Distributed mixed real and virtual Learning Environments for Mechatronics and Tele-service (DERIVE)
- Learning from Technology Enhanced Learning -

Wilhelm Bruns
artecLab Laboratory for Art, Work, Technology
University of Bremen, Germany
bruns@artec.uni-bremen.de

(1. 4. 2004 Submitted for M. Kelleher, A. Haldane, E. Kruizinga (Eds.): The Future of Technology Enhanced Learning)

Abstract: Some results of a recent European Project for specification, design and evaluation of Distributed Real and Virtual Learning Environments for Mechatronics and Tele-service (DERIVE) will be presented. The project aimed at the development and evaluation of a new kind of multi-perspective human-machine system. It was motivated from industrial practice and vocational education in the emerging professions of Mechatronics and Tele-Service. In these domains a combination of real and virtual, local and remote media to support concrete and abstract views has been found to be desirable for learning processes and for system maintenance. A concept has been developed to support a free choice of perspectives and tools. Although at first aiming at a learning environment, the environment may also be used for systems design, gradual implementation and maintenance, where on-site and remote components of a technical system, their real and virtual representations, functional, symbolic and illustrative models merge into one cooperative learning and design process.

Keywords: Multi-modal interactions, action oriented learning, embedded automation, shared environments, advanced human-machine cooperation, computer-supported collaborative work and learning

1. Introduction

Often, there is a strict separation between theoretical design of a technical system, it's test by simulation and final practical implementation. This sequence of theory and practice has some roots in vocational and engineering education, where we often find a separation of places for practice (laboratories and work-situations) and theory (lectures and seminars). For the emerging field of mechatronics (a unifying and integrating discipline of electrics, electronics, mechanics and information technology), there is an increasing demand from industry and education to foster multi-perspectives not only as sequence of learning and working, but as integrated features of methods, tools and materials. For learning scenarios, it is desirable to easily shift between various perspectives on the fly, to study certain partial phenomena in reality or virtuality but still conserve the overall context. Based on the experiences of a heterogeneous consortium and a broad user participation, a framework for multi-perspective learning has been developed and served as a guide for the development of a learning environment, content modules and course structures. This environment allows to work together with complex real and virtual mechatronic systems, consisting of parts which may be distributed over different places. The environment includes a supportive database with multimedia sequences providing theoretical background information, exercises and help to handle training tasks. Mechatronic hardware equipment can be connected to the virtual environment with a special-sensor-actor coupling, HyperBonds (Bruns, 2003). Real electro-pneumatic circuits can be directly projected and continued into the virtual world and vice versa. The DERIVE learning environment smoothly integrates equipment and can support hardware in-the-loop functionality. The project has been well balanced between industry (Festo Didactic GmbH & Co.), vocational schools (Stockport College Further and Higher Education, Great Britain, Escola Superior de Tecnologia e Gestão, Portugal, Schulzentrum des Sekundarbereiches II Im Holter Feld, Germany) and academic institutes (Eidgenössische Technische Hochschule Zürich – IFAP, Switzerland, Universität Bremen, Forschungszentrum *artec*, Germany).

The learning environment has been evaluated in various European school applications, supporting different technological equipments, pedagogical practice and individual learning styles.

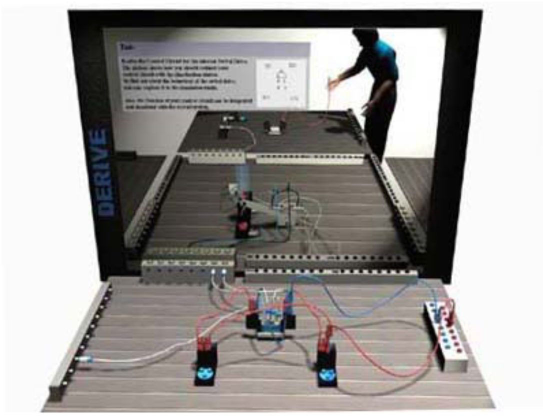


Figure 1: Learning environment of the DERIVE project

Effects of teaching and learning through the new technology were analysed in different settings, including classroom only and various types of mixed classroom-workplace learning scenarios.

