Chimia 57 (2003) 94–98

ISSN 0009–4293

New Media for Teaching and Communicating Inorganic Chemistry: The Projects CCN and CCI at the Department of Chemistry and Applied Biosciences, ETH Zürich

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Abstract: Chemistry teaching is traditionally a difficult task as it comes alive only through experiments. Secondly, extreme reductionism does not apply to chemical understanding because chemical ensembles by definition constitute very large sets of mobile particles. Teaching and learning of chemistry has to provide a feeling for the complexity of interactions, which is hidden behind the chemical symbolism. As safety requirements and reduction of costs have become important factors, experiments very often are the first to be cancelled in chemical courses. We present here an internet-based system for teaching chemistry and narrowing the gap between research and teaching in this field.

Keywords: Blended learning · CCI · CCN · Inorganic chemistry · Scientific visualization

Introduction

Life today is so penetrated by the achievements of chemical research, applications, and chemical products that even experts are not able to appreciate them in their total comprehensiveness – and for sure – we are moving in this direction. In strong contradiction to that, many people reject chemistry on the whole as something absolutely 'unnatural', dangerous, and even unnecessary. This is due to a profound misunderstanding of what chemistry is and the role it plays in our lives. Sadly enough, such a widespread attitude infiltrates young people long before they have a chance to understand what chemistry is all about. It is indeed the complexity which makes chemical processes so unique and so difficult to understand by 'daily life explanations'. There is hardly any other science that needs so profound teaching to develop a proper understanding. And even when it is taught in a reasonable way, misleading pictures are often imprinted into the minds of the students, such as the representation of molecules by spherical atoms – as if chemistry would treat a Newtonian system and not always investigate what is between the 'atoms' in a molecule. Furthermore, the ensemble character with its typical probability distributions is often not stressed and the quite natural fact that chemical processes only occur if the components are on the move – diffusing, rotating, and vibrating – is not addressed. Certainly this concept is difficult to explain and to learn but it does lead to a beautiful development of three-dimensional imagination and of a proper understanding of the complexity of our world that can only be mastered by probability strategies and not by truth arguments. For all these reasons, real experiments are indispensable and must be presented – but they are frequently omitted for economic, ecological, safety reasons, and because of the large effort involved for the teacher. Furthermore, as already mentioned, older teaching/learning structures or materials no longer match the new learning goals in chemistry.

Learning and teaching can be widely improved by the help of integrated web lessons, videos, and schematic animations. The target now is the preparation of newly developed teaching materials combined

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with new training forms while keeping in mind the crucial question: which medium will transfer optimally the content to be taught in respect to specific conditions?

During last years, new media learning and teaching tools have been introduced into higher chemistry education at ETH Zürich. Here we present two projects at the Laboratory of Inorganic Chemistry at ETH Zurich, 'CCN – the Chemistry Contact Network' [1] and 'CCI – Creative Chemistry on the Internet' [2] which investigate the usability of the new media for chemical research and education and produce new teaching contents for blended learning purposes.

CCI – Creative Chemistry on the Internet

Since 1994 'CCI – Creative Chemistry on the Internet – Experiments on the Web' has been taking videos of chemical experiments, recorded under well-designed laboratory conditions. The constantly growing internal CCI-video archive contains today up to 250 high-quality videos of chemical experiments in different formats usable for a variety of teaching purposes, as needed in a blended learning environment. Today CCI-videos are an important teaching resource at ETH Zürich, intensively used during the live lectures of inorganic chemistry as well as in advanced seminars or for public information issues. At present CCI accompanies the experimental lectures of General Chemistry I + II, Inorganic Chemistry I as well as Chemistry for Environmental Sciences. It allows for the online revival of more than 180 streaming videos of selected chemical experiments, complemented with short explanatory texts, additional detailed information as to possible applications, bibliographic information, links to the lectures, safety requirements (Sicherheitsdatenblätter), and other external resources [2][3].

The basic teaching strategy we are applying consists of five principal parts: 1) PowerPoint-based lectures, 2) live experiments, 3) videos of real experiments (CCI) and schematic animations on the web, 4) independent scripts, and 5) practical laboratory courses combined with seminars.

