite of the common outsiders' view of CSCL technology being essentially used in remote learning scenarios, shared workspace environments are often used in face-to-face settings as an additional communication channel together with natural communication and, of course, as a structured medium with external memory function. The typical usage scenarios involve smaller groups of 2-5 participants over a time span ranging from some minutes to two hours. Both limitations in group size and in time are inherently linked to the relatively tight coupling of activities between group members. It is usually assumed that there is a high degree of continuous awareness between the session participants and the cooperative activity would not allow for much parallel work in other completely unrelated activity threads (i.e., even "private" activities are usually related to the co-constructive group task). A balanced ratio between one's own active contributions as compared to the activity overhead that stems from continuous awareness (perception) is one of the main factors that limit group size, whereas time is limited by the ability to continuously concentrate on a coherent task without being able to accommodate for individual breaks or timeouts. In the following we will constructively explore possibilities to relax these constraints in time and group size while still maintaining essential features, hopefully benefits, of "communication through the artefact".

What cannot be expected to be transferred from the tightly coupled situation is the support for deictic references in (real time) communication. Yet, the external memory function can be redefined from – metaphorically speaking – short term to long term memory support. In classroom usage of collaborative modelling environments such as Cool Modes, 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. Yet, in this public situation, input is usually restricted to the moderator or teacher and the responsible group. Also, this is typically not "late re-use" but "immediate re-use". In a recent study, Katrin

Gassner compared a number collaborative discussion and argumentation environments, among other features, with respect to their support for later re-use and found a clear deficit in this respect. 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 (of) 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. Direct or indirect (i.e. mediated) content orientated social relationships have been supported and studied with anonymous groups under the notion of "social navigation" (Höök, Munro & Benyon, 2002; Dourish & Chalmers, 1994). Our intention to support the interoperability between different group scales can also be seen as an attempt to bridge the gap between direct and indirect social navigation. For CSCL purposes, we propose a specific version of social navigation that relies on the notion of "thematic objects". Thematic objects are understood as learning objects enriched with metadata which classify the object both within an ontology and in terms of social relations.

This approach of *social navigation based on thematic objects* or *thematic social navigation* is focused on the following point: It is a basic purpose of social navigation to support users in finding other users with whom to interact in some beneficial way. We assume that thematically classified learning objects can be used as indicators for "shared interests". In a learning community, such shared interests are an essential condition for mutually enriching interactions between learners. The learners could even interact indirectly through the inspection and re-use of objects of shared interest without necessarily having a person-to-person communication. A comparable approach for assessing shared interests in scientific communities has recently been presented by Francq & Delchambre (2005) using document indexing and retrieval techniques. In our approach, both the ontological classification of objects as well as the association of metadata from the activity context (user, tools) allows us to extend the search to classes of similar learning objects. This kind of content awareness functionality is built into a collaborative learning environment. This environment combines access to a repository for asynchronous sharing with synchronous shared workspace functionality.
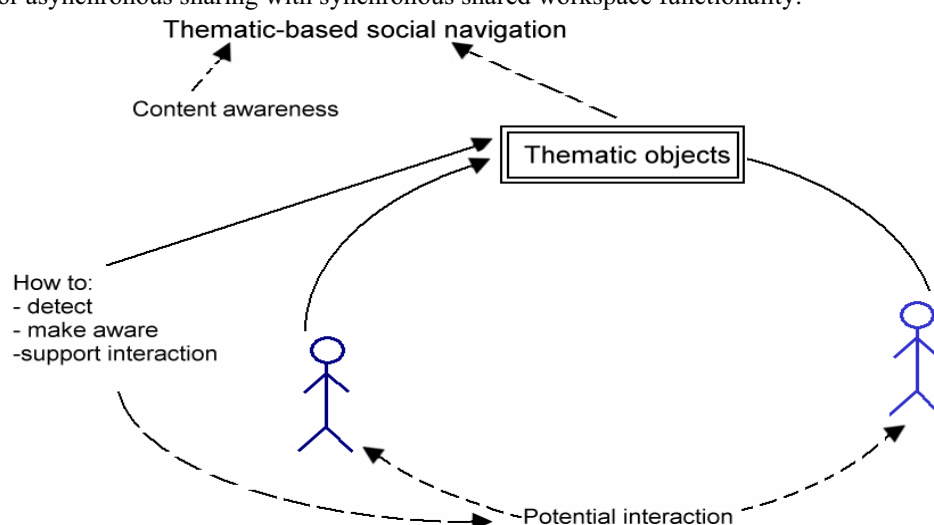
Figure 1   Social navigation through thematic objects

BASIC CONCEPTS AND SUPPORTING TECHNOLOGIES

This section intends to identify the key concepts and to put them in relation to the social navigation and artefact based communication principles that were outlined in the introduction.

