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Distributed Real and Virtual Learning Environment for Mechatronics and Tele-service

Abschlussbericht zum EU-Forschungsprojekt DERIVE

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D E R I V E

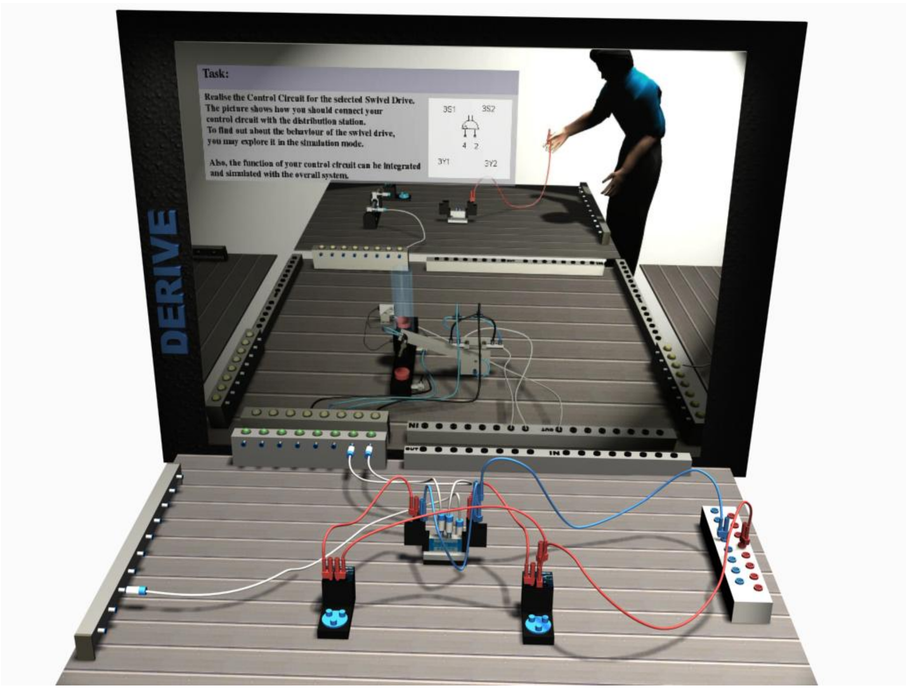
European IST
Research and
Development Project

Distributed
Real and Virtual
Learning Environment
for Mechatronics and Tele-service

information
society
technologies

IST-1999-10417

- Final Report -



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Content

OVERVIEW

Executive Summary

Project DERIVE (Distributed Real and Virtual Learning Environment for Mechatronics and Tele-service) aimed at the development and evaluation of a new kind of multi-perspective learning environment. 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 of high value. Therefore, a pedagogical concept has been developed where a self-determined choice of perspective (technical, social, subjective), action orientation and learn-work tasks are central. The pedagogical concept is supported by a learning environment, where on-site and remote components of a technical system, their real and virtual representations, functional, symbolic and illustrative models and help functions merge into a cooperative learning process.

This installation allows to work together with complex real and virtual mechatronic systems, consisting of parts which may be distributed over different places. The learning environment includes a supportive database with multimedia learning 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). Real electro-pneumatic circuits can be directly imported into the virtual world. The Derive learning environment smoothly integrates equipment and supports full hardware in-the-loop functionality. The Consortium 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).

This made it possible to elucidate multicultural dimensions of complex systems and Tele-Service work. The learning environment has been evaluated in practical school applications in different cultural and qualification contexts. Perspectives of technological developments, pedagogical practice and individual learning styles have guided these investigations at several European schools.

Figure 1: The envisioned 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.

As a further result of the project, a new company was founded to market and promote together with partners of the consortium four main results of the project:

1. 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 multiuser way (CLEAR). It supports bridges between the real and virtual world with integrated simulations. A key feature of the system is the function of freely replacing 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 will be 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.

2. 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.

3. An evaluation methodology and evaluation results to compare of different technology enhanced teaching/learning processes and learning output.

4. Hyperbonds - a new concept to freely merge real and virtual components of a complex system.

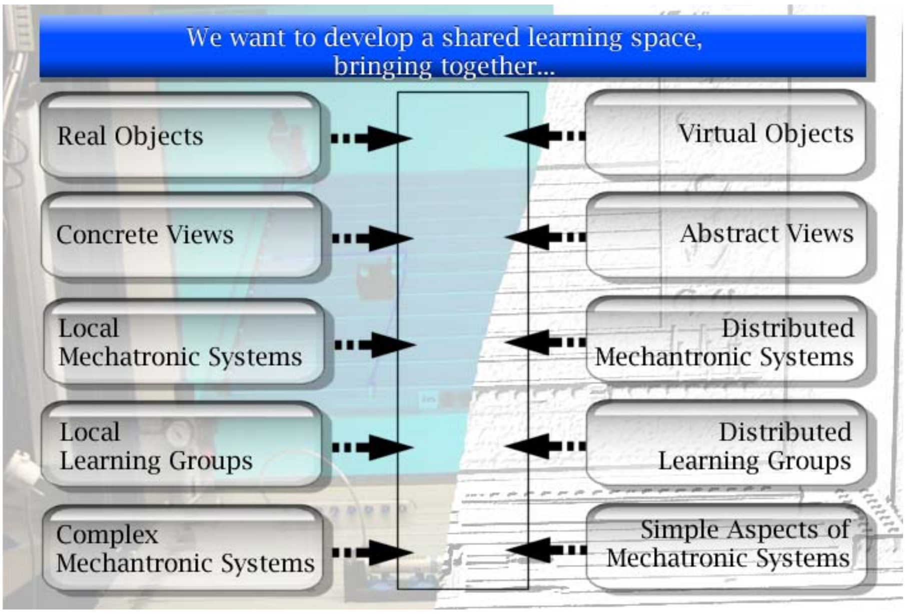

Figure 2: Shared Space

The whole system, parts of it, services and consultings for e-learning will be offered by the industrial partner as well as the newly founded spin-off company.

Background

Mechatronic systems play a key role in modern automation technology. It is obvious, that the 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.

Figure2: Role of Mechatronics

The increasing dissemination of mechatronic systems in combination with tele-service implies new demands on the skilled worker in this field. Work in mechatronics requires knowledge of structure, behaviour and function of mechatronic systems. Also cognitive and operational knowledge about building systems, diagnosis and maintenance is needed. A significant innovation is, however, the fact that working processes now are essentially characterised by the use of telemedial 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.

The market for innovative training systems for mechatronics was initialised and extended. Numerous companies provide training materials for mechatronics. The project partner Festo Didactic is a worldwide trendsetter and market leader for training equipment in automation technology. Festo offers a broad spectrum of products related to the training for mechatronics with a worldwide market share of about 25 %.

THEORETICAL FRAMEWORK

The theoretical roots of DERIVE are strongly influenced by the tradition of Shaping Technology by a Human-Centered Design Method instead of a socio-technological approach. This method, being in the tradition of Scandinavian action-research (J. Laesoe, 1993, Bedker, 1977) follows a shift compared to socio-technological approaches in that it 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. Laesoe 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. Laesoe, p.68)
4. Work culture: The design process is seen as an integrated part of the work culture.

If we try to apply this principle to the design of a learning environment, we have to take into account at least two types of users, the teacher and the learner, and the work situation is more a learning situation than a work situation. But it is interesting that we can transfer this approach also to school environments. Our 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 our approach, as they have in the Scandinavian projects. Evaluation does on the one hand try to take a point of view of objectivity, but at the same time the designers always followed an approach where they tried to get insight and a feeling for the learning process based on individual experiences. The outcome of our project will be a learning environment, which takes into account different traditions of learning, different cultures of teaching and different connections to work. This spectrum covers pedagogical orientation from the German action orientation (H. Meyer, 1987), the Scandinavian and Russian activity theory (Engström) to American constructivist or even cognitivistic approaches.

We used formal development steps, but it would be misleading if we presented them as a waterfall model or cycle model of sequential steps. The interaction between these steps too much resembles a network of influences, even if the final documents have such a sequence. This is also the reason for the difficulties our project had with the expected sequence of deliverables even if we were good in time regarding the development process. The highly iterative incremental process of development is a key element of our work.

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.

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

Engström, Y. (1999): Learning by Expanding: Ten Years After. Published as Lernen durch Expansion (Marburg: BdWi-Verlag; translated by Falk Seeger)

Meyer, H. (1987): Unterrichtsmethoden I: Theorieband. Frankfurt a. M.

PEDAGOGICAL CONSIDERATIONS

Looking Back

The analysis of future engineering workers has shown a significant change in the last 5 to 10 years. Traditionally, engineers and technicians were classified into electrical engineering or mechanical engineering. These two distinct branches would work side by side but neither would encroach on the others area of expertise. However, economic and technological changes particularly in the manufacturing industry were facing a new requirement from companies. With most manufacturing taking place in automated production lines, there is a need for technicians with a broad range of skills. Although the skills are not generally required to the same depth, the need for technicians who are able to perform mechanical and electrical operations is a clear requirement. The automation process also means that many manufacturing installations are now computer (PLC) controlled and thus a knowledge of information technology is also a requirement.

In response to these requirements from industry, governments and educational awarding bodies have developed new curricula and qualifications aimed at training technicians and engineers to meet these needs. In Germany the new profession of the "mechatronic worker" has been introduced and in the U.K. vocational qualifications in Mechatronics have been developed. Also there has been a shift towards defining core aspects of vocation curricula to include elements of both electrical and mechanical engineering.

Relevant Learning Domains

Writers tend to separate learning into three domains[1]. These are psychomotor, cognitive and affective. The first one is skills orientated and is associated with physical dexterity, in general the knowledge requirement is limited but there is a need for practice. In the cognitive domain knowledge is important. In particular the 'how' and 'why' and consequently more abstract thought processes are required. The third domain is often neglected - it is the affective domain. Here we are concerned with attitudes and beliefs. Generally, this domain deals with feelings and emotions and thus differs from the other two domains.

If we consider the domains described above in the context of DERIVE, we will have to consider the needs of the learners and the curricula requirements of technicians and engineers of the future.

These new qualifications demand from technicians to have both practical skills and theoretical knowledge - thus clearly hitting two of the domains described above. However, there are aspects of the third domain required in the training of these new technicians. The main area being in the cultural issues of manufacturing industry where there are still concerns about the value of multi-skilled technicians and engineers. The need to embrace and harness the value of new technology particularly in the areas of remote diagnostics and tele-service has also an impact on the training of new technicians.

