ViCToR-Spaces: Cooperative Knowledge Spaces for Mathematics and Natural Sciences

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Abstract: Cooperative knowledge spaces have a high potential to improve eLTR (eLearning, eTeaching and eResearch) at universities. Since there are few implementations deployed, notably in the fields of mathematics, natural sciences, and engineering, we propose a concept for field-specific knowledge spaces for those disciplines - the “ViCToR”-Spaces (Virtual Cooperation in Teaching and Research for Mathematics, Natural Sciences and Engineering). ViCToR-Spaces present novel collaborative working environments for knowledge gain and research, supporting well-established forms of scientific and technological cooperation without geographical or technological boundaries. In this article, we will describe the requirements for ViCToR-Spaces, the components that are already available, and further developments.

1. Introduction

The central concept of virtual communities is the room, a virtual meeting place where the interaction, communication and collaboration takes place. The environment as a whole, in the following called knowledge space, is defined by the combination of its dynamically linked objects, i.e. members, documents, tools and services (Hampel and Keil-Slawik, 2001). Hence, the design of those components and the way they are linked is the key issue to successful cooperation and knowledge gain.

A wide variety of CSCL (Computer-supported Cooperative Learning) environments has been developed during the last 15 years. However, since the requirements for cooperative knowledge spaces for mathematics and natural sciences differ greatly from what is supported by existing solutions, there is still a lack of implementations actually deployed. Many noteworthy results have been achieved, notably creating components such as electronic learning platforms. But to fulfill the specific requirements of teaching, learning and research scenarios typical for technical disciplines, we need a profound specification of cooperative knowledge spaces. We call them “ViCToR”-Spaces.

In this article, we discuss the state-of-the-art of ViCToR-Spaces. An analysis of the existing problems and technical shortcomings, followed by a description of the work in progress, will demonstrate the concepts created to transport the spirit of cooperation to everyday life, especially at universities and institutes of technology (Haake et al. 2004).

2. Requirements for ViCToR-Spaces

In this section, we describe the special requirements for ViCToR-Spaces. Here we, being a multidisciplinary team from a technology-oriented university, can rely on a rich experience in the daily practice of students, teachers, researchers and users of mathematics and natural sciences.

As outlined in the introduction, the room metaphor is of great importance for shaping a knowledge space (Hampel and Keil-Slawik, 2001; Greenberg and Roseman, 2003). The underlying room concept is derived from MUDs and MOOs (Multi-User Dungeons/Multi-User Object-Oriented Environments) where rooms are central meeting points in a network. Since we consider the room to be not only a collection of structured content, but also a medium to be filled in a more atmospherical way, it becomes even more important to identify and determine the future users of the room and their special interests and requirements. Keeping in mind that users of the ViCToR-Spaces will come from the fields of mathematics, natural sciences, and engineering, a seamless integration and complex interactivity of the required components is strongly desirable.
2.1 Virtual Laboratories & Remote Experiments

Experiments play a central role in natural and engineering sciences. The integration of new media into teaching and research has led to two principal kinds: virtual laboratories and remote experiments. Integrated into a cooperative knowledge space, they enhance access to experimental setups for all students independent of limitations in time, budget or access to classical laboratories.

Virtual laboratories (Jeschke et al., 2005; Karweit, 1997) use the metaphor of a “real”, scientific laboratory, thus providing a framework that emulates a scientific workplace for hands-on training in a virtual environment. Similar to a real-world laboratory, devices and measurement tools are provided that allow experiments within a specific field. Virtual laboratories for different fields of mathematics and physics form an important contribution to the realization of new learning and research scenarios and are therefore currently under intense development. For theory-oriented areas such as mathematics, theoretical physics and chemistry, they help to bridge the gap between the abstract theory and the real phenomena. Applications of virtual laboratories range from practical support for traditional lectures (e.g. demonstration), over homework assignments and practical training for students up to aiding researchers in experimentation and visualization (Jeschke and Richter, 2006).

Complementary to virtual laboratories, remote experiments are real-world experiments, remotely controlled from anywhere outside the laboratory, at almost any given time. They consist of two essential parts, namely the experiment itself, which is supposed to be conducted remotely, and the remote control mechanism. Remote experiments are capable of enhancing the access to “real” experimental techniques which are often extremely complex or cannot be transported and are therefore restricted to a rather small community of students and researchers.