The PowerPoint-based lectures concentrate on highly interesting or specifically difficult parts of the full term program. The students' attention is captured by a well-chosen set of live experiments, videos of real experiments, computer animations (which are integrated into the PowerPoint media and are intended to aid the imagination of the student to a relevant understanding) and just short explanatory texts which accompany the free speech of the lecturer. As the students can only take short notes during PowerPoint lectures they are obliged to work through the full contents utilizing the accompanying script which is offered on the web, and which is directly linked to the corresponding movies in CCI. An alternative single picture mode of CCI takes into account the students' budgets and possible bandwidth problems at home [4]. As the script is differently organized than the lectures, the students have to work through the contents once again from a different perspective, *i.e.* by an asynchronous independent home-based learning process. In addition, one or two textbooks are recommended for further learning.

CCN – The Chemistry Contact Network

'The Chemistry Contact Network' (CCN) [1], which is part of ETH-World [5], the Virtual Campus project of ETH Zürich, has been operating since 2001. CCN is designed as an internal and a public platform communicating chemical contents for research exchange, for public media, and for teaching as well as learning. Thus, CCI is now part of CCN.

The recent fast developments of networking technologies, scientific visualization techniques, and the availability of fast and rather economic machines to perform

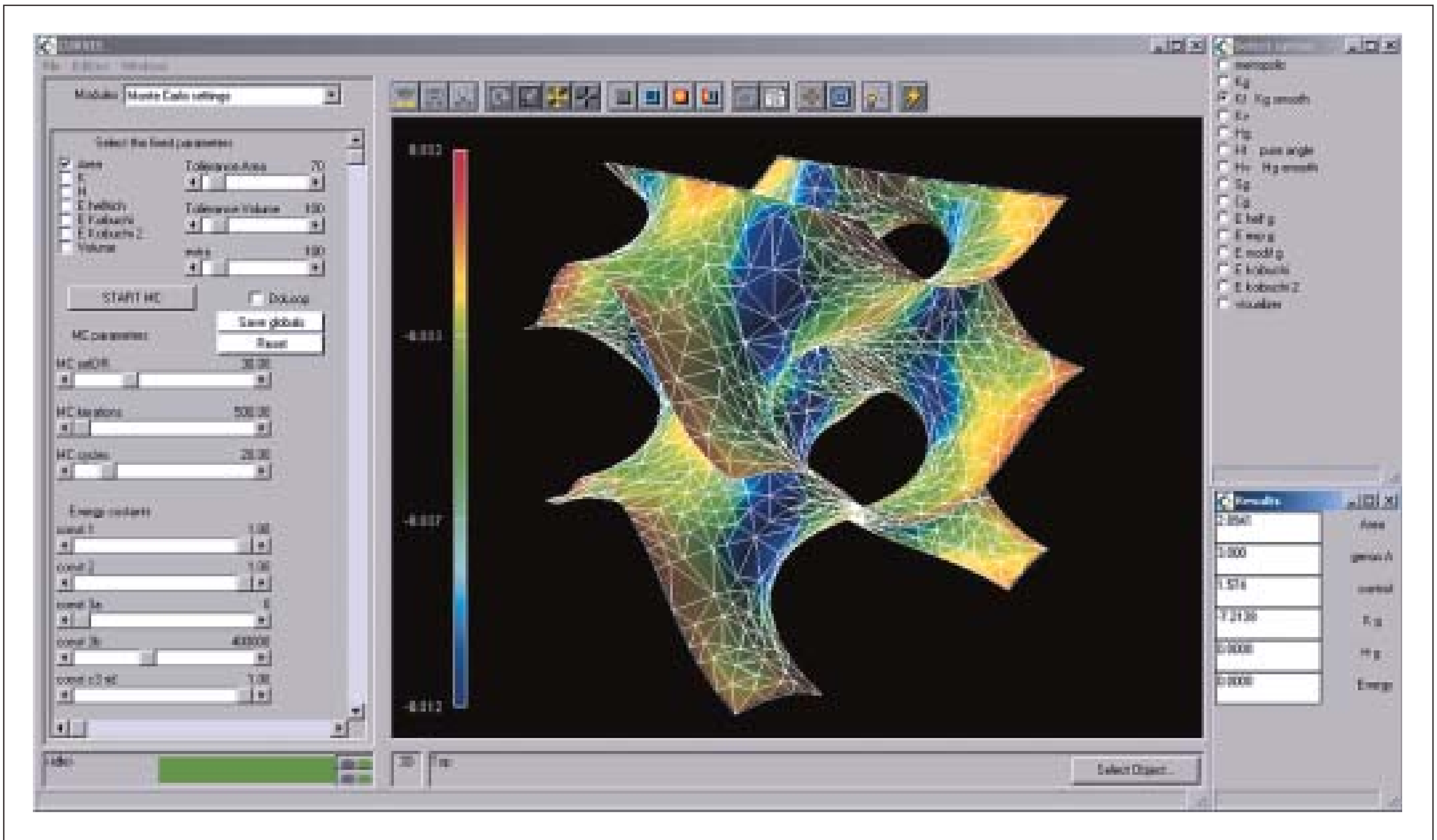

Fig. 1. Example of the user interface of the program CURVIS

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interactively and real-time computer calculations for a fast information exchange are essential for CCN.