Adult Education

It has been argued by Knowles[2] that adults prefer to learn in different ways to that of children. He identified 6 assumptions[3] made about adult learning.

1. the need to know. Adults need to know why they need to learn something before starting to learn it.

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[1] Discussion from Chapter 2 I.Reece & S.Walker "Teaching Training and Learning a practical guide" BEP.

[2] Knowles M. "Andragogy: an emerging technology for Adult Learning (1970)

[3] Knowles M. "The Adult Learner: A Neglected Spieces" 1984

2. self-concept. The self-concept moves from teacher dependence to self-direction in the learning process. Adults have a self –concept of being responsible for their own lives. Once they have arrived at this self concept a need is developed to be seen by others and treated by others as being capable of self-direction.
3. experience. Adults have a reservoir of experience upon which to draw for their learning/
4. readiness to learn. Adults are motivated to learn those things they need to know and be able to do in order to cope with real life situations.
5. orientation to learning. Adults are motivated to learn when it will help them to perform tasks or deal with problems that the meet at work.
6. motivation. While adults are responsive to some external motivators the best motivators are internal pressures.

Conclusions

If we consider the theories and concepts set out in the above discussion and how they relate to DERIVE and the training of new mechatronic technicians, we come to some conclusions. Mechatronic technicians need to develop practical skills and have 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 andragogy discussion implies that adults would be motivated to learn new concepts and skills in relation to their work if it makes their work easier and they can see the reasons behind learning new skills and ideas.

In the work of BREVIE we discovered that the building of mental models can be improved by the use of symbiotic real and virtual worlds. In DERIVE this work is expanded by setting the real world situation into the context of a whole working machine.

From a practical point of view the concept of learning is complex and influenced by many different factors. No two individuals are alike and the skill of a teacher is in presenting learning situations that support each individual's style of learning. Motivation to learn is a critical factor and should not be underestimated in its affect on the learning outcome students.

The key element to the DERIVE learning environment is its flexibility. The methods employed by the teachers using the environment can range from free action orientated exploration, to tightly controlled planned activities.

The use of a central complex model develops a holistic approach and places the learning into the context of the real world. This develops relevance for the learning and gives it a practical application both of which are known to increase motivation.

The symbiotic link between the real and virtual world, helps to build on the cognitive theories that learners need to link their new experiences with existing perceptions. The use of symbolic and real world representations is known, from BREVIE, to aid in the development of mental models, thus in theory leading to deeper understanding.

In a practical teaching workshop (see *0 Getting Involved*) it became clear that learners, given the freedom, prefer to select their own learning style. With sufficient motivation and goal orientated approach it is clear that all methods lead to the same conclusion. In DERIVE the learning environment provides practical, theoretical and hypothetical approaches to learning. Development of communication tools within the environment can only help to encourage the sharing of information between protagonists of these different learning styles.

METHODOLOGY

Dual Approach

The profession of Mechatronics is a new and far-reaching occupation, therefore any user-requirements and acquisition for appropriate learning environments remain somehow speculative. To broaden the input for the DERIVE system, we use two different methods of user-participation:

- one by explicit questionnaires and interviews of representatives of stakeholder-Classes,
- the other as hermeneutic action oriented acquisition or "by getting involved" (known in the Scandinavian Work-Technology Science-Community as "Action Research").

The aim is to get an implicit and explicit knowledge and insight into the field of application. Especially for areas of uncertain development, innovative concepts or large differences in culture and experience, a method of subjectivist participation and observation in a common work oriented learning process seems to be promising.

In a Guide to Curriculum Revision and Development (CURRENT), Gronwald et al (1999) introduced a concept of curriculum development, differing from the traditional syllabus: "learning objectives and contents are included or excluded from the curriculum on the basis of their relevance for future situations in which the learner will find him/herself, rather than merely as dictated by the systematic of the subject in question." (p. 2) The decision-making criterion - "relevance for the future situation of the learner" however cannot be derived in a static analysis of the work performed at an existing work place or an existing learning situation.

"The formulation of learning objectives has in some places become an academic and semantic exercise. The original intention of making the situation in the working world in which knowledge and skills will later be applied as the criterion for deciding whether to include or exclude subject matter was never translated into practice. Now, at least in Germany, excessive formulation of learning objectives is at last seen with more scepticism.

In an effort to avoid the further formulation of unrealistic learning objectives, and to bring together, more closely, the learners with the work environment in which they will later apply their skills and knowledge, we will in general use the term "competencies", i.e. the goals of the learning process are defined in terms of the competencies to be acquired. *Competencies* embrace abilities, skills, knowledge and patterns of behaviour which are necessary in order to perform an activity. Traditionally a distinction is made between specialised, methodical and social competencies. The distinction between the major vocational competencies, as required for training, then results in the categories *technical/craft, business/entrepreneurial and environmental competencies* which translate the three traditional factors (specialised, methodical and social competencies) appropriately."(p 3)

We agree with the position, that an excessive detailed description of learning objectives is misleading, even if they are derived from a prospect of competencies. Instead, the aim of these learning objectives is to "strengthen the employment orientation, the relevance of the labour, goods and services markets in the competencies to be acquired in training. The curriculum should include *learn&work tasks* which combine congruent contents and methodical components that are tailored to the labour and/or goods market"(p.3). The term "Learn&work task" describes a concept of work-process oriented learning, where a learning task is derived by didactical and by/through social reduction and enrichment from a working task. "Learn&work tasks tell teachers, instructors and learners in concrete terms *what* should be done during training and *how* this should be organised. They thus encourage a practice orientation which is not achieved merely by listing learning objectives or competencies. Learn&work tasks, which for example include the production of simple products, can be presented in the form of sketches or drawings. They do not require long-winded written presentation. They thus take into account the disinclination of some teaching staff and learners to read long texts.

The term "curriculum" as we understand it thus includes exemplary learn&work tasks, as well as methodological pointers alongside the description of the competencies to be acquired and the subject matter to be covered, which should be laid out as briefly as possible. The learn&work tasks can, for example, be disseminated with the curricula in the form of flexible components.
A distinction is generally made between open and closed curricula; the former do not specify everything, but leave some leeway for teachers and learners to decide on contents and methods. Not infrequently, closed curricula are called for on the grounds of the lack of competence of teaching staff. It is however impossible to "cover" a closed curriculum with learn&work tasks. The learn&work tasks should rather be used as examples, to give teachers and learners ideas on the basis of which they can develop their own tasks in line with local conditions and possibilities.
We do not see curricula as a static diktat, but rather as a process-type development in which teaching staff, learners, employed individuals and "users of manpower" (employers and self-employed small and micro entrepreneurs) should be involved on an ongoing basis. This is the only way of ensuring genuinely employment-oriented training, that not only takes into account the dynamics of the working world, but actually helps to shape this.

We try to reflect this position in our focus on learn&work tasks. On the other hand, we have to fulfil traditional requirements of curricula based on systematic objectives and competences. We therefore also derive a framework for desirable and supportable competences as a complementary perspective. These two views on vocational education (learn&work tasks and competence orientation) will be supported by a dual mixture of user-requirements acquisition: by interviews and by case studies.

Our search for adequate learn&work tasks is an iterative process of action research taking place on different levels of application and different levels of cultural background. One characteristic of these activities is, that they are not always deliberately organised for the aim of user requirement specification (for DERIVE) but may have their primary reason in some other contexts. Some of them are

- laboratory work with a Modular Production System for teacher-students
- laboratory LEGO work for teacher -students
- experiences of classroom teaching done by teacher-students
- theoretical framework of experienced based simulation
- self experience of the DERIVE project team
- further education of polytechnic teachers and chamber of commerce experts
- further education of vocational, high school and college teachers
- in depth study of maintenance and repair work at an airplane service SME
- installation of PLC-programmes at an automotive producer by a service provider
- installation and optimisation of control programmes for a unique CNC-milling machine
- installation and adaptation of operating systems and control programmes for material testing machines
- maintenance of a laboratory equipment for a Flexible Manufacturing System (FMS) with non-frequent use for education
- remote installation of a learning environment supported by desktop-sharing
- understanding and presentation of the DERIVE concept from some popular point of view

From these case studies and interviews our assumption that the work-situation of mechatronic and tele-service workers and their competences and qualifications are far from being clear, is well supported. Nevertheless, the sum of interviews and case studies experienced so far, provides a good basis for a rough picture of needs.

If we want to support all these different needs with one learning environment worldwide, we have to be very modular, very scalable (up-gradable), very visionary. With Festo's Modular Production System (MPS), we have chosen a good starting point. Further requirements should improve this product to suit new learning tasks.

Getting Involved

In order to explore the pedagogical concepts and teaching methodologies of action orientated learning and constructivism, members of the DERIVE consortium and students from ARTEC embarked on a workshop exercise in November 2000.
The aim of the exercise was to explore the experiences of students placed in an action orientated learning situation and to look at the management of these experiences from a teaching perspective. The participants at the workshop were 3 teachers of Mechatronics and Electronics and 3 Engineers with experiences in Mechanics, Electronics and Informatics. The group comprised a mixture of novices and experts but had no concrete knowledge about the FESTO modular production system.