Main results of the project are:

- A new type of *Mixed Reality* learning environment for mechatronics and tele-service which allows a flexible learner-centered transition between real and virtual aspects of a complex technical system in a local and remote, single- and multi-user way. It supports bridges between the real and virtual world with integrated simulations. A key feature of the system is it's possibility to freely replace virtual parts by real ones and vice versa. With a special kind of electronic-electro-pneumatic coupling between the computer and a mechatronic hardware kit, it is possible to build hybrid-hyper-systems which can be considered as a mixture of real and virtual parts. The system may be distributed, having a set of real parts at one place and the virtual counterparts at remote places. This coupling will be realised by Internet links.
- A concept of teaching and learning mechatronics in an action oriented way.
  The pedagogical and training concept is focused on providing courses in automation technology together with experiences of the complexity of real production systems allowing students to use resources which are normally only available at specialised sites. The tele-cooperation functionality in the learning environment allows companies to use the training facilities of vocational schools and/or other providers for training their own employees. The new environment permits different groups of staff at remote locations to take part in training courses. Trainees will be able to work in a collaborative way to solve problems and to explore learning situations. This new kind of interaction will allow the systematic support of skilled workers and engineers by educators in vocational schools.

- An evaluation methodology and evaluation results to compare of different technology enhanced teaching/learning processes and learning output.
- Hyperbonds - a new concept to freely merge real and virtual components of a complex system.
- Foundation of a spin-off company to market and promote the results of the project (Bendit GmbH)

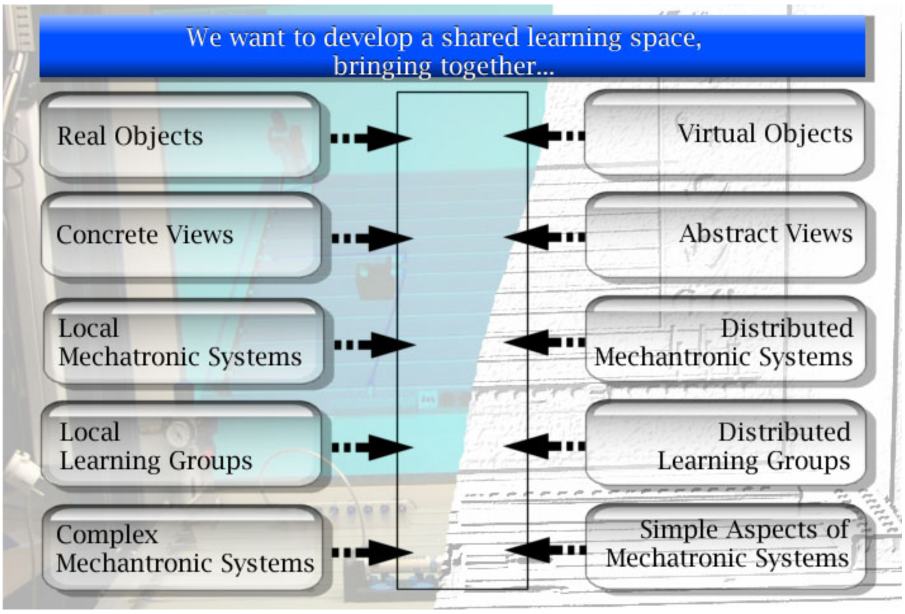


Fig. 2: Shared Space of Multi-perspectives and Multi-modalities (Ernst et al, 2003)

2. Background and Theoretical Framework

Mechatronic systems play a key role in modern automation technology. It is obvious, that a dissemination of mechatronic systems simultaneously requires adequate service techniques. Mechatronic components can be easily integrated into telematic environments and corresponding work-concepts for tele-service such as remote diagnosis and maintenance. Mechatronics is therefore an enabling technology for tele-service. The emergence of remote diagnostic systems is very appealing to companies as it permits a more efficient maintenance and service of equipment. Problems can be diagnosed off site, and the appropriately qualified staff and equipment can be dispatched to solve problems.