Dealing with documents and document handling, the notion of *metadata* (i.e., data describing data) is of obvious importance. Related problems are the often needed manual generation, which users may conceive as an annoying task they tend to avoid (Wickens, 1992). Other critical aspects are related to standardisation and interoperability. A frequently chosen technique to overcome the interoperability concerns are *ontologies*. In the sense of Gruber (1993), an ontology is an "explicit specification of a conceptualisation". Other definitions are more operational and conceive an ontology as a conceptualisation of a domain into a human-understandable, but machine-readable format consisting of entities, attributes, relationships, and axioms (Guarino & Giaretta, 1995). One benefit of ontologies, as compared to other less structured and formal approaches, is their suitability for

classical AI and knowledge representation techniques (Uschold & Grüninger, 1996). Another advantage of ontologies is that they allow for adding a new abstraction level upon the metadata layer. This draws out links between entities that were apparently unrelated, thus extending the querying vocabulary for the users. Furthermore, the ontology can be used for guiding the users by sorting out this larger amount of possible queries and by providing mechanisms for deriving new knowledge. Finally, an ontology may facilitate navigation through repositories by taking profit from the available context information.

Apart from the more descriptive approaches of ontologies and related taxonomy based techniques, there is a variety of technologies that deal with the usage and processing of data and metadata. These range from classical search approaches with Boolean logics up to complex *information retrieval* methods, which are able to deal with vagueness of queries and uncertainty about data (e.g., Fuhr, 2001). For our aims, the field of information retrieval thus offers important inputs through the algorithms it provides. Yet, classic information retrieval methods do not consider user specific and task related information and can therefore not serve as a basis for our implementation.

Research on *recommender systems* is probably the most closely related and therefore most relevant area for our approach. Similar to information retrieval, recommender systems aim at providing users with relevant documents. Yet, the principal approach differs in that recommender systems rely on (user provided) ratings of documents, which are either used directly for recommendation of the rated document, or indirectly to infer ratings for similar documents (Resnick & Varian, 1997). A frequently applied method in the field of recommender systems is *collaborative filtering* (see Konstan & Riedl, 2002). This algorithm essentially follows three steps:

1. search for users with a profile similar to the current user
2. search documents that these users rated positively
3. order these found documents using relevance criteria of the current user

Obviously, this algorithm is closely related to the ideas of social navigation through thematic objects as expressed in the introduction – in a sense, it is orthogonal, as our approach first searches for documents and then, in a second step, finds users. The collaborative filtering method has proven to be effective, but has several inherent problems. These include the *cold start problem* ("how to give recommendations for newly introduced items?") and the early-rater problem which describes the problems arising from new documents (Sarwar et al., 1998). Several mechanisms to overcome the cold start problem have been proposed. Some of these are based on the idea of community membership (Glance, Arregui & Dardenne, 1998). Here, new users assign themselves to communities, and the system takes other members of that community as reference. The general consideration of community aspects in recommender systems was also used to take into account the fact that people in a community potentially share topics of interest – accepting that people may be members of several communities with different shared topics. Another approach to overcome the cold start problem of recommender systems has been proposed by Middleton et al. (2002). They investigate the synergies evolving from an integration of recommender systems with ontologies, the latter being used to determine initial user profiles. However, their approach still relies on explicit and manual user assessment of documents.

The driving ideas for this paper differ from all the listed concepts in that they do require neither explicit nor implicit document assessment but instead make use of automatically available activity context for indexing and retrieval. One of the case studies contained in this paper presents how functions can even be embedded in the tool that provides the task context. Technical aspects of this solution are explained in Pinkwart et al. (2004).