In both scenarios, the experimenter manipulates a set of parameters controlling the experiment and interacting with it, e.g. by a motor, the magnetic field, or – in case of a virtual laboratory – also by manipulating the boundary conditions. Additionally, a set of measurement tools is provided to collect data from the running experiment, e.g. the temperature, the magnetization, a rotation frequency, the mechanical force, etc. Thus, the different approaches possess a number of similarities, but also enrich each other through their differences: remote experiments allow the investigation of real objects including hands-on measurement experience, which obviously does not hold true for virtual laboratories. On the other hand, virtual laboratories are capable of mapping the complete process of constructing an experiment, whereas this kind of flexibility is clearly reduced in remote experiments.

2.2 Content Repositories & Information Retrieval

Plenty of eLearning content (eContent) material has been developed in the fields of mathematics, natural sciences and engineering, mostly in previous projects on a local or national level, driven by individual researchers and their institutes. This material is not restricted to text-based knowledge elements, but includes a high degree of multimedia objects and interactive components instead. So far, these resources are widely spread, stored in local databases of eLearning and eResearch projects only accessible to a small, restricted user community. However, in the meantime the development of appropriate metadata and other standardization efforts have provided the means to build large, comprehensive knowledge repositories.

Since these content repositories will consist of a huge number of elements, automated information retrieval systems capable to handle text, sound, images, data and other objects are becoming more important. So far, web search engines such as Google are the most visible applications of research on information retrieval. To handle scientific and educational material, advanced search mechanisms are needed which are capable of interpreting the content of an object in a more comprehensive manner. Semantically enhanced information retrieval techniques are being developed which are usually based on computer linguistic analysis combined with statistical methods.

2.3 Support for Special Notations

When exchanging mathematical knowledge in a web-based CSCL or CSCW system, one of the problems one is most likely to encounter is the limited support for writing anything other than plain text. A small set of predefined graphical design elements is available in most systems, e.g. for emoticons in discussion forums. However, special notations such as mathematical formulae (where, besides special characters, fractions, sums, integrals, superscripts, subscripts etc. are needed) or diagrams (e.g. UML) cannot be readily entered into forums, wikis, chats, or similar communication and cooperation facilities.
For mathematical formulae, the most obvious solution to this problem appears to be \textsc{\LaTeX}, since it is well-accepted not only among mathematicians, but also among users of mathematics, as their authoring tool of choice. There exist converters which can produce web-compatible content from \textsc{\LaTeX} sources. However, competence of \textsc{\LaTeX} is far from universal, especially among students and scientists outside mathematics and computer science. Thus, when teaching mathematics (or any other field of science and technology) one cannot require users of a cooperative knowledge space to be familiar with \textsc{\LaTeX}. This makes an integrated graphical tool for editing mathematical formulae a desirable and useful extension to a virtual knowledge space.

Support for special notations also has to be taken into account when developing external tools for editing mathematical content for ViCToR-Spaces.

2.4 Distributed Cooperative Writing

The traditional way of cooperation between mathematicians or natural scientists uses face-to-face communication, where two or more scientists discuss a formula, develop a proof, draw a schematic diagram for an experiment together on a chalkboard or a whiteboard, each of them writing their annotations between their co-researcher's writings. This way, of course, requires each of the participants to be at the same place at the same time. Geographical distances and various other reasons, however, make this an option which is not always viable.

\textbf{Shared whiteboards} represent an approach to overcome these distances. Generally speaking, shared chalkboards serve as a common workspace for all members of a group - e.g. the aforementioned mathematicians developing a proof cooperatively. Thus, all members of that group can work on the same set of data synchronously. The chalkboard itself is a virtual or real drawing board on which objects are displayed graphically and can be manipulated. Very much like a chat client, the data which users are working on is displayed identically on each user's chalkboard.

However, when discussing a mathematical formula, simply seeing what the other person is writing is not sufficient in most cases. One may want to have an equation solved or some numerical analysis made on-the-fly. To achieve this, the shared-chalkboard system has to offer a facility to integrate computer algebra systems (CAS), numerical software etc.

Whereas shared whiteboards are aimed at synchronous distributed writing, content for ViCToR-Spaces (eContent) may also be created or edited cooperatively in an asynchronous process. In software development, e.g., this is the normal case. Moreover, creating or editing content may be linked to other actions, such as reusing or forwarding a content item.

For both synchronous and asynchronous distributed cooperative writing, a rights management is essential. Lack of rights management may cause content to be changed in a way contradictory to the original creator's ideas, or may allow malevolent users to join a shared-chalkboard session and arbitrarily change or even delete objects on the board. Likewise, both forms of distributed cooperative writing require a suitable version management which allows tracing back changes and, if necessary, reverting a content item or a shared-chalkboard session to an earlier state.