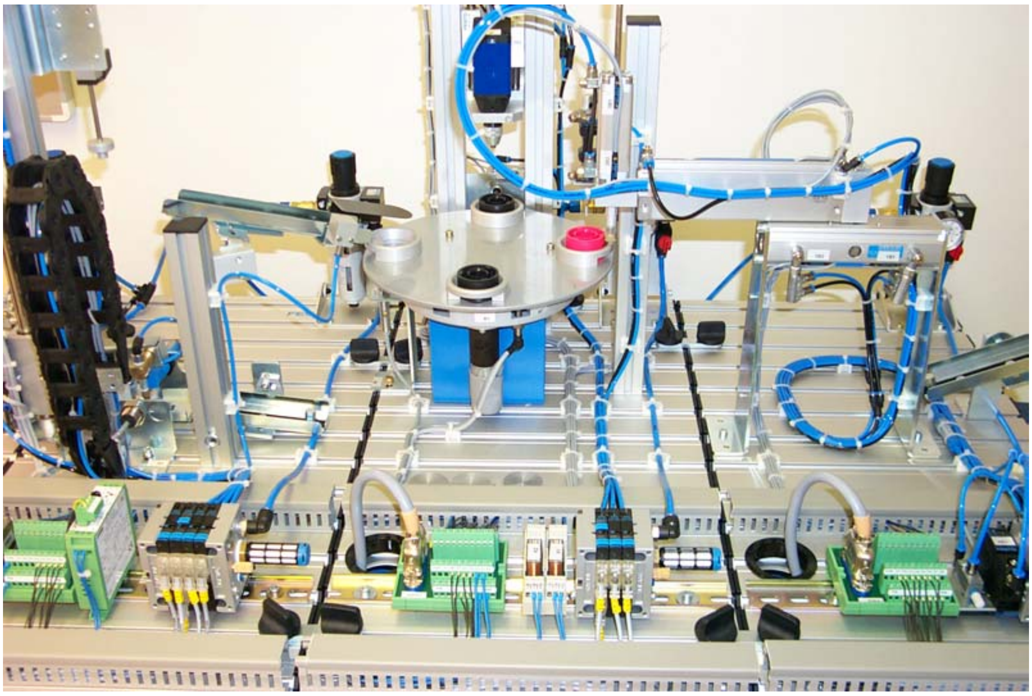


Figure 3: Distribution and testing stations of MPS

The participants were given the task of exploring an automated production line consisting of 4 stages. The scenario set was that the machine was not working and that there was no person available to operate the machine. The documentation for the machine was incomplete but detailed component descriptions were available. A further though unplanned complication was that the machine had a real fault not known to the facilitator at the start of the workshop.
In summary the participants moved through a number of phases. Initially, sub-groups were formed having the idea of looking at individual stages of the production line. This approach quickly failed due to the complexity of the machine and the interrelationship between the stages. After a period of time a realignment of the groups took place. The participants were now working with partners having similar learning styles. Three groups emerged: a practical group, a theoretical group and an activist group. The practical group continued to look at the real hardware. The theoretical group concentrated on the documentation and the activist group looked at a software simulator to hypothesize about the actions of the machine.
During the first group review it became clear that this approach to learning required the group to self-organise and also to have good lines of communication. As the group was highly motivated there was a clear drive towards achieving the goal from all members. However, it was recognised by the group that the facilitator was required to ensure that good levels of communication were existing in the group and, when the group realigned, to ensure that the talents and merits of the individuals were recognised. The group would also have benefited from a more formal team building approach with the identification of leaders/coordinators.

The group reached a number of brick walls and it was only the motivation of the participants that allowed them to pursue the solution to the unknown fault. The group discussed at great length the motivation factors for students in mechatronics. This now raises a question in terms of the teaching approach. In the previous section it was suggested that adults are motivated in different ways to children. During this workshop this proved to be the case, in that the participants were all adults and all highly motivated being in the upper stages of Maslow's hierarchy of basic needs.
But were do students in tertiary education sit? Before this stage of their education they are considered to be children and then they are suddenly exposed to the adult world. This transition is clearly not a step change and for some students the transition time takes a number of years. In terms of Maslow, these students are generally only in the middle stages of basic needs and are still seeking acceptance in the real world. At this level they cannot be considered to have the mature motivating factors associated with adults and this means that teachers need to consider how many degrees of freedom are afforded to students in vocational studies.
The workshop undertaken in November 2000 was extremely useful in highlighting the approach to be used in DERIVE and how it may need to be adapted for the situations experienced by teachers in the classroom.

User Participation

There were several user participation activities. Links to industry, to institutes as well as to teachers and students in other schools were established and interviews were made.
A special workshop for user participation issues took place in Denkendorf with all project partners (17. and 19.5.2000). We had a brainstorming session concerning user requirements as well as training scenarios. We defined user participation mechanisms, coordinated the forthcoming tasks for each partner and prepared material for the interviews with potential users. Furthermore, all partners had installed contacts to local industry and involved external experts in mechatronics training at that time.

During the interviews it turned out that the new learning environment might be successful if it can be used as a universal tool supporting multiple and manifold training scenarios for mechatronics. Therefore an adequate level of system complexity is important. The necessity of integrating PLC was stressed out in several interviews.

Despite demanding a lot of effort, these interviews and contacts will be continued. Demonstrations of DERIVE prototypes will offer the companies, schools and other institutes the opportunity of observation and further influence on the design of the new learning environment.

Participation Tool

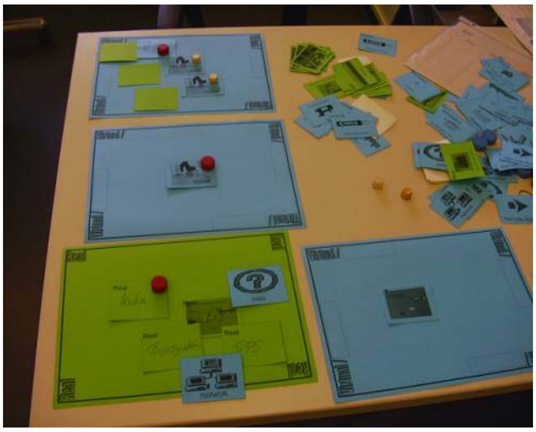
The participation process itself required new tools and methodological means, therefore we developed a participation tool, based on a concrete open mock-up toolbox (J. Huyer 2000) and guidelines for user inspiration

For each partner, we put together a box of materials, which we called 'DERIVE Participation Tool'. The material was designed to be versatile enough to discuss different scenarios.

It consisted of:

- Brainstorming material in terms of cards with images
- Information flyer as a handout for external users/experts

Interview guide including a template for interview protocols



Interview with User Participation Tool

DERIVE Information Event in Zurich

Partner IfAP (Institute for Work Psychology) ETH Zurich invited 52 companies, 16 vocational training schools, and 8 ETH Institutes all over Switzerland, to take part in a DERIVE information event by an invitation letter including research and project information. The companies and schools were selected by their vocational training proposal for students to study polytechnician, the mechatronic expert in Switzerland. The event took place on 8th of December, 2000 at the ETH Zurich. Three vocational training schools (Bern, Solothurn, Winterthur), three companies (Gretag Imaging AG, Alstom and Rockwell, Zellweger Luwa AG) and two ETH Zurich Institutes (Architecture, IHA) participated in this event. The following topics were presented:

- Presentation of the BREVIE and DERIVE concept and further developments
- BREVIE research results: Are real experiences still necessary in vocational training?
- Live on-line demonstration of the virtual DERIVE system with artec performed by Kai Schmudlach in Zurich and Juergen Huyer at artec in Bremen
- Discussion about open questions and further cooperation

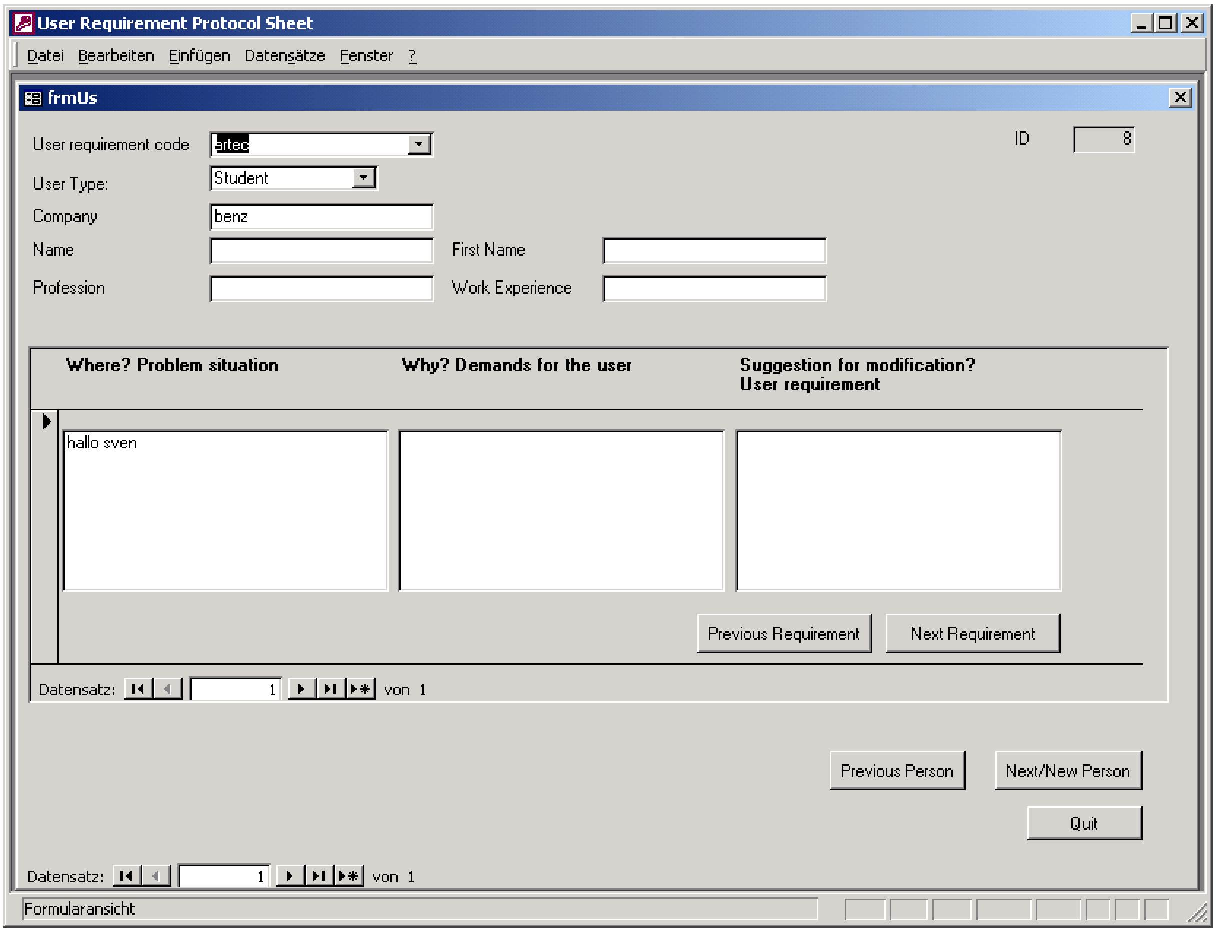
The event started at two o´clock and ended at half past five in the afternoon. The participants were interested in the research results as well as in the DERIVE system. In discussions we talked about their personal experience in training with new technologies, options of cooperation in usability tests and system use at their schools and companies. The minutes were send to each participant at the end of the meeting.