Today, most university lecture halls are equipped with projection facilities for computer-based media. In addition, a wireless LAN environment allows the student to directly use their laptop computers during the lecture courses. Such systems have been installed at ETH already for some time.

Inside the framework of CCN, the usability of new technologies for research and education in chemistry is being investigated, focusing on a blended learning environment with dynamic linking of research and teaching emphasizing the following main objectives in education:

- Expand teaching to a new, virtual level by generating new teaching and learning tools not only for basic chemical education at different departments of ETH and higher level education at the Department of Chemistry, but also for schools, and for continuing education.
- Establish dynamic links between teaching, research, and applications, moving towards a comprehensive interaction with present and future chemists and to bring back the challenge of research into chemical education.

Therein, CCN has two interrelated main topics:

The first (*education*) is to work out how the learning of university students can be improved by the help of multimedia elements for integrated web-based courses as well as for live lecture purposes. Since the target is the preparation of completely new teaching materials considering the specific advantage of certain media types for different teaching purposes and conditions, the results in merging commercial and newly designed tools will be shown here.

The second topic (*research*) is a trial to modernize the methods of chemical and pharmaceutical research, bearing in mind their usability for fast scientific exchange and higher chemical education.

The role of scientific visualization of spatial complex systems or time-dependent processes is becoming increasingly important. Current advanced analytical and theoretical methods provide enormous amounts of data, which can be condensed and visualized by sophisticated techniques. Most centers of scientific research provide some advanced visualization facilities. CCN has a novel strategy to increase the usability of scientific visualization and remote networking for research and education at the same time by developing software designed for tools such as smart boards, interactive plasma screens and three-dimensional stereo