Increasing dissemination of mechatronic systems in combination with tele-service implies new demands on skilled workers in this field. Work in mechatronics requires knowledge of structure, behaviour and function of mechatronic systems. Also cognitive and operational knowledge about the construction of systems, diagnosis and maintenance is needed. A significant innovation is, however, the fact that working processes now are essentially characterised by the use of tele-medial systems. In the professional field, users need the ability to achieve their aims in (tele) cooperation with others, and they should be able to cooperate in virtual and supranational forms of organisation. Both, the professional and the social-communicative part of the working tasks are concerned. Schools are required to expose students to the types of equipment and situations they may experience at the workplace. With the increasing complexity of production systems it is unrealistic for schools to be able to simulate adequately the full range of systems operated in the industrial sector. Therefore, a cooperation between schools and industrial partners is required.

It is evident that many industries are pan-European or international. This situation requires the staff to meet at central locations to take part in common courses. This is very costly and the key staff is off the company for several days. On the one hand there is a move in many countries towards an emphasis on multi-skilling and a European harmonisation of training courses. On the other hand, there are no elaborated concepts concerning pedagogical, technical and organisational aspects, particularly in the emerging field of mechatronics. Cultural differences and similarities concerning learning and collaboration styles can be noticed but have not been integrated into curricula, courseware and teaching methods.

Theoretical roots of DERIVE were strongly influenced by the tradition of Shaping Technology by a Human-Centered Design Method. This method, being in the tradition of Scandinavian action-research (J. Laessoe, 1993, Boedker, 1977) is interested in the question "How do we enable people to design or change their own System?" instead of asking "How do we design systems to fit people?". L. B. Rasmussen and J. Laessoe propose four main principles of this approach:

1. Action research: Research and action, knowledge and utility are interwoven, not kept apart
2. User cooperation: Alternation between theory and practice is established as a dialogue between researchers and users.
3. Tool perspective: Users work methods and their tools "constitute a sensuously experienced knowledge, historically developed through practice, which we neither can nor should try to objectivize. Instead, we are to support the development of their work methods and use of tools by taking our point of departure in the tradition,…" (J. Laessoe, p.68)
4. Work culture: The design process is seen as an integrated part of the work culture.

This principle, applied to the design of learning environments, has to take into account various types of users (teacher, learner, administrator, expert advisor ..) and the situation, shifting between learning and production. The project did not aim at a certain best practice or theory of learning, but asked for a close integration of teachers and students into the design process. Learning places, teachers and students were chosen to be very different, from a cultural, a technological, an educational level and a teachers experience point of view. Experimental prototyping and visionary talks have proved to be a key element of the approach, as they have in the Scandinavian projects. Evaluators did on one hand try to take an objective point of view, whereas the designers followed an approach to get insight and a feeling for the learning process based on individual experiences. The outcome of the project is a learning environment, which takes into account different traditions of learning, different cultures of teaching and different relations to the work-place.

3. System Description

The system is best described by a simple design session for a pneumatic circuit. (A safety circuit to activate a cylinder if two push-buttons are pressed simultaneously - typical AND function, will be provided in the final paper). More details can be found in the final project report (Ernst et al 2003).

A virtual construction kit allows the collaborative multi-user construction of a 3D system via Microsoft-Internet-Browser with VRML-plugin using functionally modelled electro-pneumatic components, fig. 3. Components can be connected via pressure tubes at sensitive connectors and activated by mouse pushbutton. The circuit then shows its simulated behaviour generated from VRML-Java models. Fig. 4 demonstrates the use of a switch providing alternative single acting cylinders with air-pressure. The simulation functionality may also be provided by external state of the art simulators if they provide an adequate interface, fig. 5.