As special actions additional trials were organised with external partners in Switzerland:

- At a school in Solothurn 3 days project oriented work with a DERIVE prototype were carried out. Also, the prototype and the project were presented to the whole school and local companies. An interesting experience was the installation: it was done by the students and was only supported from Bremen via Netmeeting.
- In Wintherthur 4 lessons of 2 hours are currently realised with a DERIVE prototype (including the hyperbond coupling!). Afterwards, the results will be presented at the school. The school is highly motivated for further cooperation and is interested in organising tele-teaching lessons with Bremen.

Selection Process

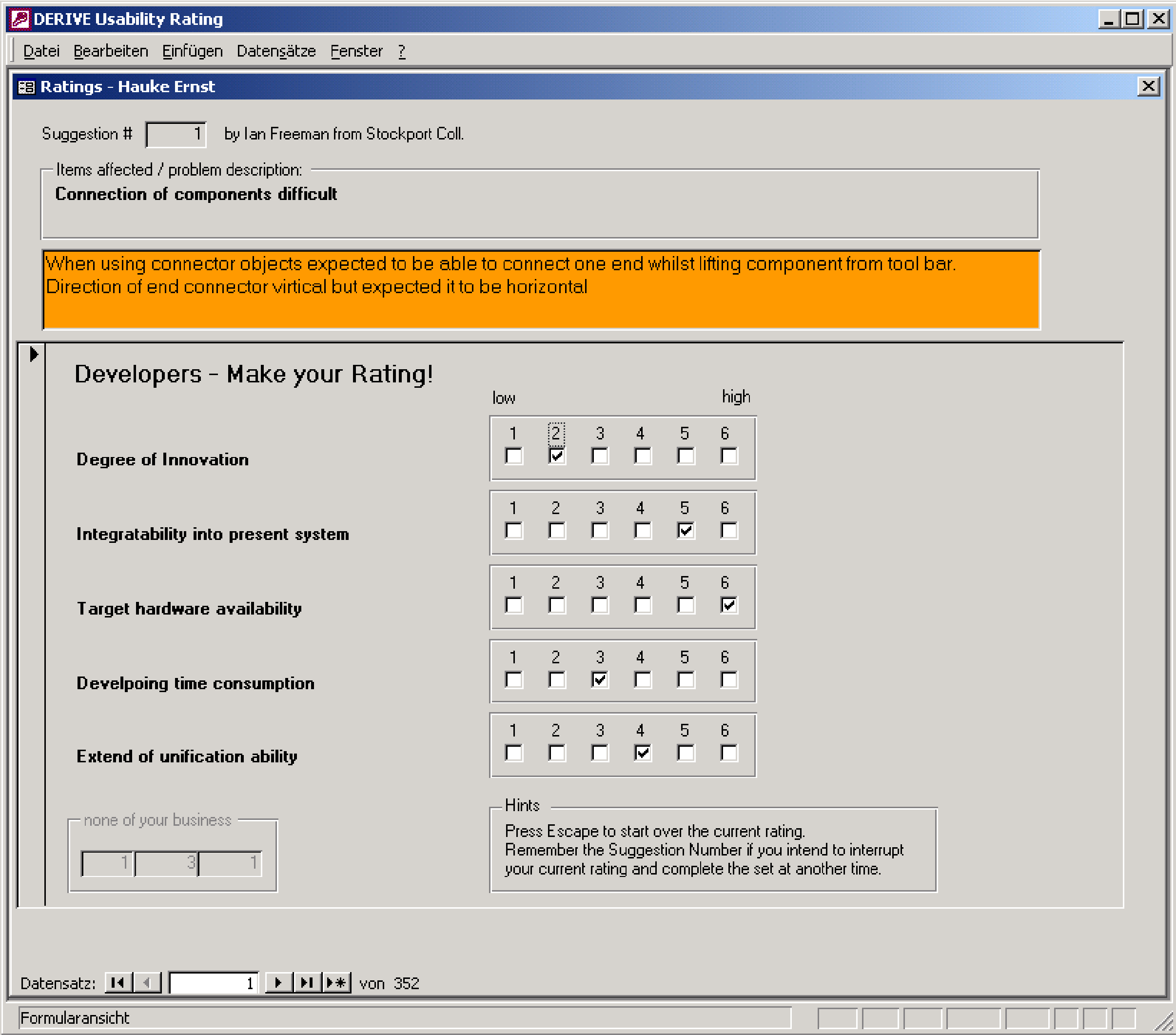
User requirements are collected during interviews with the participation tool (see chapter above) or by observations during trials with prototypes. To maintain and filter the resulting user requirements, ideas and hints, we developed a database tool. With the following form the interviewers can type their session protocol as a structured list of personalised user problems together with hints to solve the mentioned problems.



The user requirements database is maintained at the ETH Zurich. Regularly, the project enters a requirement scoring phase, where new requirements are scored by the pedagogical and technical experts in the project. Two scoring forms with pedagogical – or respectively technical - scoring categories are used:

Pedagogical Categories	Technical Categories
Support Pedagogical Subjectives	Degree of Innovation
Support Different Learning Styles	Integratability into Present System
Motivation	Target Hardware Availability
Independent Learning	Developing Time Consumption
Knowledge Transfer	Extend of Unification Ability

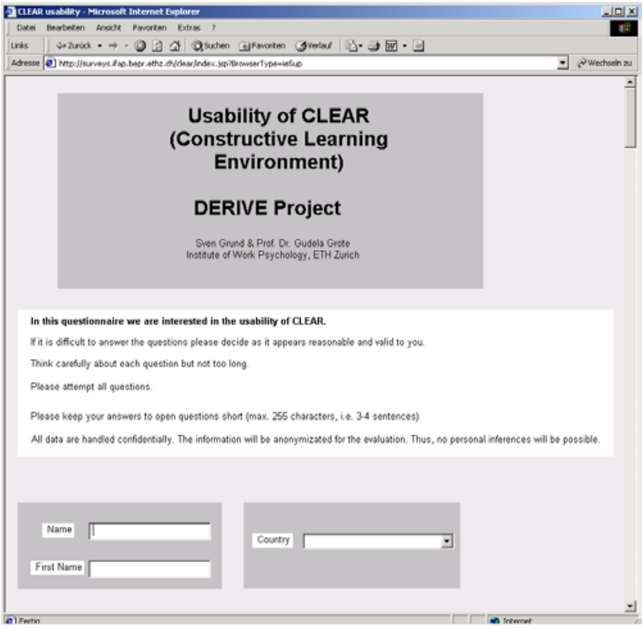
Scoring Form for Technical experts:



The result of the scoring is a sorted list of requirements which is an appropriate basis to discuss and decide which requirements should be implemented within the project.
The user requirements from the first evaluation (more than 500) were scored by two interest groups within the project: teachers and developers. At a project meeting in Bremen, Germany on 17th and 18th July the results were presented and the impact for further development was derived. A common top-ten list of requirements to be implemented came out of the discussions during the project meeting in Bremen.

Online Questionnaires

We performed an **intensive market analysis** for online questionnaires and tested some systems for their applicability (http://rogator.de, http://internet-rogator.de, http://www.siriusteam.ch/english/default.htm, http://www.surveyormanager.com/default.htm , http://nettz.de/Formular-Chef/, http://www.spss.com)
After the test we decided to use the SPSS software package, because of the stability on different browsers and server accesses.
An online questionnaire for the first evaluation phase (focussing on usability) was developed and published on a web server.



Interview Guide

In the area of **evaluation design specification** we developed a usability interview guide including a protocol sheet and a usability video (30 minutes) as an example on how to perform the DERIVE usability test.

CIELT (Concept for Interdisciplinary Evaluation of Learning Tools)

The new concept CIELT was developed as a potential standard for evaluations in interdisciplinary research projects:

The concept for interdisciplinary evaluation of learning tools (**CIELT**) aims at helping heterogeneous teams to define development goals by visualising the connectivity of didactic, technical, pedagogical, psychological and evaluation aspects. Stretching the importance to implement a moderated workshop at the beginning of each project focusing on evaluation aims and their constrains. The pre-condition pyramid shows research teams what should be reached in system stability, course duration, etc. in order to conduct a specific evaluation. Finally, the concept offers different instruments to carry out a learning tool evaluation:

- **System definition:** The user participation tool carries out system requirements in the early phases of the project. The method is based on Dauscher's (1998) future workshop concept and includes interview and task preparation guidelines to develop problem-solving mock ups with end users as well as protocol guidelines to prepare a first prototype requirement list. The tasks to develop a mock up contain a real working and a future scenario to gain creative system solutions.
- **Prototype testing:** The usability tool for prototype testing includes a usability questionnaire with detailed user profile information, instruction guidelines to develop test tasks for different user groups, observation and interview guidelines. A data base supporting the handling and rating of gained data by criteria defined within the research team.

- **In-depth evaluation**: Questionnaires to measure user profiles, user behaviour, diaries to measure interactions between instructor/coach and student for learning tools and quasi-experimental design concepts to analyse learning output and mental models.

The implementation of an evaluation is still a neglected topic (Reinmann-Rothmeier & Mandl, 1998). According to Reinmann-Rothmeier & Mandl (1998) the following factors must be considered in the implementation process of new teaching-learning-approaches:

- teacher's experiences, qualifications, practices and attitudes
- learner's cognitive and motivational premises and habits as well as their learning history
- curricula
- assessments
- school management and
- environment

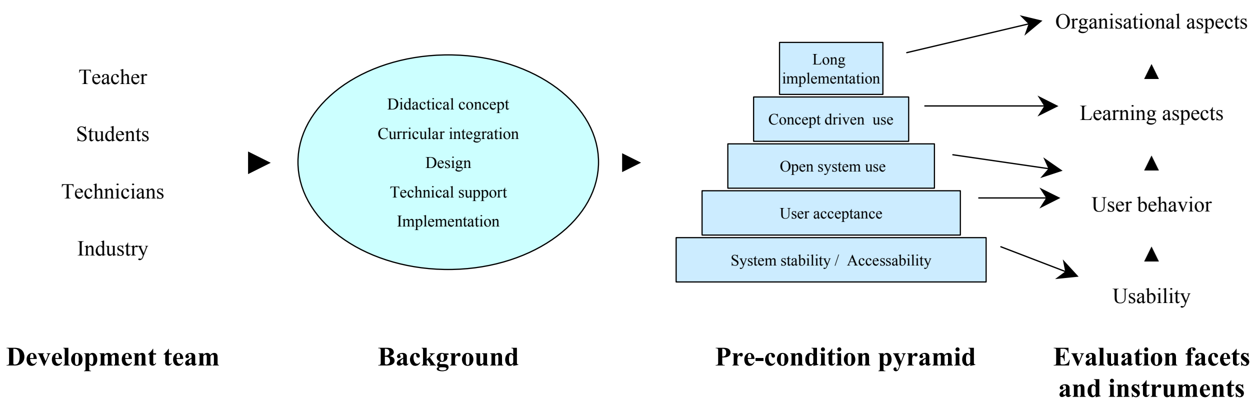


Figure 4: CIELT

CIELT aims at the involvement and consideration of all these factors in the entire development, planning process and implementation process to guarantee sufficient information for people involved and their commitment to changes in teaching and learning practices.