In our approach, the activity context links interest-related aspects to object-bound features and can thus be conceived as a connection of user- and document-related metadata. The aims are similar to those of recommender systems, and in particular to the idea of collaborative filtering. Yet, we are able to exploit a richer source of information due to the additional context dimension. The context of a user activity is characterised by the types objects worked on as well as by the types of activities performed. The repository we suggest provides an adequate framework for storing, retrieving and re-using groups' results and by-products, and the portal we propose supplies new ways of finding context information. Finally, as an added-value, the portal makes it easier for users to access the community, their results and a number of helpful facilities such as semantic navigation or enhanced searching. The next sections of this paper show how this information can be used to enhance re-use options of documents in a community, and support the exchange of communities through documents. The latter aspect illustrates the idea of the seeding of new collaboration options through social navigation by thematic objects in the sense as motivated in the introduction.

SUPPORTING A COMMUNITY OF SCIENCE LEARNERS

The example application scenarios used in this paper are all related to the ongoing European project COLDEX ("Collaborative Learning and Distributed Experimentation"). COLDEX takes 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. Within this project, learning experiences and results

based on local experimentation in personalised local communities are considered to be a subject of exchange in a broader community, including long-distance communication. In this sense, the aim is to provide and explore exchange mechanisms between local communities in Europe. Here, direct communication channels, e.g., by e-mailing between learners, are not the primary and original goal. As motivated, we focus on artefact based exchange mechanisms – not excluding their potential function as triggers for direct communication, however. The central medium for exchange is the "Learning Object Repository" (LOR) which is described in the next section of this paper. It provides both group and community navigation tools as well as mechanisms to detect similarities of interests in terms of the produced objects or artefacts. This is a special case of the general ideas related to "social navigation and community support" introduced above.

One of the tools used in COLDEX is Cool Modes (Pinkwart, 2003), a multi-representational framework to enable collaborative modelling. The Cool Modes tool supports synchronous cooperation in a shared workspace environment with coupled objects. Specific types of objects and relations can be defined as domain-dependent plug-ins. Most of these plug-ins offer graph-based representations, but also handwriting annotations are provided.

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 these groups, but also external visitors interested in the contents of the repository because of its relation to scientific topics.

Groupware support for challenge-based learning

The COLDEX project aims at supporting learning and experimentation with open-ended challenges for which no ready-made solutions can be found in a textbook. The themes are mostly inspired by "exploring space" and include examples such as lunar cartography, the programming of robot vehicles, or growing plants in space. Our idea of *challenge-based learning* (or henceforth ChBL) is thus a special form of problem-based learning (cf. e.g., Barrows & Tamblyn, 1980; Koschmann et al., 2001) characterised by targeting non-standard, typically extracurricular, problems in a research oriented learning mode. It aims at familiarising students with adopting a scientific attitude and approach. Here, the advantage of a centralised learning object is the potentially highly contextualised and diverging background of the thematic learning objects. This complexity is a necessary ingredient for a meaningful and rich collection of data and metadata.

Research and practice in CSCL shares a basic experience with other groupware applications in that using group orientated software tools puts additional demands on the users. I.e., the use of group or community orientated tools comes with an additional cost (in terms of additional coordination and interaction efforts). Thus, from a motivational point of view, there should be a clear benefit in using these tools. For example, if the explanation of an experiment is standard content of textbooks, it is quite unlikely that learners would engage in time consuming communications with people around the world to understand the experiment. On the other hand, if the problems dealt with are non-standard and of really open-ended and exploratory nature, there is an obvious incentive to engage in such an exchange. This is the basic argument for concentrating on challenge-based learning as an educational approach. So, the specific pedagogical approach of "building bridges within learning communities" (not only within the COLDEX project) can be characterised by the three basic elements:

- extending "communication through artefacts" from local to global learning communities,
- contextualising community information bases with thematic and task-orientated parameters, and
- using challenge-based learning as an overall educational design principle.

These themes have an innovative potential, both from a scientific point of view (in CSCL and Community Information Systems) as well as for educational practice.

Examples challenges and thematic exploration

One of the COLDEX learning scenarios is "robot in a maze" (Jansen et al., 2004). It has two characteristic activity modes: (1) the construction of a new maze as a challenge to other learning groups, and (2) the definition of a robot strategy to escape from (hopefully any) maze in the form of *situation-action rules*. For example, a rule for the given situation "free in front and on the left, but blocked on the right side" could be: "go forward". One of the most obvious strategies for guiding a robot out of a maze is "wall following" which can be challenges by putting islands in the maze. The Cool Modes system supports both maze construction and the definition of rule sets. The corresponding learning objects (of type *maze* or *rule set*) can be put in the LOR. A rule set can additionally be executed with a Lego robot in a physical maze.