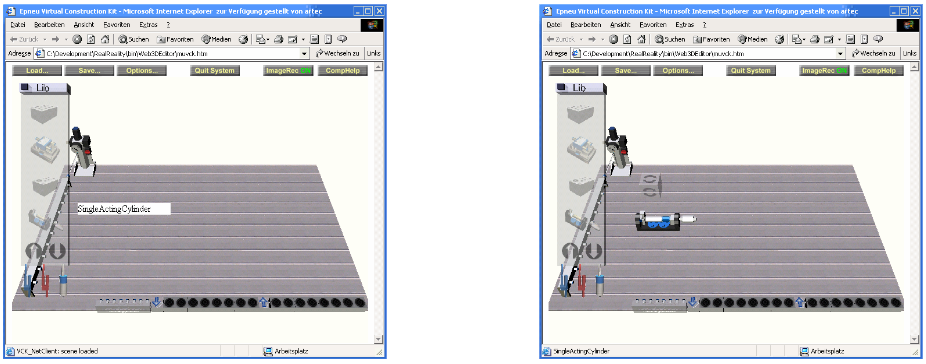


Figure 3: Creating a circuit
(Select a component from a virtual component-box , Drag and Drop it on the Modelling Desk)

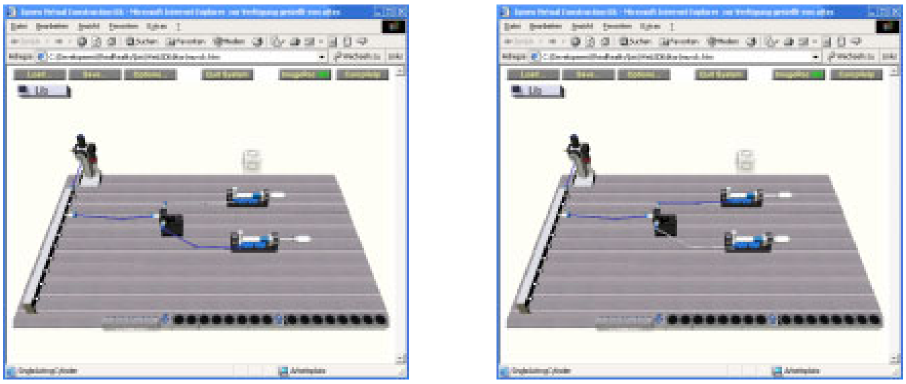
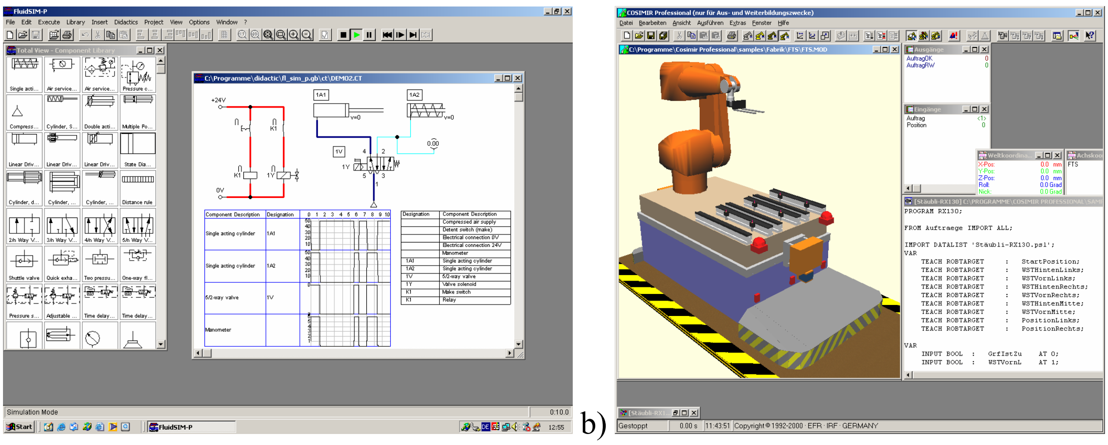