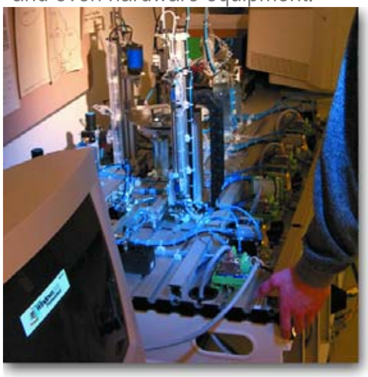
CLEAR^{tm}

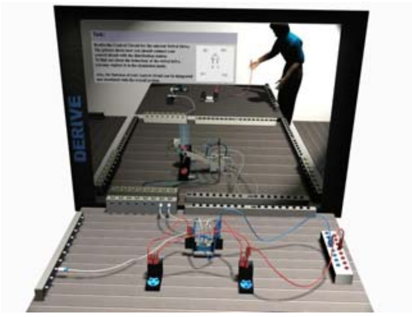
Constructive Learning Environment

for Mechatronis

Clear^{tm} for Mechatronics is a dedicated learning environment for mechatronic training. It provides you with a suitable set of tools and equipment for your laboratory and covers a wide spectrum of your curriculum. With **Clear^{tm}** for Mechatronics you can run real pneumatic or electro-pneumatic components on a baseboard. Your real circuit can run together in connection with a complex, simulated factory context. The real subsystem can be handled as a separated aspect of the virtual system, integrated with a special sensor/actor interface. The system works both in a local classroom setting as well as in a network of distributed learning groups, using **Clear^{tm}** as a platform for communication and collaboration. This provides the possibility to work with remote schools or companies together on complex tasks or projects.

Clear^{tm} for Mechatronics is not just a loose collection of standalone tools. Instead, it is an integrated learning environment providing diverse interfaces between software components and even hardware equipment.





Distributed Constructive Learning Space

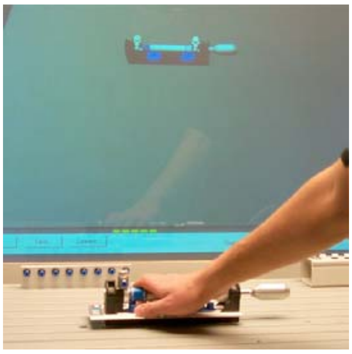
A 3D environment with avatars provides a consistent and intuitive user interface. Virtual mechatronic systems can be visualised, safely simulated or even constructed. Also, the environment includes communication functionality.

Mechatronic Construction Kit

With the reliable hardware toolkits of FESTO Didactic students can construct authentic pneumatic or electro-pneumatic circuits.

Simulation

Simulation has proven to be a valuable tool for planning, programming and optimisation of robot work cells and control circuits. It is cost efficient, safe and supports explorative learning without any risks. Complex system behaviour can be easily understood.



Hyperbonds

Mechatronic hardware equipment can be connected to a virtual environment with a special sensor-actor coupling. This virtual environment gives you i.e. the impression of tubes and wires as if they were reality.

Optical Circuit Recognition

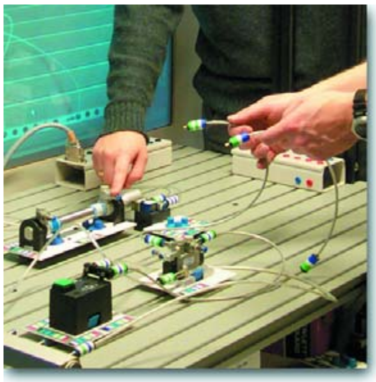
Real electro-pneumatic circuits can be directly imported into the virtual world. A system with camera and image recognition software captures the components as well as tubes and wires with barcodes. 3D representations and circuit diagrams are automatically generated.

Hypermedia Assistant

Easily accessible web-based learning material contains theoretical background information, online exercises and component libraries.

ROMAN^{tm} Technology

The RealObjectManager (**ROMAN^{tm}**) platform coordinates the interoperability of the software tools and hardware equipment. It synchronises model data in the system components and handles network access.



Architecture

The architecture consists of several modules that together build the system.

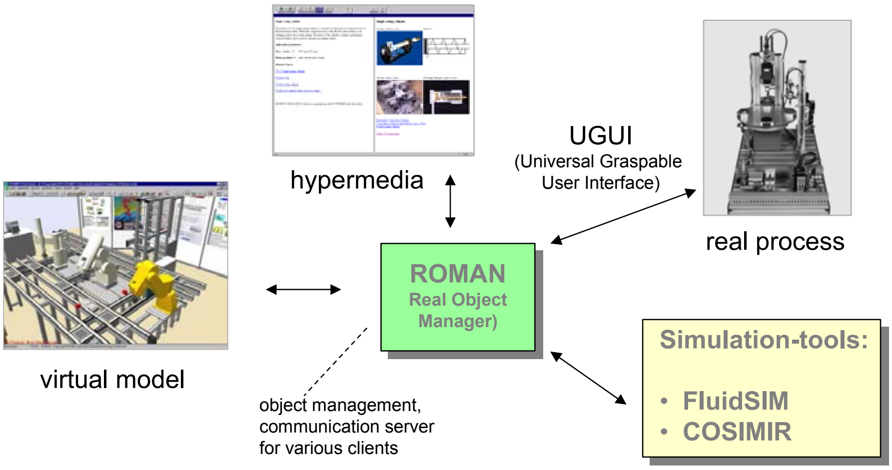


Figure 5: System Architecture Overview

Figure 5 shows an overview about the main components of the system. Each component has its own dedicated task, e.g. simulation.

A central module which controls the communication and data flow between the different subsystems is the Real Object Manager (ROMAN). He maintains a model data base of the virtual model. The scene itself is assembled with the Virtual Construction Kit (VCK). The VCK is built by using a VRML Browser that was extended through the External Authoring Interface and Java in order to communicate with ROMAN.

Via the Universal Graspable User Interface (UGUI) the virtual model is interfaced to the real hardware process, utilising diverse innovative devices such as the hyperbond, an image recognition system, etc. With the help of video-streaming the changes to the real hardware can be observed at distant places. To increase the usability the camera can be remote-controlled (zoomed and rotated) which allows the focussing on specific parts of the real hardware.

All software components are realised as specialised software agents that connect to the central ROMAN, register their services and communicate with each other via ROMAN. The protocols are based on standard Internet protocols (TCP/IP).

The network of communicating clients forms the overall (software) system. Additionally to the ROMAN a DirectPlayerLobby handles the audio, video and chat communication.

System Components

1.1.1 Hardware Setup

Common to all DERIVE setup is the modeling table with the hyperbond and camera mounted on top. In addition to that a back projection system was created (Figure 6). The setup with the modeling table in front of the projection system was chosen because the projection is the logical continuation of the real circuit within the virtual world. The effect of the merging real and virtual spaces is enhanced by the projection system. For the user it seems as if the boundaries between the worlds are vanishing, providing one interaction space.

a) b)

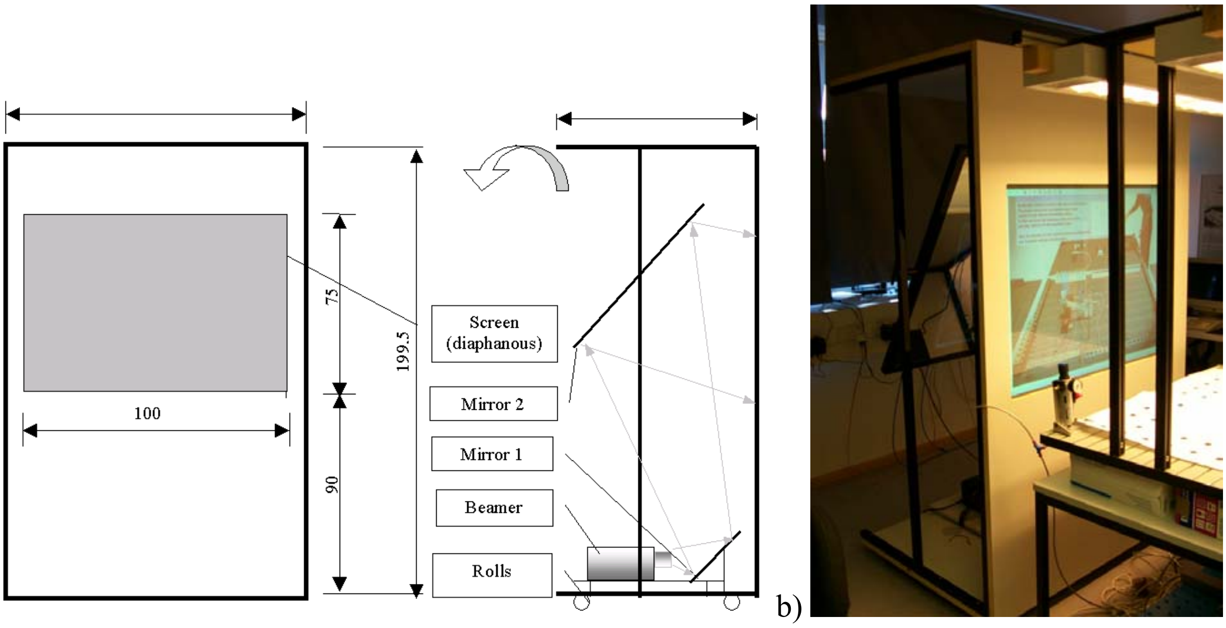


Figure 6: DERIVE Hardware
a) Sketch of the back projection system b) Photo of the hardware

1.1.2 Virtual Construction Kit (VCK)

The Virtual Construction Kit (VCK) is the front-end of the DERIVE system. The user interacts with the system through the VCK. On one hand the VCK visualizes the scene that is maintained by ROMAN and on the other hand it gives the user the possibility to assemble the scene.