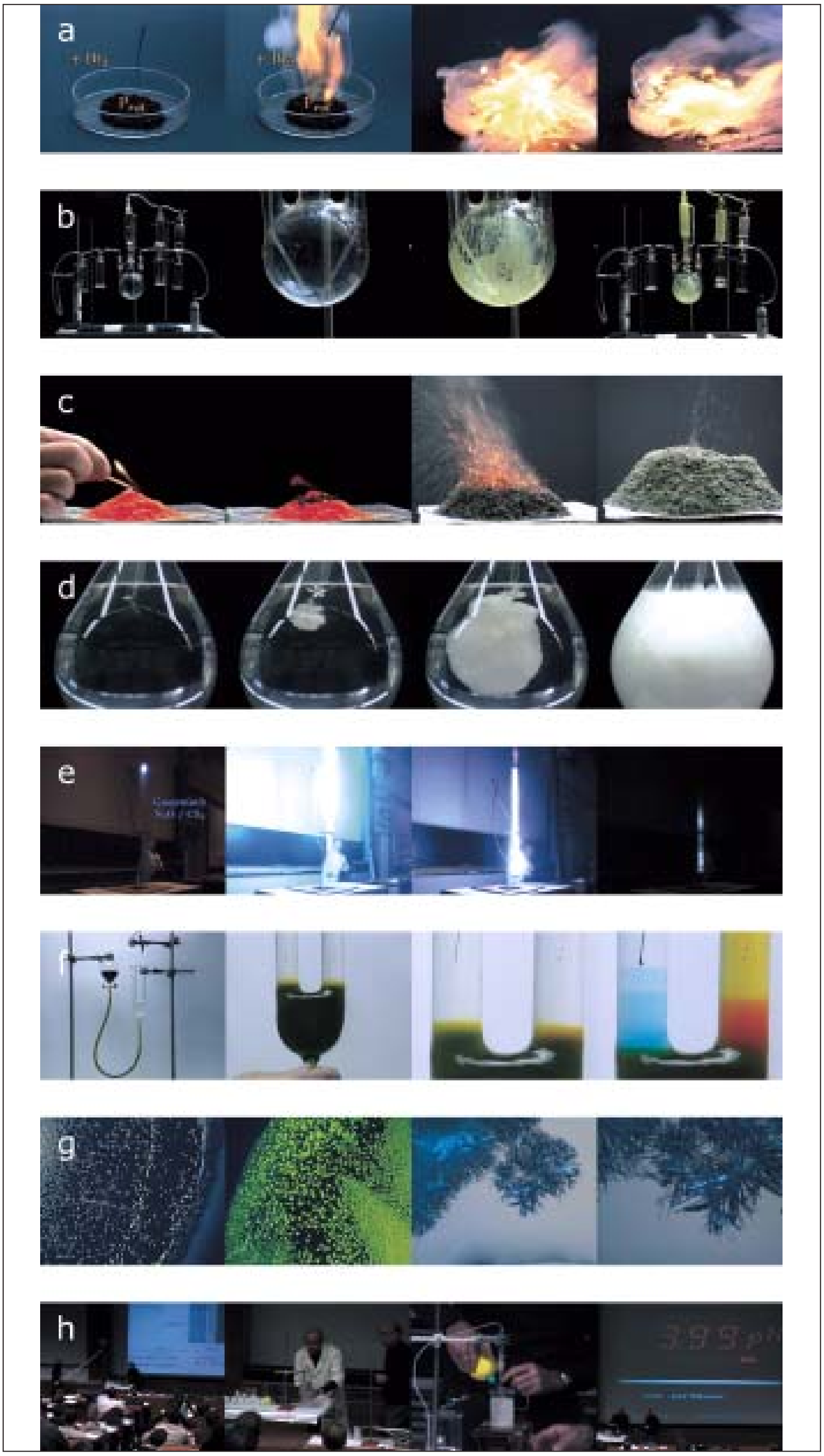

Fig. 2. Screenshots of CCI-videos used for demonstrating a) extremely dangerous, exothermic, and explosive reactions (reaction of red phosphorus and bromine); b) unpleasantly smelling and often toxic experiments (Clauss process); c) toxic experiments, not allowed to be performed in normal lecture halls (volcano, ammonium chromate decomposition); d) experiments difficult to perform (spontaneous crystallization from hypersaturated solution of sodium acetate in water); e) expensive, sumptuous experiments ('Bellender Hund', combustion of CS_2 with N_2O); f) the visualization of very slow reactions by time-lapse recording (electrolysis, ion diffusion); g) the visualization of microscopic experiments (crystal growth); h) simultaneous projection (magnification) of details during a live performed experiment, which would be too difficult to perceive at larger distance (pH measurement).

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projections. CCN aims to create a new type of interactive research and learning environment, for researchers and teachers of chemical issues.

Fig. 1 shows a screenshot of CURVIS, a scientific computer program to visualize and investigate 3D data, developed within the framework of CCN in respect to its usability for the production of teaching material.

A chemical laboratory or seminar room equipped with projectors and wireless devices, and possibly by smart-boards/interactive plasma screens and/or 3D stereo projection facilities, enables the researcher as well as the teacher to establish a seminar style, which makes use of the benefits of interactive group work and remote controlled teamwork as well as today's most advanced visualization techniques.

Tools for education have been conveniently combined with the research tools for both new synchronous and asynchronous teaching and for the communication of research results. Some specific advantages of the following three different media types:

1 Video and movies,
2. Vector-based schematic animations and interactive Flash elements, and
3. 3D-elements as for example in VRML-format or QuickTime VR,

need a more detailed description.

Video to Support Teaching, Learning, and Research

Traditional videos are still the first choice to show time-dependent and dynamic processes. They can either be recorded or computer-generated. For different purposes, different techniques such as video screen capturing, video recording, and computer-generated video output, are used.

CCI-videos of chemical experiments at ETH Zurich supplement or replace live experiments during lectures for ecological, health, or economic reasons. Fig. 2 shows screenshots of eight CCI videos as examples of extremely dangerous, exothermic, and explosive reactions (a), unpleasantly smelling (and often toxic) experiments (b), toxic experiments, not allowed to be performed in normal lecture halls (c), experiments difficult to perform (d), experiments too expensive or which require large dimensioned lecture halls (e). Videos are also extremely useful to visualize very slowly developing reactions by means of time-lapse recording (f), or microscopic experiments (g). Additionally simultaneous projections of live experiments permit perception at larger distances (h).