The two different aspects of the described scenario foster a special kind of competition between the maze constructors and the students that program their robots. The users can categorize different classes of mazes (with or without islands, single or multiple exits, exits at the edge or within a maze), and other users can find different

strategies to solve arbitrary mazes of these classes. This allows for a mixture of competitive and collaborative group work patterns. Using this scenario, the role of the repository is evident, as users can retrieve more classes of rule sets or mazes which they then try to compete with there own mazes or strategies. Further usages of the repository (beyond simple searches for mazes and rule sets, or analysis of the contained data) arise if descriptions and keywords are considered. For example, a user can add the information about his maze class, or can state that his rule set is "the best" and succeeded in all tested mazes.
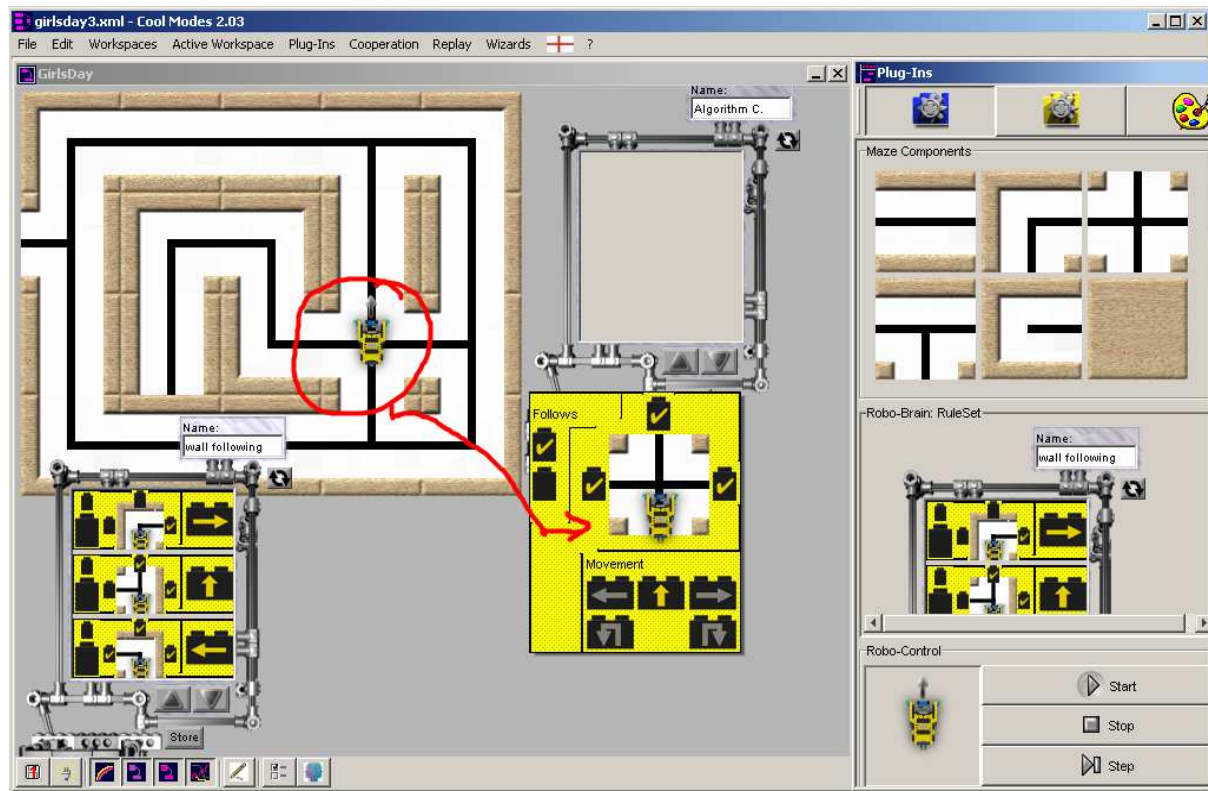
Figure 2   Maze scenario: simulation in the modelling environment

Another example of a scenario is "lunar cartography" (Hoeksema et al., 2004). Here, the activity flow spans from taking pictures of the moon to calculating measures such as diameters or crater heights by using an interactive tool embedded in Cool Modes. Using the LOR, users can exchange different (annotated and contextualised) moon pictures to cover different phases of the moon, in order to compare the same crater shown in different views taken at various sites. The repository can also serve as a platform to extend and enhance a collection of moon objects with measurements.