3. Implementation Approach

3.1 sTeam as the Base for ViCToR-Spaces

In order to avoid “reinventing the wheel”, we decided to build ViCToR-Spaces on top of an existing CSCW/CSCL platform. When choosing which platform to build upon, our two chief constraints were first, it has to be open-source, and second, its communication and collaboration facilities should go beyond forums and chats.

Open source software gives us a guarantee that we can apply any changes and extensions we consider necessary without having to fear any legal issues. Yet, existing open-source learning platforms such as Moodle or Ilias do not offer many more collaboration facilities than forums, chats and wikis since virtual cooperation is not their main purpose.

The above considerations left the sTeam (Hampel and Keil-Slawik, 2001) and CURE (Haake et, al. 2004) platforms shortlisted. Whereas University of Paderborn's sTeam platform has been developed as an open-source project from the start, the CURE platform is to be released under an open-source license by the FernUniversität Hagen in the fall of 2006.

sTeam and CURE likewise are based on the concept of virtual rooms which serve as shared workspaces for user groups and as meeting places for students and teachers. Both platforms support shared viewing, exchanging and re-arranging of items, links between them, and discussions between users. Finally, both sTeam and CURE facilitate
spontaneous forming of groups by providing awareness information and by managing access permissions on rooms and documents.

Since presently CURE adheres more closely towards established standards and already provides a basic support for mathematical notations, it is used as a technological basis to implement the first prototype of the ViC-ToR-Space concept.

3.2 Integration of Existing Components

3.2.1 Electronic Chalkboards

As mentioned in the previous section, the chalkboard is still the prime medium for education and information transfer in the field of mathematical and engineering sciences. The electronic chalkboard “eChalk” (Friedland et al., 2002, Friedland et al., 2003) has been designed especially for application in these fields at the Freie Universität Berlin. It combines an electronic whiteboard or similar interactive screen (acting as the chalkboard) with numerous multimedia features. Ideas developed at the board can be enriched e.g. by the inclusion of images or Java applets. A mathematical formula recognition acts as a direct interface for handwriting to computer algebra systems working in the background. The numeric or symbolic results or even function plots can be seamlessly integrated into the board drawings.

![Figure 1. eChalk, the Electronic Chalkboard](image)

![Figure 2. eChalk in practice](image)

In E-Chalk, each board stroke as well as audio and video data is simultaneously recorded and transmitted as well as stored. Thus the whole session can later be replayed by a Java applet in a Java-enabled browser. A static copy of the board content is provided in the form of a PDF file for printing. As a result, taking notes during the lecture becomes largely unnecessary.

The integration of the concept of a traditional chalkboard into a multimedia environment offers access to new, additional pedagogical benefits, avoiding the old-fashioned image associated with the standard chalk board.

Work in Progress: Different instances of an E-Chalk server have to be enabled to communicate with each other over the Internet. Synchronization issues have to be addressed such that E-Chalk can be developed into a fully-fledged shared-chalkboard environment. Thereby, synchronization has to be applied not only to the E-Chalk system itself, but also to external software tools which are used from within the E-Chalk system. The tools have to be capable of tracking contributions to identify their author at a later stage.

3.2.2 Authoring Environments

In the past years the XML-based standard MathML has enhanced the professional presentation of mathematical formulae on websites significantly. This development formed an important step for modern eLTR(environments in
particular as it allowed for the creation of reusable, adaptable mathematical content. Nevertheless, the editing process for formulae encoded in MathML still represents a complex task which has to be supported by suitable authoring environments. These editing tools have to be based on common standards such as e.g. \LaTeX, which have found a wide acceptance in the worldwide mathematical community. Furthermore, these tools have to be capable of converting the input into a file format strictly separating content and layout.

One of the most important characteristics of computer-based learning is the possibility to implement and connect different, especially interactive content elements. This allows the realization of individual, explorative learning environments which are considered to be one of the most effective and sustainable ways of introducing complex topics. An authoring environment called “mmcdk” has been developed within the framework of the Mumie platform, which allows the integration of interactive objects into eLearning contents. Since the original \LaTeX is directed towards printable media-types and thus does not support formats like applets or animations, a \LaTeX-based converter has to implement suitable extensions. These extensions have to take into account that interactivity also implies that contents can be connected with each other via links, a feature that is essential for a web-based eLearning environment.