The VCK consists of the following parts:
- Java Applet for communication with ROMAN
- Java Script for communication with VRML
- User Interface.

VCK is based on a Java-Applet which handles the communication with ROMAN. The main purpose of the applet is the translation between function calls and ROMAN protocols. Incoming messages are translated into Java-Script calls. On top is the user interface.

User Interface

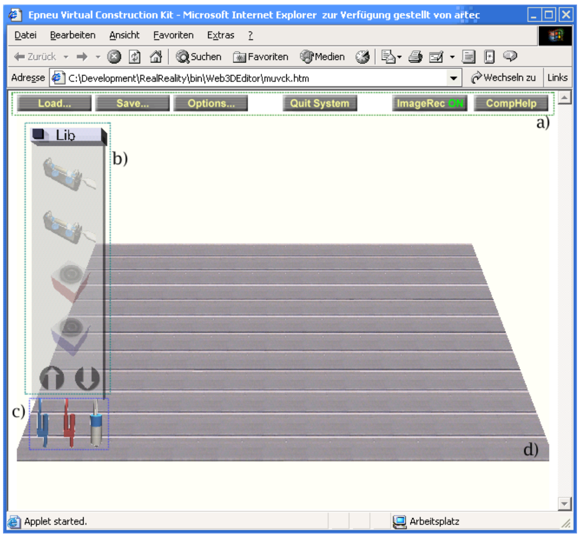


Figure 7: VCK a) Menu b) Component Library c) Shortcut to tubes and wires d) Working area

Figure 7 shows the user interface of the VCK. The menu is located on top of the window. It consists of buttons for loading, saving, configuration and help. On the left the component library is shown. Components are shown as icons that can be dragged onto the work area. On the bottom of the library shortcuts to tubes and electrical wires are shown (they are also available in the library). To create for instance a component the user simply drags and drops the icon onto the working area as shown in Figure 8.

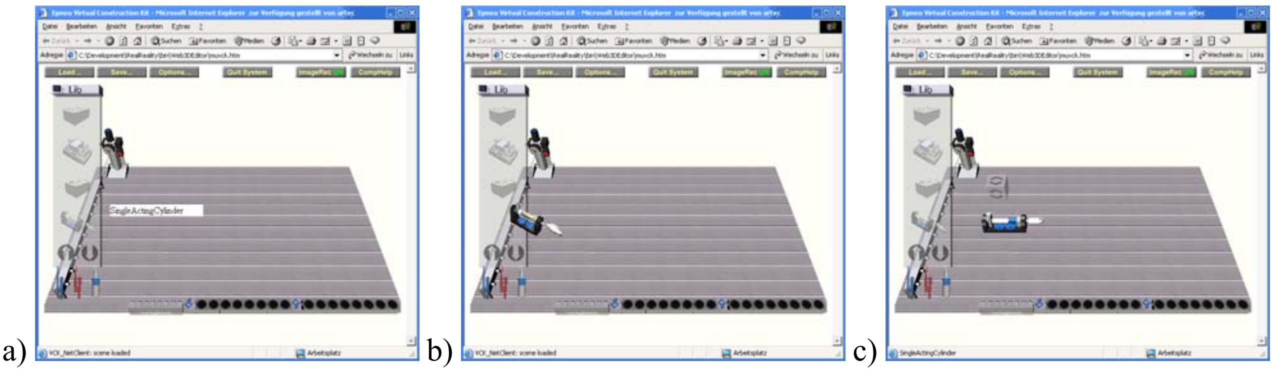


Figure 8: Creating a component
a) Select a component b) Drag component c) Drop component

Models

All models were generated by using 3D Max Studio from Discreet. The component models resemble their material counterparts, so that all constituents of a component can be recognized well. The VRML model was generated by using the export functionality of 3D Studio. Geometric primitives (e.g. sphere, cylinder) were recognized and the corresponding VRML primitive was produced. This ensures good legibility and makes it easier to modify the created VRML files. Recurring parts of the components are modelled once and reused by using the VRML import (PROTO) feature.
The Virtual Reality Modelling Language (VRML) is an international standard for interactive 3D graphics in the Internet. Beside the graphical representation of complex objects VRML files contain simulation functionality (see also chapter 1.1.4, internal simulation functionality).

1.1.3 Help

The help system is based on HTML thus being flexible to use any state of the art features like Java-Applets, Flash-Animations and others. The help system can be used by first selecting a component in the VCK and then pressing the help button. Figure 8 shows an example of a help window. On the left side textual information about the component is presented along with links to related topics. On the right side a 3D and a 2D symbolic representation is shown. In addition a video that demonstrates the function principle is embedded.

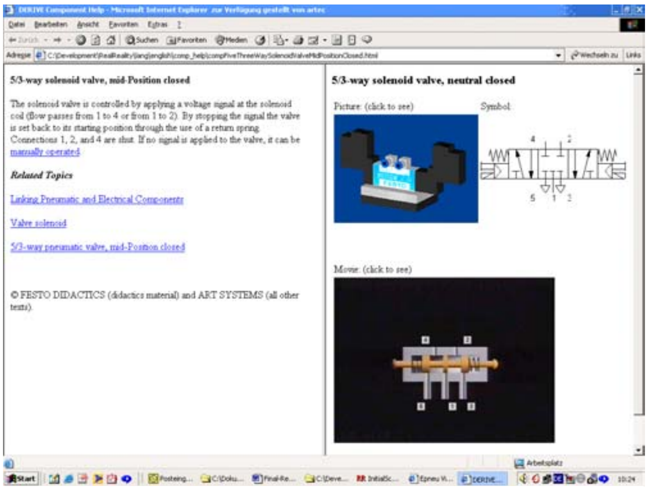


Figure 9: Help System

The language used in the help window depends on the settings of the Virtual Construction Kit. The DERIVE system supports English and German.

1.1.4 Simulation Functionality

DERIVE uses two kinds of simulation concepts. The first one is integrated into the VRML components (**internal**) and the other concept makes use of COTS packages (**external**).

Internal Simulation Functionality

The internal simulation is directly available in the Virtual Construction Kit. Functionality is implemented as JavaScript-Methods inside the VRML files. This type of simulation uses an event-based kernel which implements the basic functions for the pneumatic and electro-pneumatic elements. Nevertheless it allows complex simulations consisting of different pressure values, flow control valves and electrical components. It simulates the phenomena but is not based on differential equations.
The following figures show an example where a switch is used to redirect the air pressure stream between two single acting cylinders:

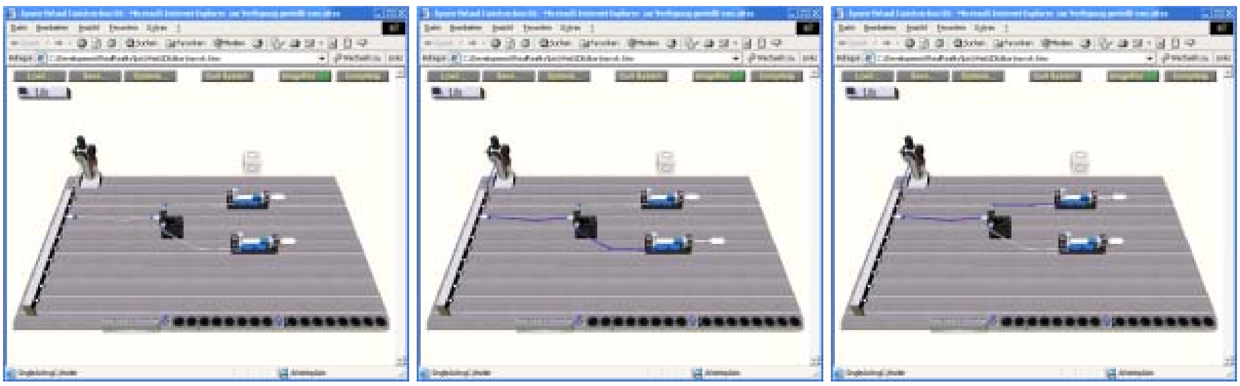


Figure 10: Internal Simulation example

External Simulation Functionality

The internal simulation is limited and not capable of simulating every type of elements and phenomena. Therefore external simulation packages are used to fill the gap. Interface clients are translating the ROMAN protocol into native simulator protocol and vice versa. The output of the simulation is visualized not only in the program itself but also in the three-dimensional scene maintained by ROMAN. Therefore distant clients are able to see the results of the simulation directly in the VCK. The VCK is used twice: firstly as an input medium and secondly as an output medium.

In DERIVE two kinds of simulators are used:

1. FluidSIM → Two-dimensional symbolic simulation
2. Cosimir → Robotic and work cell simulation

The two-dimensional symbolic representation is a widely used concept for describing circuits. FluidSIM was used to provide the symbolic functionality in the DERIVE System. The package simulates fluids, i.e. pneumatic and electro-pneumatic elements. The interesting aspect is that the package itself doesn't allow any distant interaction because it provides only a local interface that is based on Windows IPC mechanisms. The interface client actually enhances this interface by adding an Internet protocol, the DERIVE System itself adds multi-user functionality.
A completely different package is Cosimir, which does three-dimensional robotic and work cell simulation. With Cosimir, a high variety of objects can be simulated, for example Festo's MPS modules, robot cells or complex industrial plants. The interface to Cosimir smoothly integrates within the simulation of electro-pneumatic parts.