Costs and benefits

The costs of using the repository for retrieval issues are the following: just on their own, users have to elaborate solutions in a potentially complex and highly demanding way, there are no ready made solutions available. In contrast, the user can collaborate, search the repository for helpful examples, share partial solutions with the community and thus compose one possible solution for the problem at hand. The additional time effort, of course a cost aspect, faces the benefit to minimise manual indexing. Similar trade-off situations have been discussed for information pooling scenarios with database tasks (Cress & Hesse, 2004).

Again, a big problem concerning repositories is again the "cold start problem": There will be no benefit in spite of the required efforts before a critical mass of reasonable retrievable thematic objects is reached. Of course students should be informed about the future benefit to motivate their efforts. Often, it is also possible to provide an initial set of learning objects from previous experiences or even constructed by a teacher. A similar problem occurs with user profiles in a growing group of users/learners. Therefore the initialising of user groups and thus an initial set of user information (partly provided through tedious manual input) should be facilitated as fast as possible.

Non-standard challenge-based learning activities require higher "investment" of creativity and involve a higher risk of failure. They typically come with less context information and scaffolding than, for example, in common practice scenarios in schools or undergraduate academic settings. On the other hand, they are highly

rewarding in case of success and they can strongly benefit from exchange in large learner communities, including asynchronous settings and initially anonymous groups.

	Cost	Benefit
Finding resources	Time effort	Information pool
Creating documents	Additional time and work effort	Learning by doing
Contextualisation	(Automatic generation: system cost)	User benefits from context information
Indexing	(Automatic indexing: implementation cost)	Large range of possible queries to serve different information needs
Session preparation	Start server, join session	Collaboration (+ log data, i.e. more context information)
Storing documents in a repository	Additional time effort: uploading and manual input of additional metadata	Information pool
Re-use of documents	Retrieval and adaptation	Learning from other users' experiences, getting different views of the same challenge (ideally: understand other users' approaches)
Extracurricular nature of repository usage	More time effort to research, to find interesting thematic objects	Learning not only facts, but also acquiring scientific working mode
Challenge-based learning	Potentially highly complex tasks	High user motivation due to the non-standard nature of topics, opportunity to learn from experience rather than from textbooks
Learning community	Not knowing everybody personally	Connection of peers with similar interests

Table 1   Costs and benefits for ChBL

THE LOR

In order to describe, integrate, and retrieve information created by a learning community with a variety of resources, our approach is to define a learning object repository (LOR) with an explicit conceptual model, an ontology, capturing community work processes and resources (Verdejo et al., 2003). The ontology we employ consists of the following top level concepts:

- *Learning Objects* (LOs), the core data entities stored in the LOR. Their structure includes references to associated resources, tools, learning design parameters and other contextual educational information, and (in some cases) information about input and output formats.
- *Actions*, which allow the classification of user actions according to several categories (e.g., Activity Theory or models of scientific experimentation activities).
- *Goals*, which specify the purpose of certain actions.
- *Complementary* metadata information, encapsulating domain or scenario parameters.

The expressive power of a learning object management system is a function of its vocabulary, but also of its description format and the abstraction levels enabled by its definition. In our case, this vocabulary includes standard (IMS-LOM) as well as non-standard metadata slots, as learning communities may often want to define their own descriptions to suit their needs.

The LOR integrates data and artefacts created from heterogeneous resources. Artefacts, in this sense, are the products created by the learners using certain tools. It is possible to upload results in arbitrary file format, such as images (e.g., from telescopes) or multimedia documents created with commercial tools. These objects are uploaded through a web interface. As for content keywords, such objects have to be indexed manually whereas user and group information can be added by the web environment. Using specific COLDEX tools such as the Cool Modes system the upload is directly embedded in the tool environment and allows for generating more metadata automatically. These "metadata generated from tool context" include not only user information (from the login and an internal user profile) but also information about the course context (represented as metadata in hand-outs and working instructions) and information about object types and operations known in the tool environment. E.g., in the maze application it is possible to distinguish a maze design from a rule set by the object types. A maze document can be easily distinguished from a lunar cartography calculation by the different plug-ins (and by the different object types).