Much more than simply documentation of lectures, special events, or live and simulated experiments, videos can be used in manuals and tutorials for computer programs or chemical instruments. Video techniques allow simultaneous peer-to-peer collaborations, call-the-tutor facilities for distance-learning purposes, or even simultaneous lectures among several universities. Finally, streaming video techniques permit web broadcasting, which is essential for web-based chemistry courses.

Vector-based Schematic Graphics, Tutorials or Manuals, Animations, Quizzes, and Games to Support Teaching, Learning, and Research

Vector-based graphics and animations in popular formats like Flash [6], are the first choice for schematic representations with high graphical abstraction as shown in Fig. 3. Students can, for example, learn the principles of electrochemistry in an animated and attractive form. Scripting languages (*e.g.* ActionScript for Flash) allow interactivity and the production of learning games. Vector-based files are ideal for blended learning purposes because of their small size and their on-screen scalability. The same teaching module can be used for web-based tutorials and for live lectures, as stand-alone application, or embedded into html pages or PowerPoint presentations.

3D Elements, Animations, and Simulations for Teaching, Learning, and Research

A complete understanding of complex chemical structures or crystal lattices requires sophisticated abilities in spatial perception. Whereas for simple structures like enantiomeric forms of simple molecules, excellent results are achieved with real ball and stick models, more complex object can only be tackled with the aid of 3D computer representations, which can allow high interactivity.

In the CCN project a variety of tools and techniques are used to fit any particular case. A chemical representation is much more than a static displacement of atoms. Structural (geometric) elements such as polyhedra and 3D surfaces are important elements that can be visualized with VRML (Virtual Reality Modeling Language), Quick Time VR [7] and Flash animations. For relatively small structures, PDB [8] and VRML models are provided. The PDB or VRML format can be easily visualized on any web browser after installing the Chime

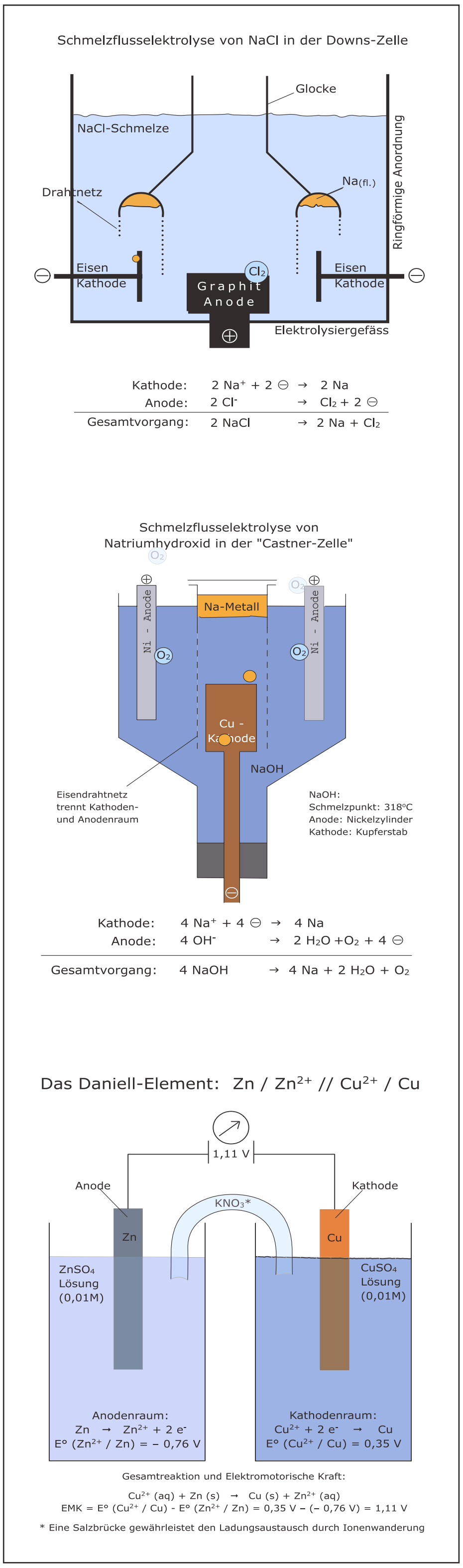

Fig. 3. Three examples of vector-based schematic animations (Flash) for teaching electrochemistry. Due to their small file size and their on-screen scalability, vector-based animations are very useful for web-based learning environments as well as for huge projections in large lecture halls.