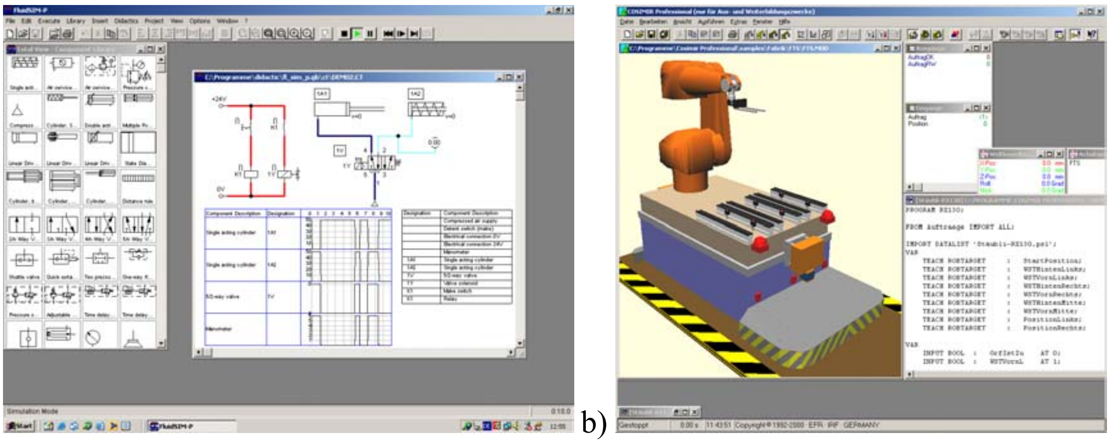
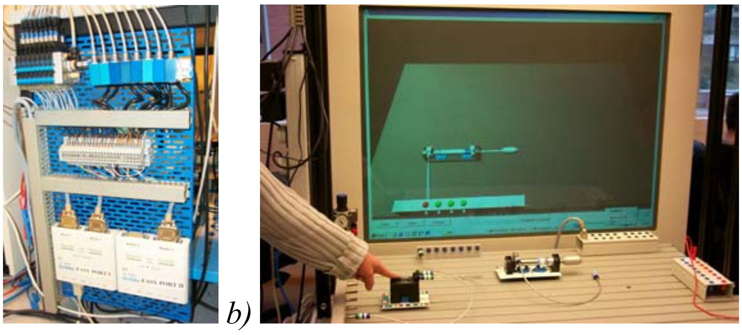
a)  b)

Figure 11: a) FluidSIM b) Cosimir

1.1.5 UGUI

The Universal Graspable User Interface is the interface for real hardware. It is implemented as a ROMAN-Client. Device drivers are added using the plugin capability of the UGUI component. A plugin is a Dynamic Link Library (DLL) which is loaded at startup or at runtime. Each library adds its own configuration dialog. The UGUI process is accessible in the Windows Tray-Bar.
There is only one UGUI component per host allowed. All plugins are sharing the communication channel in order to reduce the network load for the ROMAN. Also the plugins are synchronized by the process. It is possible to have multiple UGUIs running in one scenario, each on its own computer. The different hardware elements are distinguished by the name of their virtual counterparts. Typical plugins are the hyperbond and the camera driver.

Hyperbond
The hyperbond is the medium that merges Reality and Virtuality. It is based on FESTO's IO-device Easyport. Along with additional circuitry each connector is capable of sensing and creating a phenomena like voltage or air pressure. It is made available to the DERIVE System as a UGUI plugin.



a) b)

Figure 12: a) Hyperbond Hardware b) Hyperbond in action

Camera
Another plugin is the camera control. The camera can be controlled by using the event-level protocol from ROMAN. This is not intended for the user only for other clients. An easy access was made available with Java and JavaScript. The user works on a graphical visualisation that internally translates the clicks into events and distributes them.

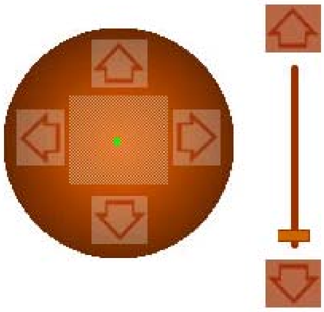


Figure 13: Camera Control Panel

1.1.6 Image Recognition

The image recognition system is used to recognize the position and orientation of real objects and connections between them. The scene is reassembled in virtuality and updated if changes to the real world are made.
To identify components, wires and tubes two labeling systems are used:

- Matrix-Code for component recognition and
- Bar-Code for wires and tubes.

The Matrix-Code is very small (only 1.7x1.7 cm²) and directly placed on the components. For the wires and tubes a cylinder was added where the Bar-Code was placed on.
Each code consists of a start Bit and the number coded as bits. Figure 14 shows an overview about the image recognition process.

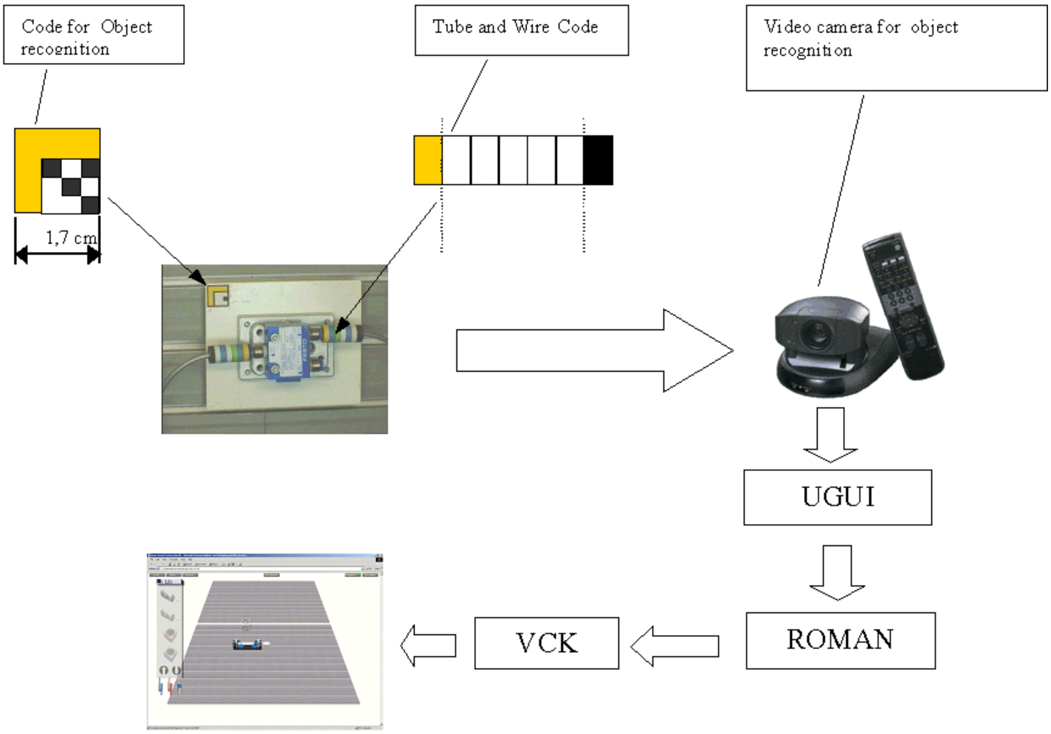


Figure 14: Image Recognition Overview

1.1.7 Eventmapper/Scripting

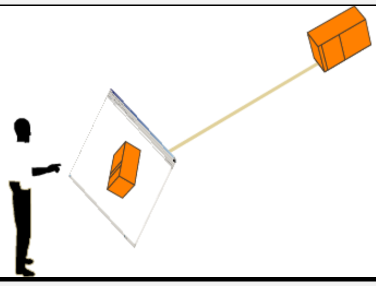
In a diploma thesis the existing Event-Mapper was extended and is now capable of handling scripts. The aim of the Event-Mapper was for example to map the pressing of the F1-Key (Help) to the event HELP which was distributed by ROMAN. Now there is the possibility to script the mapping of events which allows complex control scenarios.

Configurations/Scenarios

The DERIVE system is capable of handling different scenarios. Each scenario fits a specific need.

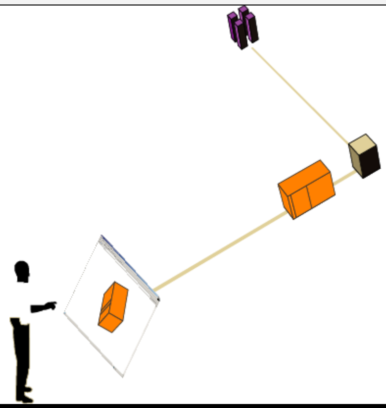
Standalone

All modules are running on the same computer. This configuration targets at experiments, demonstrations, on-site testing (with UGUI interface to real hardware). In most cases only the ROMAN and the VCK are running and internal simulation is used



Distributed I

To overcome the limits of the standalone version an external simulator is used. Because of the fact that a lot of computing power is needed this program runs on a separate computer.

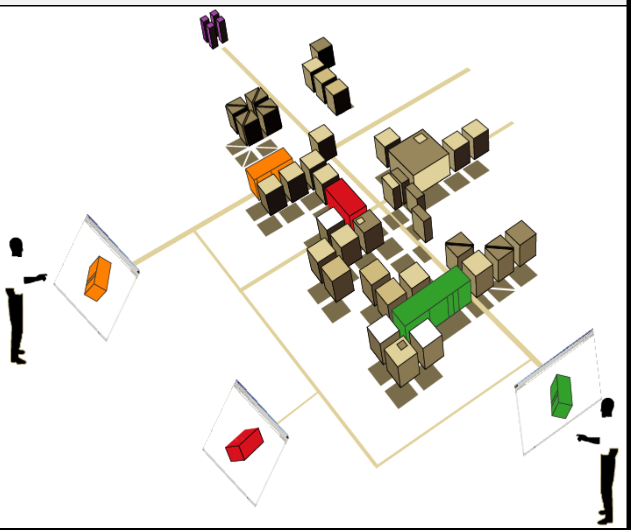


Distributed II

In this configuration all modules are spread over a wide area network. Different sites are doing collaborative tasks like:

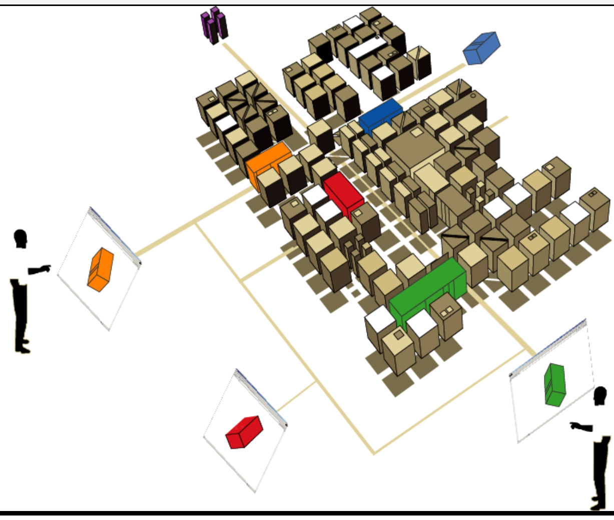
- Collaborative modelling,
- Distant teaching,
- Distant failure search and
- Tele-Service.