There is general mechanism for interfacing between the LOR and single tools, which is essentially enabled by mapping schemes between the LOR ontology and the tool dependent information. The LOR also includes a mechanism to create object descriptions from contextual community information derived from the conceptual model, to further enrich an object description with social data in a transparent way. A by-product of this is the

ability to support personalisation for specific sub-communities, as these define different application contexts. Once a new LO type is defined, the LOR will be able to store it, providing adequate metadata values taken from the community portal or the tool context.

The LOR is a service to store LOs and enable their retrieval. Users can define new object types, and add or delete objects of any of the types available. The mechanism to define a new object type consists of declaring the list of metadata to be added to this LO type (apart from the standard set, which is automatically added to every type). This operation is performed once to make the system aware of the new LO type existence. Once we have a set of object types, any user can add or delete objects, either through a web portal, which provides to the user a direct access to the LOs, organised in workspaces (Verdejo et al., 2004), or directly through specially enhanced tools in the original task environment (Pinkwart et al., 2004).

To this point, we have described the mechanism for storing and indexing results of learning activities. Next we have to define corresponding mechanisms for navigation, retrieval, re-use and information sharing. The following subsections will explain principles of navigation support based on group context, semantic navigation, and navigation and exchange through thematic objects. A common point in these subsections is the notion of *contextualisation*. The central idea discussed in this paper is the use of learning objects as a means for initiating asynchronous artefact-centred communication. Here, contexts are used in two different aspects: first*, learning object contexts* serve as (meta-)data resources upon which explicit retrieval functions and navigation strategies operate. Second, *task and tool contexts* are exploited in implicit, similarity based retrieval operations: without leaving the current activity context and tool environment, users can, e.g., ask for similar documents or objects (i.e., similar to those they are working on) and can retrieve peers with supposedly similar interest, namely the authors of these documents. The found "similar" documents can, again, be directly accessed and manipulated within the tool context.

Semantic Navigation

Semantic navigation is enabled by the ontology, which establishes a new abstraction level upon that provided by raw metadata. A benefit of this higher level of abstraction is bringing out links between entities that were apparently unrelated. For instance, a particular tool could be discovered to be related to a given project or to another tool by means of the ontology. Thus, two different groups could be found to be related by the fact that they work on projects which share a common challenge or because they have participated in activities which required using common tools.

The importance of this new level does not rely only on permitting new or more elaborated queries but also on adding the concepts represented by these queries to the user's working vocabulary. For example, a user can discover an association between two learning objects which were linked because they have one of their authors in common. These queries allow users to think in terms of different similarity variants: document based, person based, and task based.

The ontology consists of entities and relationships, but it also has inference rules. Rules allow for deriving new information from existing knowledge. Thus, for instance, a rule could state that every project needs a challenge, that whenever a new Learning Object is created, it is linked to the service which was used to make it or that users belonging to a group are considered to be developing the group's current project. New connections open new ways of walking through the LOR. The ontology makes it possible to navigate them by viewing these links at a higher abstraction level, that is, rather like relations between concepts than metadata annotating objects.

Finally, the portal brings forth context information, which enables new knowledge to be derived, such as the current activity being carried out within the project a group is developing or the tool they have selected for solving a particular task. Rules, again, apply to this knowledge to derive meaningful relations or facts, like offering that group this particular tool whenever a similar task is to be done.