Mmtex (Dahlmann et al., 2005) is a command-line based converter written in Perl, chosen for the capability of being easily extensible. Currently, Mmtex can handle two different \LaTeX dialects as input; one is very similar to standard \LaTeX, with the limitation that a few commands and environments are not implemented. The second dialect is a very specialized one, developed for the contents of the Mumie eLearning platform, focusing on the creation of mathematical texts. In both dialects, the non-mathematical parts of the \LaTeX source are converted to a specific XML dialect, whereas the actual mathematical parts are converted to MathML. With the appropriate stylesheets, this XML then can be transformed into the desired output format (e.g. XHTML, with the formulae coded in MathML).

Besides those posed by the mathematical scientific community, there is another problem to face: \LaTeX is not universally used within all technology-oriented disciplines, particularly not in engineering, experimental physics and similar, application-oriented fields. Its special syntax, close to a programming language, makes \LaTeX a very powerful tool, but requires a considerable adjustment period. Therefore, WYSIWYG editors for \LaTeX such as texmacs (TexMacs, 2006) have a great potential to popularize \LaTeX-based authoring tools.

Work in Progress: To enable a broad community to cooperate within the ViCToR-Spaces, convenient authoring tools following the “Wiki philosophy” are to be integrated. These authoring tools are not restricted to the development of larger text elements such as learning objects, papers and teaching material, but are also necessary for text editing in chatrooms and forums to incorporate mathematical notations and formulae in these media.

3.2.3 Virtual Laboratories

Virtual laboratories have revolutionized education and research as they allow direct experimental access to abstract objects and concepts. The Virtual Laboratory VideoEasel (Jeschke et al., 2005) is capable of simulating various models from the field of statistical mechanics, problems of thermodynamics, wave phenomena and chemical reactions. Measurements are performed by tools plugged into the experiment by the user even at runtime, allowing to observe magnetization, entropy, free energy or other measurable quantities during the experiment. Simulations in VideoEasel are based upon the implementation of microscopic dynamics by Cellular Automata (Toffoli and Margolus, 1987) dynamically programmed at run-time. When experiments of higher complexity are performed, the experimental results can be automatically exported into computer algebra systems for further analysis. To enhance cooperative work between students, or students and their teachers, VideoEasel is able to support distributed access in the form of measurement processes on the same experimental set-up, including remote access from outside the university.

Work in Progress: So far, the VideoEasel lab is mainly covering different fields of statistical mechanics and thermodynamics. Currently, integration technologies – in particular Web Services – are under investigation to
allow the combination of VideoEasel with kernels from other laboratories (e.g. Atomistix/Denmark) to enhance the spectrum and the complexity of the experiments. Extensions are under development, applying VideoEasel to the fields of nanotechnology as well as biochemistry. Finally, since one of the major challenges in teaching is given by the broadness of the audience and their varying prior knowledge, intelligent assistants exploring the user behavior to support intelligent feedback strategies and to build up individual learning paths within the system are under development (Jeschke et al., 2006).

3.2.4 Remote Experiments

Remote experiments are real experiments controlled from a location outside of the laboratory (figures 4 and 5). The important components are therefore the experimental set-up itself and the technology used for the remote access.

For the remote experiments developed at our university, National Instruments Labview is used to control the hardware and collect the experimental data. Labview also offers a convenient web interface which enables the remote experimenter to perform any necessary adjustments. In order to view and control the experiment, a freely available web browser plug-in has to be downloaded and installed. Due to the modular programming structure of Labview, remote experiments can easily be combined or extended. At the TU Berlin, several remote experiments, the so-called “Remote Farm”, have been set up by C. Thomsen and his group (Thomsen et al., 2005).

Figure 4. The remote laser in the lab ...

Figure 5. ... and the experimenters outside the lab, using Tablet-PCs to perform experiments

Work in Progress: Networked virtual laboratories and remote experiments form an important part of virtual knowledge spaces suitable to the realization of teaching, training and research concepts in natural sciences and engineering disciplines. Through eScience-based forms of cooperation, highly specialized experience and equipment - so far, only available at selected places of excellence - can be made accessible within a worldwide research and education landscape. To reach this goal, a service-oriented infrastructure based on Web Service technology will be designed and implemented (Jeschke and Thomsen, 2006), targeting distributed collaborative composition and execution of experiments in the natural sciences including data analysis, interpretation of the results, and development of applications. A common portal infrastructure including a “service broker” will enable access to virtual and remote experiments through standardized interfaces.