Figure 4: Test Behaviour by internal Simulation



a) b)

Figure 5: Use external professional simulators a) FluidSIM b) Cosimir

A special virtual component, seen at the lower corner of the screen in fig. 6, represents a connection to a bi-directional pressure sensor and generator mechanism below a real modelling table, which is connected to a corresponding real connector-ledge on the table, allowing some correlations between the graspable ledge-connectors and the virtual ones. Connecting a virtual component with a virtual connector via virtual pneumatic tube, provides a connection between the real connector and the virtual component. Thus, any pneumatic system can be distributed through virtuality and reality and also via Internet through different locations. Of course, the current Internet does not ensure short real-time reaction-times, but in principle this can be demonstrated. This new concept of connections, *hyper-bonds* (Bruns, 2003), is related to the theory of bond-graphs (Paynter, 1961), which offers a unified view on power-flow driven systems.

a) *b)*

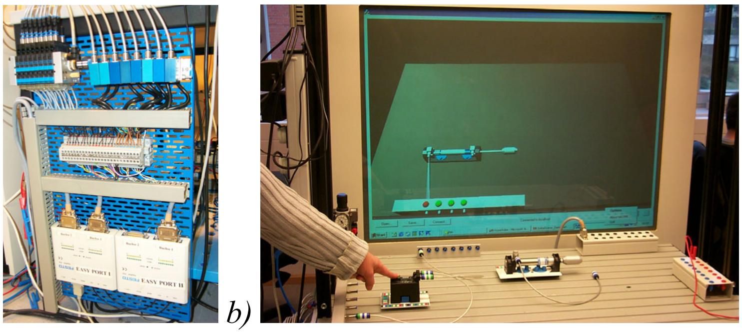


Figure 6: a) Hyper-bond Hardware b) Hyper-bond in action

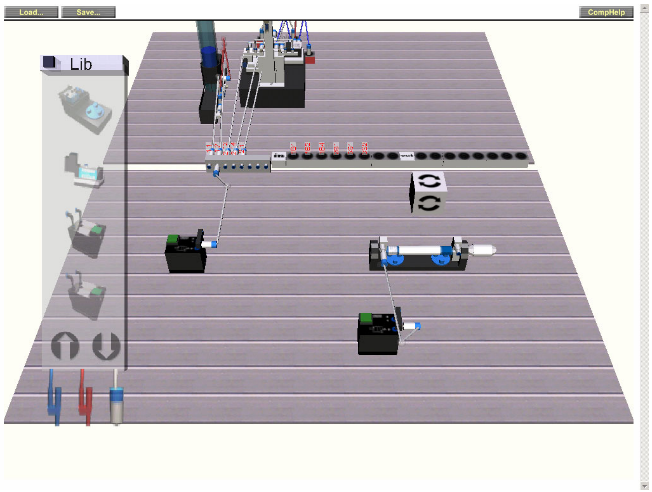


Figure 7: Hyperbonds between two tables

Another configuration may consist of more than one hyper-bond, fig 7. Further examples are shown in fig. 8 and 9 with a pneumatic and an electrical hyper-bond.
Additionally, for further tele-cooperative scenarios, a new demonstrator/prototype was created, providing a coupling of a virtual model with a remote real circuit, including video observation of the remote real situation.