Navigation support based on context and thematic objects

Users can either access the LOR through the web interface or through one of the available tools. In the first case, the web interface would present the metadata for a user-selected learning object together with the possible search categories, with values automatically filled according to the selected LO and its context. This object description is then taken as a query, allowing the user to edit or include fields (thus, adding constraints) or delete them (i.e., relaxing existing constraints). The results of these specifications define the kind of object the user wants to search. Then, the LOR searching mechanism will be triggered, and the results will be presented. If necessary, the user would be able to iteratively refine this search.
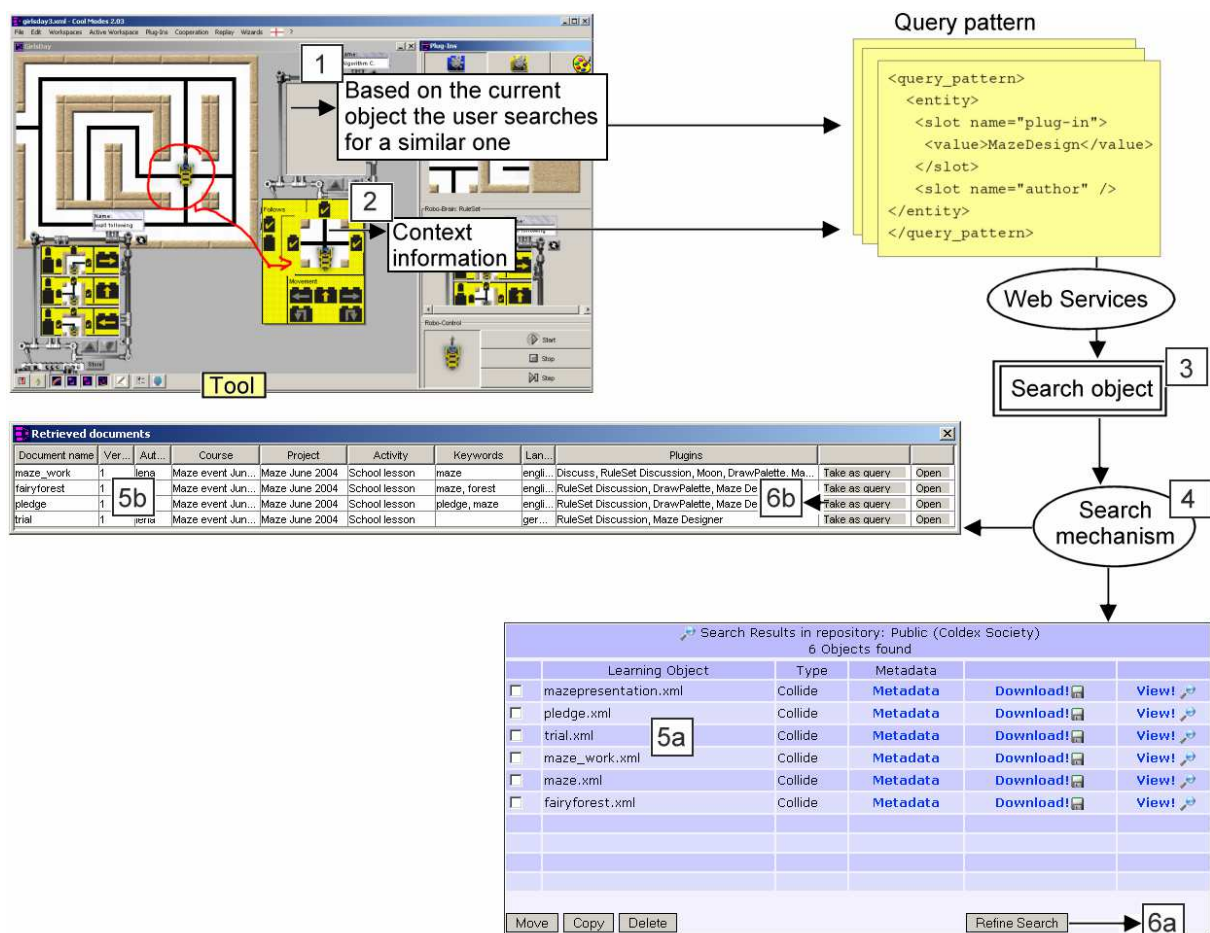
Figure 3 Searching LOs from a tool (Cool Modes) using query patterns

Figure 3 illustrates how thematic learning objects can serve as a source for finding "similar" documents that resemble the user's current task context: from within the modelling environment Cool Modes (here, used with a maze plug-in again), the user can initiate (without further parameter specification!) a LOR query for "related objects", whose implementation is based on the context of the current learning object and the ontology structure. The results of this query (i.e., the list of candidate objects) is mirrored back to the user, who can then either refine his search, or access one of the proposed documents *directly from within his current environment*.

This lookup mechanism for objects is "associative" in the sense that it enables the use of prototypical objects as a starting point for query generation. The user does not have to learn any query language in order to make use of the LOR. Based on this core functionality, we have implemented a number of search and retrieval mechanisms that work on the archive. The advanced mechanisms exploit the context of the current task of the user: together with the content of an object, the metadata about the tool, the user(s), and the current task (which may be associated to documents that have a history and, e.g., originate from the repository) constitutes thematic objects in the sense as described in the introduction of this paper.