3.2.5 Learning Platforms

One important prerequisite has to be fulfilled before the vision of a “mathematical knowledge network” for research and education can be realized within a cooperative virtual knowledge space: a stable computer-based representation has to be developed to facilitate the interexchange of mathematical objects between heterogeneous software environments. For the field of mathematics and natural sciences, e.g. the OMDoc format (Open Mathematical Document (Kohlhase, 2000)) serves as a content markup scheme for mathematical documents including articles, textbooks, interactive books, and courses. OMDoc also acts as a content language for agent communication targeting on the interconnection of mathematical software. OMDoc approaches this goal by attaching information to mathematical documents that identifies the document structure, the meaning of the text fragments, and their relation.
to other mathematical knowledge. The power and versatility of fine-granular content structuring and the use of formal representation languages as realized by the OMDoc-approach is obvious and has been proven in existing eLTR platforms: The open-source, mathematics-oriented eLearning platforms Mumie (Mumie, 2006), ActiveMath (Melis and Siekmann, 2004) and Connexions (King and Baraniuk, 2006) are characterized by their common approach, including the use of fine-granular knowledge elements and the consistent semantic encoding of their content as well as content management based on ontological structures. The platforms operate on the principle of strict separation between the representation of mathematical knowledge from pedagogic forms of presentation and principles of multimedia-based functionalities.

The Mumie platform (Dahlmann et al., 2005b; Dahlmann et al., 2003) focuses on the interactivity and multimediaity of the granules of content as well as their usability in multiple, diverse learning scenarios: Mathematical objects are flexibly combined by a CourseCreator into individual teaching units and presented in an exploration-oriented environment (content scenario). The presentation of content on the one hand is complemented by practice scenarios and virtual laboratories supporting the individual and independent approach to mathematical content on the other hand. Mathematical objects are being presented in lexicographical form or stressing relations and interconnections within the field but detached from the context of any actual courses (retrieval scenario).

The focus of the ActiveMath eLearning and eTeaching platform developed at the DFKI (German Research Center for Artificial Intelligence) in Saarbrücken is on the adaptivity to the needs of the individual user. ActiveMath embeds functionalities, supervising, recording and analyzing user activity, allowing the system to model the user’s progress and analyze her/his preferences. This feedback loop allows functionalities normally reserved to intelligent tutor systems.

The Connexions system developed at Rice University (Houston/Texas) is a powerful content management system for content-oriented mathematical knowledge elements. It is used internationally and already contains several thousand elements ranging from the support of basic math courses to advanced research topics. The use of Open-Content licenses attracts a growing number of coauthors to Connexions.

Work in Progress: Content markup schemes like OMDoc contribute intensively to overcome the problem of semantical content structuring but do not address semantical encoding of the content itself. Further efforts have to be undertaken to enable authors to produce semantically enriched eContent in order to enable intelligent user adaptation mechanisms on all levels.

3.2.6. Information Retrieval

mArachna (Natho, 2005), a subproject of the Mumie platform development, provides an innovative information retrieval system in the form of an interactive, mathematical “encyclopedia” containing multimedia objects of all kinds. mArachna analyzes mathematical texts by using natural language processing techniques and mathematical background knowledge. The semantic information thus extracted is inserted into a knowledge base, which is based on one specific, selected ontology of the field of mathematics. This knowledge base represents the background knowledge which in turn influences the natural language processing. As a result, the user is able to query not only for mathematical terms as in a traditional, keyword based approach, but also for dependencies between mathematical statements.

Work in Progress: Beyond extension to languages other than German, the further development of the mArachna system will allow to analyze the content structure of large written texts as textbooks for students. For each book, this structure forms a special ontology which represents the authors’ particular view on the field. Different ontologies – formed by different authors – can be compared, e.g. in respect to different target groups, varying cultural approaches and varying learning goals. Additionally, comparing these author-specific ontologies with abstract field specific “upper ontologies” allows to gain insight into formerly unknown types of interconnections between different fields, thus making mArachna an instrument of “knowledge evolution technology”.

4. Conclusions and Outlook

In the work presented here, we have defined and elaborated a set of special requirements to cooperative knowledge spaces for mathematics and natural sciences. Due to the variety and complexity of curricula in these subjects, this set should not be considered a final and exhaustive specification. Moreover, we have outlined existing tools and components, most of which have already been deployed successfully in university courses.

Enhancing these tools and interconnecting them will allow content-oriented, experimental and cooperative learning scenarios to be realized in equal measure. Through this, we expect computer-supported learning, teaching and research in mathematics and natural sciences to improve considerably.
References


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