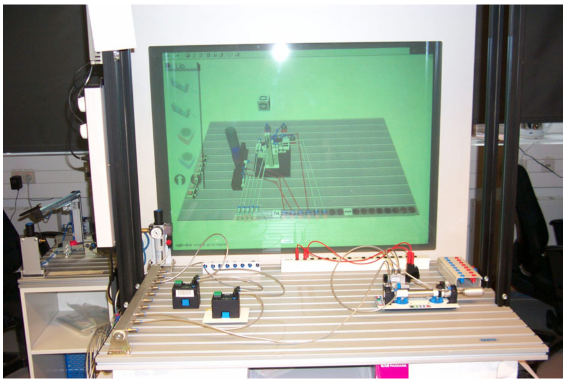


Fig. 8: Simple real connected to complex virtual (with electrical hyperbond)

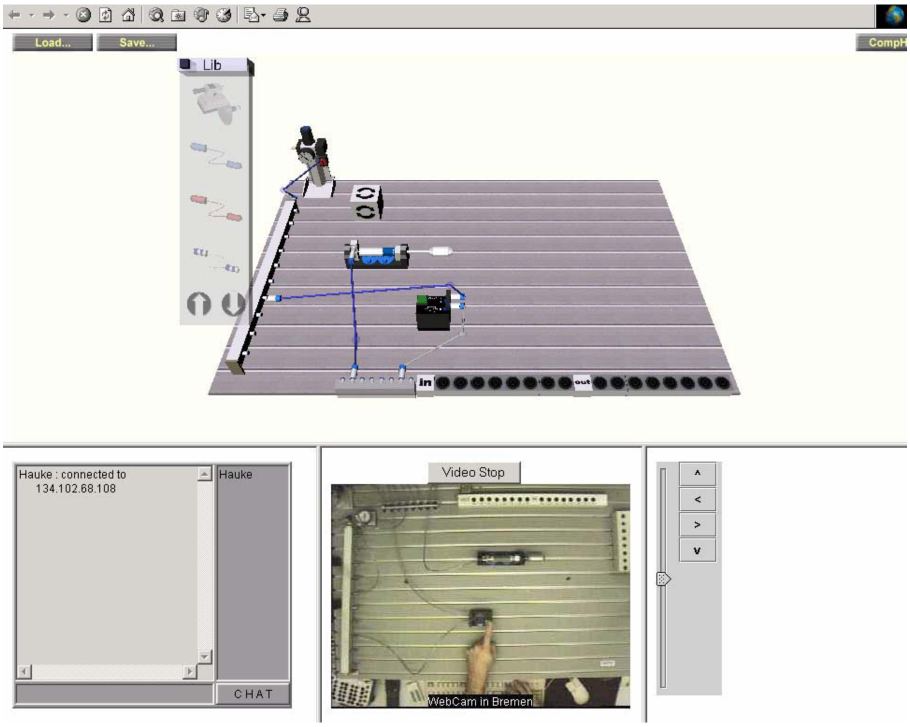


Fig. 9: Simple virtual connected to complex virtual

Examples are only basic starting positions to demonstrate the functionality of the concept. More complex electro-pneumatic scenarios are of course possible and more relevant for systems design. Imagine a tele-service situation, where a remote service expert successively connects parts of the real system to his simulated double or extension to find malfunctions.

4. Evaluation

The evaluation has been carried out by IfAP-ETH-Zuerich (Grund, 2003). Several trials were carried out in three phases as shown in fig. 10.

phase	***Title***	***duration***
1	DERIVE Usability Testing	2 hrs
2	Collaboration and Communication Analysis	3 x 2 hrs
3	Advanced Mechatronic Systems (learning output)	20 hrs

Fig. 10: Different trials

The three phases were dedicated to three different aspects of the project:

1. Usability Testing of the first prototype
2. Analysing computer supported cooperative teaching, learning and fault diagnosis
3. Analysing the learning benefit of the new mixed reality concept compared to traditional, virtual and complex real training settings

Some of the conclusions drawn from both task analysis and online questionnaires are:

Usability
A total of 29 persons consisting of employees as well as students and teachers participated in the usability trial. Interesting ideas for improvements of the system were gained.