Technically, the implementation relies on query patterns, which can be conceived as query masks generating concrete queries through filtering processes. There are two ways to define these, either using the ontology querying language or (in a more simple manner) through a combination of metadata. The latter is mainly offered through web services and permits establishing a link between the LOR and a number of previously known external tools. It would be initiated on demand of an external tool. A tool can define a query pattern library (Pinkwart et al., 2004), which allows the specification of particular search strategies for target objects. Some pieces of information needed for searches can be taken from the task context and thus be automatically provided by the tool itself at the moment an instance of the query is generated. For the example case of Cool Modes, the generated metadata currently includes, e.g., the employed modelling language, the user and his collaborators, and inferred educational parameters as well as relations to previous document versions - further slots are under development. This process is illustrated in figure 3 with an example using Cool Modes and goes as follows: first, the user would ask for LOs similar to his current one (step 1 in figure 3). An appropriate query pattern would be extracted from the library, and serve the purpose of generating a concrete query based on the user's current context and the strategy encapsulated in the pattern (step 2 in figure 3). Then, a "search object" (labelled

3 in the figure) would be built to trigger the search process (step 4 in figure 3). The rest of the procedure can either follow the steps already explained for portal-initiated search, or lead back directly to the tool and allow direct access to the LO (steps 5a/b and 6a/b).

With this document navigation based on thematic objects and their similarity, even more advanced usage scenarios are possible: based on a simple relation between users and the documents they have used, an extension of the similarity measure between documents to the associated users enables finding peers or groups of similar interest and, iterating this process, to realise social navigation based on the documents contained in the archive. For the user, this process breaks down to the simple question of "is there someone who is doing similar things to what I am working on?" The possibility of a system-side answer to this question is indeed a valuable point if one aims at fostering learning communities and their exchange.

Both ways, from the portal or by the tool, meet at a common point before triggering the actual search: an intermediate "search object" is generated, which includes the sought after properties for the target LO as well as relevant context values. The search object's content is either directly gathered from the portal context, as in the first case, or supplied by the tools, through a data exchange process, which, in turn, can be completed with contextual information. Once the search object has been built, the searching can be run, which would produce a result set. The process can be iterated and the user can participate in refining its results by changing values or adding constraints.

CONCLUSIONS AND OUTLOOK

So far we have explored and developed mechanisms to use learning objects in context as mediators for community interactions. These mechanisms are designed to support the sharing of ideas in open-ended and ill-defined problem domains. I.e., the expected benefit lies in improved problem solving performance facing the given challenge. The COLDEX environment is fully implemented and demonstrates the feasibility of the general approach, and particularly the Cool Modes system exemplifies the possibility of using tool information for contextualised indexing and retrieval. This, as such, is an added value regarding community support functionality. As one of the reviewers has correctly pointed out: this is a logical value added, not necessarily a psychological one. Indeed, the psychological validity of the described mechanisms has still to be studied beyond functional test of our system implementation.

The initial motivation for (re-)using objects in the community database can also be viewed from a sustainability perspective: what would long term effects look like? We assume that, under certain conditions, the development of social relations might gain a dynamics of its own beyond the sharing of thematic objects. This could in turn have an impact on the content level: the stimulation of social relations might foster certain types of innovation and even the definition of new challenges in the learning community! The investigation of this effect within the community will be one issue for the future research. Another open research issue is the following: Similar to "feedthrough mechanisms" in synchronous collaboration with direct manipulation, the artefacts that mediate the communication in our approach may be used as message containers through embedded annotations which "let the object speak" like a message in a bottle (e.g., a handwritten comment "whoever re-uses this model, may contact me for a further exchange"). This is possible and it would add a direct communication channel to the asynchronous exchange.

We believe that it is worth investigating the aspects of the enabling mechanism and the sustainability effects on an empirical level. Research on sustainability effects will typically require statistical types of analysis. Such types of long term analyses need data about a community using systems of the types we presented in this paper. For these purposes, we are currently developing (and using continuously in all our university lectures) an integrated web based learning support system (Pinkwart et al., 2005) that allows for a variety of evaluation methods, including "mixed mode social network analyses" (Wasserman & Faust 1994). On the evaluation level, we are also discussing pathways to analyse "hybrid networks" (ontology terms and persons), both in context of the LOR and the accompanying web portal. Applying this concept as a real time social network analysis for group reflection may also have interesting effects on the enabling mechanism.

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