plug-in [9] or a VRML viewer. The QuickTime VR format is the first choice to explore spatial complex objects with many polygons. Alternatively videos of the rotat-

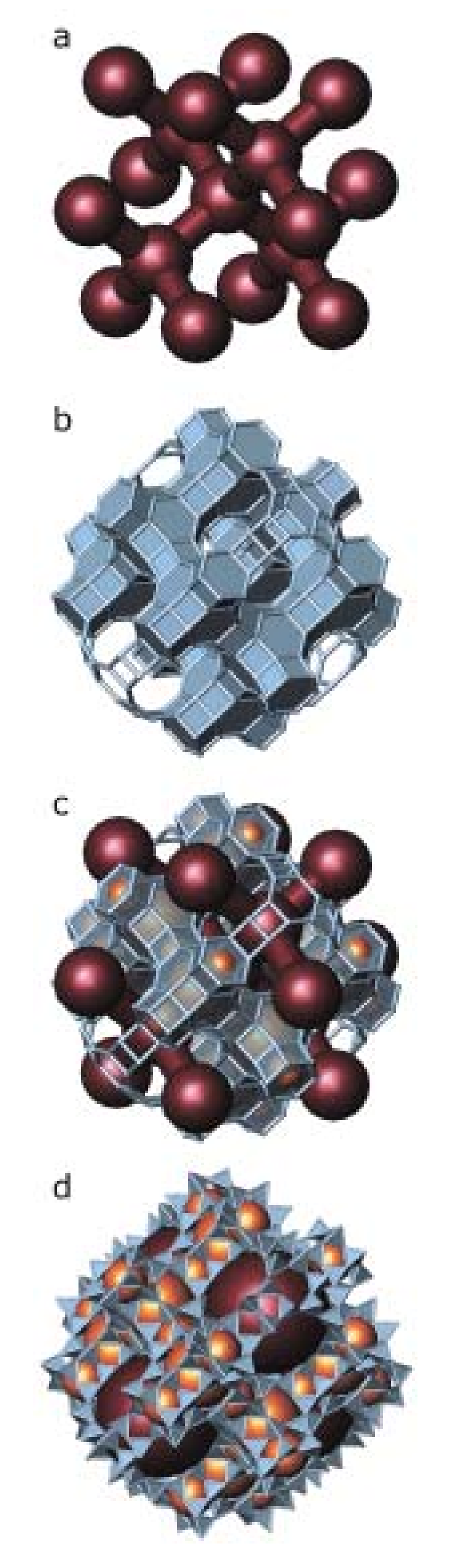

Fig. 4. Different aspects of the crystal structure of faujasite which visualize its relationship to the diamond structure: 4a) one unit cell of the diamond structure; 4b) the framework of the zeolite faujasite; 4c) the topological relationship of the faujasite channel system and the diamond structure; 4d) the different cavities of faujasite.

ing object or, for low bandwidth and slow computers, a single picture mode could also be used.

Fig. 4a–d show different aspects of the crystal structure of faujasite [10] and its relationship to the diamond structure. The interactive 3D teaching elements (VRML for the small structures, for the larger ones QuickTime VR) allow an intense analysis of crystal structures, in terms of their topology and symmetry. In the single picture mode, all pictures are designed in the same perspective. This allows for the production of slide shows, and to visually link different aspects of the crystal structures.

Conclusions

Learning and teaching can be greatly improved by the help of integrated web lessons, videos, and schematic animations. Especially it was shown that the new media provide novel possibilities to exploit, to explain, and to perceive complicated time-based processes or spatial complex structures more efficiently than before. The projects CCI and CCN at ETH Zürich comprise systems for the integration of traditional and novel educational and research tools, to establish dynamic links between teaching, research, and applications, towards a more comprehensive information management.

Received: January 16, 2003

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[2] 'CCI – Creative Chemistry on the Internet', *www.cci.ethz.ch*, R. Nesper, W. Uhlig, C. Mensing, B. Rüttimann, Laboratory of Inorganic Chemistry, ETH Zürich.
[3] 25 experiments of CCI are designated for the NET project of the University of Fribourg.
[4] The CCI package is available from Vismedia GmbH, CH-8802 Kilchberg, E-mail: vismedia@inorg.chem.ethz.ch
[5] 'ETH-World', *www.ethworld.ch*, ETH Zürich.
[6] Flash, from Macromedia Inc., *www.macromedia.com/software/flash/*
[7] QuickTime VR, from Apple Computer Inc., *www.apple.com*
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