Communication and cooperation results
"Some of the tools were obviously used selectively: the scenario influences the choice of the learning environment. Symbolic and actual visual depiction were used for tele-teaching and tele-cooperation tasks, the real circuit for remote diagnosis. Media were utilised less selectively. Audio connection clearly was the medium most frequently required. Only in the tele-teaching scenario other media were utilised: chat, pointer and especially whiteboard were hardly used in any scenario (the whiteboard solely in the tele-teaching scenario!)." D53-Grund

Learning Benefit
Learning benefits were investigated at four different locations applying 4 different teaching methods on 84 students in a full 20 hours standardised lesson plan on electro-pneumatics: traditional teaching with conventional media, teaching with only the simulation functionality (DERIVE light), teaching with a complex real modular production system (MPS) and teaching with DERIVE. In a post-test at the end of the course, students had to complete an electro-pneumatics knowledge test, a paper based construction task, a practical fault finding task in a real MPS and a fault finding task in a symbol-based circuit diagram.
In general a strong personal factor, namely technical understanding and previous knowledge, could be identified influencing the learning output. These results had been found already in previous studies (Grund & Grote, 2001). Some remarkable new results were (Grund & Grote, 2004):

- A significant difference in *Factual Knowledge* could be observed: students with tactile/haptic experience combined with a more realistic training situation gained more factual knowledge than the others.
- No significant differences in *Procedural Knowledge* could be found.
- Significant differences could be found in *Real Hands on practical Fault Finding*, but a clear identification of the reasons was not possible and still has to be investigated in further studies.
- Significant group differences could be found in *Symbol based Fault Finding*: students with a real modular production system (MPS) and DERIVE performed better than the simulation and the conventional media groups.

5. Conclusion

Mechatronic technicians need to develop practical skills and underpinning knowledge in their subject area. They will need to be able to develop logical thought processes for problem solving and most importantly be able to continually update their own knowledge.
The use of symbiotic real and virtual worlds seems to improve the building of mental models for practical problems and allows a broad variety of learning and teaching styles and

motivations. The key element of the DERIVE learning environment is its flexibility. Methods employed by the teachers using the environment can range from free action orientated exploration to tightly controlled planned activities. Use of a central complex model supports a holistic approach and situates learning into a real world context. Completeness of action and relevance for a practical application both are known to increase motivation.

A close coupling of the technological development and the evaluation process has been very fruitful for the development process, because the pressure of scheduled trials forced the team to a strong discipline of production and reflection. However, it also was a burden for the evaluation with respect to learning improvements.

Beside results originally aimed at, we gained several insights and experiences, which for some of us are of even importance compared to the concrete graspable results:

- the undiscovered potentiality and richness of interdisciplinary and multicultural background of the project partners and difficulties to turn them into a productive team. Therefore the value of prototype mock-up games to form understanding and language, the importance of self-experience and reflections in action and observation. Examples: tele-service scenario, design scenario, installation scenario, course scenario.
- the importance to concentrate on the pedagogy of a focused domain
- the diversity of interests, especially of industrial, market oriented partners
- the importance of freedom from the mainstream of "Useable Systems"
- the richness of possible by-products emerging from the main roadmap
- the illusion of a balanced participation process of pedagogues, engineers, psychologists
- the high value of evaluation for the development process, beside its value for scientific results related to learning benefits
- the emergence of visions
    - recognising the importance of simulation extensions for the learning process resulted in a new concept for mixed reality systems design, a new type of human-computer interface and interactions: hyper-bonds
- the lack of knowledge about how pre-conceptions, concepts, knowledge systems and action competence are formed from experience. The need for more basic research related to concrete questions in specific domains: How do we form understanding of a pneumatic circuit, how is it related to an electrical circuit, how can it be abstracted to a mechatronic circuit, how do we solve problems in these domains?
- fruitfulness of a theatre metaphor for systems design
- fruitfulness of academic lectures accompanied by project work of students
- further participation in running EU-projects (Lab@Future, Adman, Marvel)
- publications, which mostly started after the end of the project about the graspable results and therefore rely on the academic partners.

Acknowledgments

Many thanks to my colleagues and partners Gudela Grote, Sven Grund, Ulrich Karras, Ian Headfield, Paulo Gata Amaral, Hermann Gathmann, Hauke Ernst, Kai Schmudlach, Jürgen Huyer, Bernd Robben and to the students using our incomplete not yet very stable system.

References

Boedker, S. et al (1977): A UTOPIAN Experience: Design of Powerful Computerbased Tools for Skilled Graphic Workers, In: Bjerkens; Ehn; Kyng (ED.): Computers and Democracy

Bruns, F. W. (1999): Complex Construction Kits for Coupled Real and Virtual Engineering Workspaces, in: Streitz, N. A., Siegel, J., Hartkopf, V., Konomi, S. (Hrsg): Cooperative Buildings – Integrating Information, Organizations and Architecture. Second Int. Wrokshop, CoBuild'99. Lecture Notes of Computer Science 1670, Heidelberg: Springer, S. 55-68

Bruns, F. W. (2000): Complex Objects and anthropocentric Systems Design, in: Camarinha-Matos, L. M.; Afsarmanesh, H.; Erbe, H.-H. (Ed.): Advances in networked Enterprises: Virtual Organizations, Balanced Automation and Systems Integration: Kluwer Academic Publishers, pp. 249-258

Bruns, F. W. (2001): Hyper-Bonds – Enabling Mixed Reality, *artec*-paper Nr. 82 ftp://loki.artec.uni-bremen.de/pub/Field1/Publications/artec-01-Bruns-hyperbonds.pdf

Bruns, F. W. (2003): Hyper-Bonds – Human Skills oriented Systems Design with Mixed Reality, 8th IFAC Symposium on Automation Systems based on Human Skill and Knowledge, Gothenborg

Ernst, H., Bruns, F. W., Grund, S., Gathmann, H., Karras, U., Hadfield, I., Amaral, P. G., Schmudlach, K., Huyer, J. Pundt, R., Faust, M. (2003): DERIVE - Final Report of EU-Project IST-1999-10417, Bremen

Grund, S., Grote, G. (2001). Integrating Real and Virtual Training Tools via a Graspable Interface in Vocational Training: The Evaluation of a New Training Tool, In: M. J. Smith & G. Salvendy (Ed.): System, Social and Internationalization Design Aspects of Human Computer Interaction, Lawrence Erlbaum Association, London, 2001, 819-823

Grund, S. (2003): Lernen mit neuen Technologien – Die Rolle der Gegenständlichkeit und Multicodierung von Information für die Entwicklung von Fachwissen, praktischer Kompetenz, mentalen Modellen und Problemlösestrategien. Dissertation, ETH-Zürich

Grund, S. & Grothe, G. (2004): Specific Learning Effects of a Mixed Reality System in Automation Technology Training. In publication

Ishii, H, Ullmer, B. (1997). Tangible Bits: Toward Seamless Interfaces between People, Bits and Atoms. *CHI, 1997*, ACM, Atlanta, Georgia

Laessoe, J. (1993): User-participation in the Shaping of New Technology. Cooperation between Researchers and Users in a Danish Project. In: W. Müller, E. Senghaas-Knobloch (Ed.): Arbeitsgerechte Softwaregestaltung.

Müller, D. (2001): Simulation und Erfahrung – Konzeption und Gestaltung rechnergestützter Simulatoren für die technische Bildung. Dissertation, Universität Bremen

Müller, D., Martins Ferreira, J. M. (2003): MARVEL: A Mixed Reality Learning Environment for Vocational Training in Mechatronics, Proc. Int. Conf. T.E.L'03, Milano

Paynter, H. M. (1961). Analysis and Design of Engineering Systems, MIT Press, Cambridge, MA

http://www.derive.uni-bremen.de