This configuration was demonstrated several times with sites in USA, England and Zurich. The real hardware is interfaced via the internet and the result is visualized by a web-cam. This configuration is also referenced as: ***Air Pressure to the Internet***.



Distributed III

This is the most complex scenario which is based on the configuration described above but with enhanced audio, video and chat functionality. An example is the demonstration on the Super Computing 2001 conference. Here high-end audio- and video-streaming but also a distributed PowerPoint presentation was used.



There are several sub configurations that are not yet mentioned. These settings mainly influence the visualisation within the VCK but belong to the categories. An often used configuration is a pure virtual hyperbond. Here the same functionality of the real one is used but the events don't leave the virtual world.

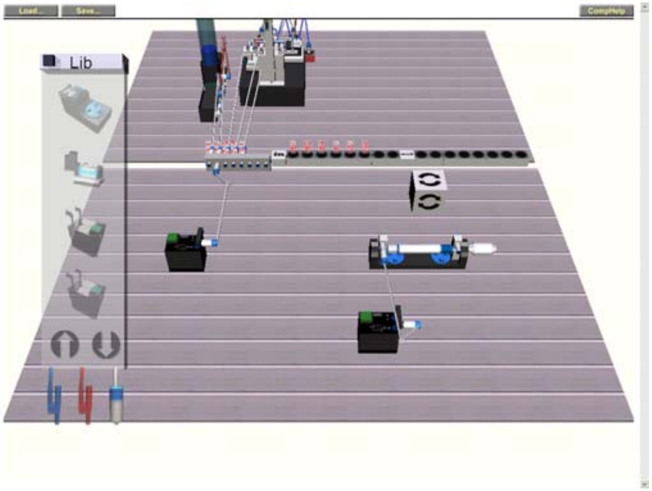


Figure 15: Virtual Hyperbond

Another configuration may consist of more than one pneumatic Hyperbond. That were only two of many variations that are possible. In most cases the settings are specialisations of generic scenarios previously mentioned.

Simple real connected to complex virtual:

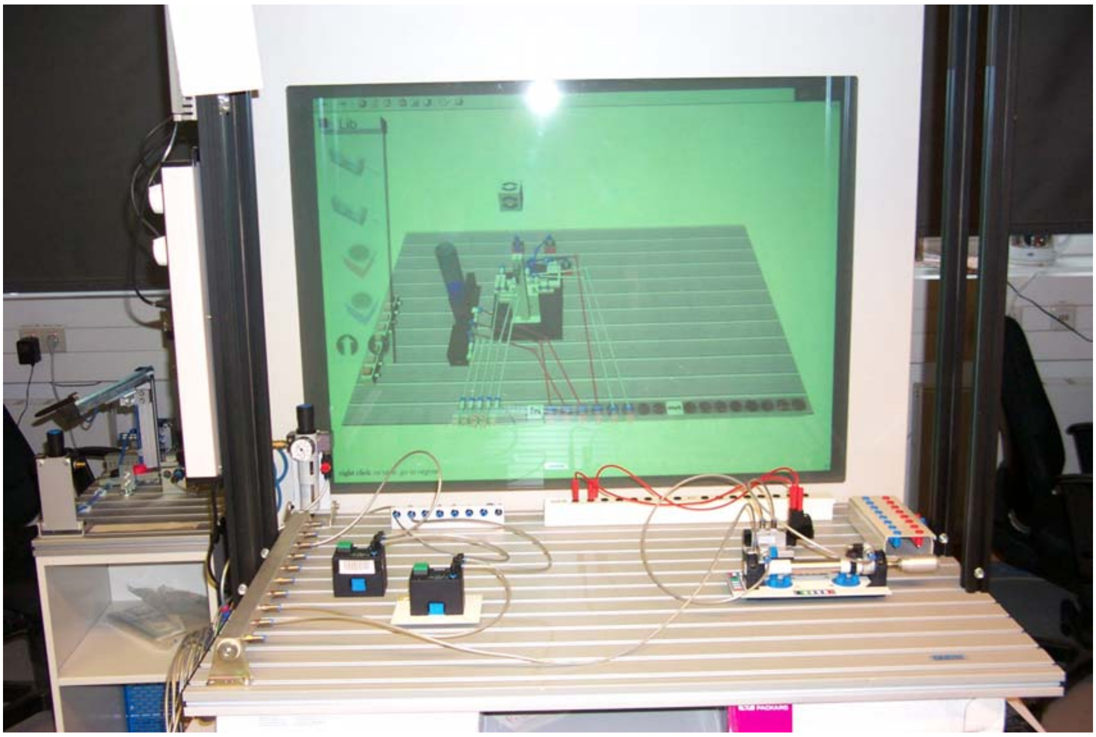


Figure 16: Simple real connected to complex virtual

For the trials in Stockport, a purely virtual environment was integrated:

Simple virtual connected to complex virtual:

Additionally, for further tele-cooperative scenarios, for example in the context of dissemination activities, 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:

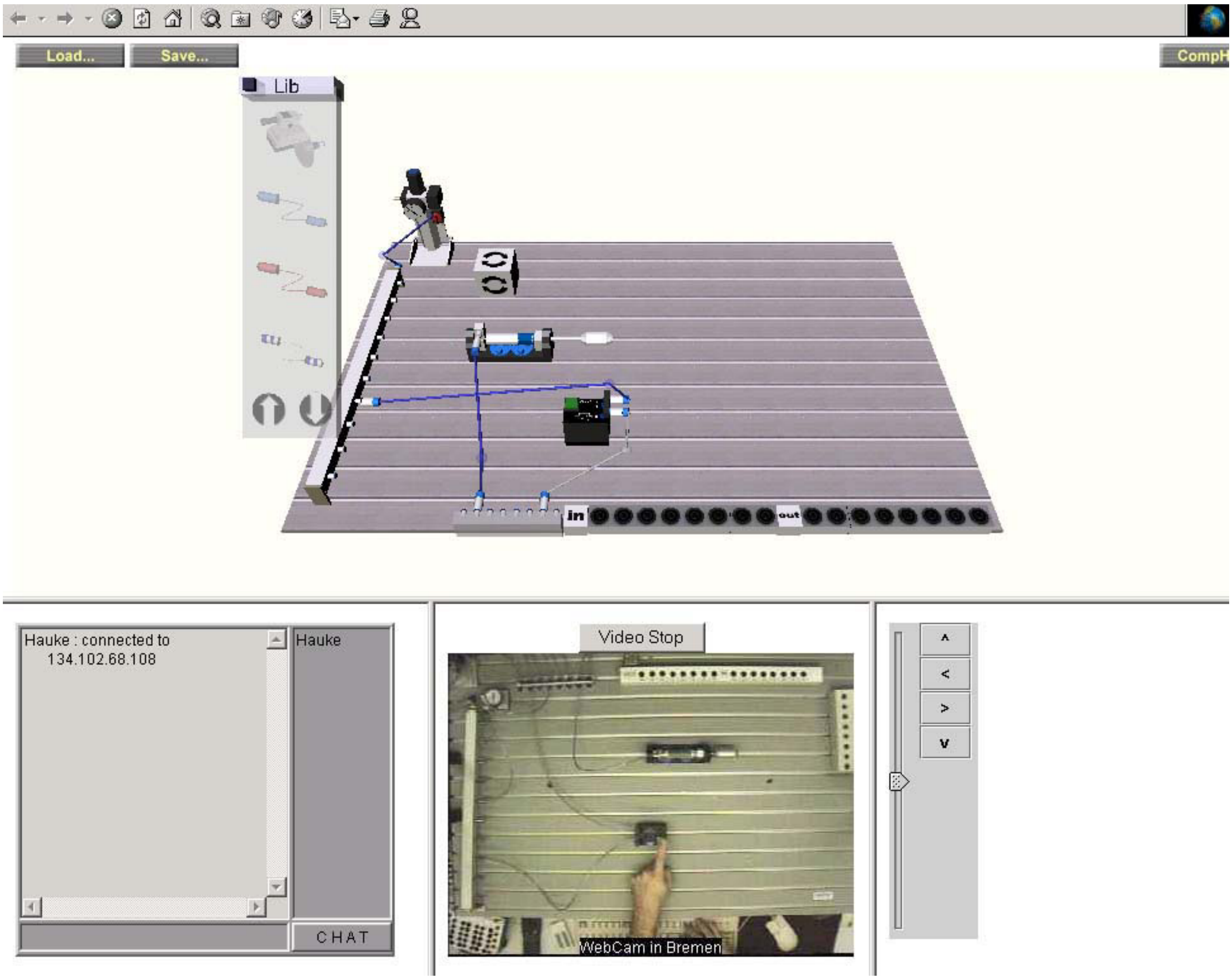


Figure 17: Simple virtual connected to complex virtual

EVALUATION

In DERIVE several trials were carried out in three phases as shown in the table below.

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

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

Phase 1 - DERIVE Usability Testing

The first phase of the evaluation was realised in May 2001 and was dedicated to usability testing of DERIVE system components. The aim of the evaluation was to examine software ergonomics and to detect minor faults in general. The results of the evaluation was a list of requirements that then were tested against criteria for inclusion in the final development of DERIVE. The first teaching unit proposed to use a typical fault finding scenario. Students were presented a circuit containing simple and complex faults and could use the tools of the DERIVE system to find the faults. During a teachers meeting in Zurich (January 2000) it was commented that these tasks would not allow the consortium to fully explore the features of the DERIVE software. It was also evident that the hardware would not be sufficiently developed for the evaluation to encompass the hardware aspects at all training and test sites. Tue to these circumstances it was decided that the teaching unit should focus on the design, i.e. the construction (virtual) and simulation of circuits, rather than fault finding existing hardware circuits. In terms of the evaluation these changes would allow the consortium to explore more aspects of the DERIVE environment whilst still providing typical learning scenarios.
An important feature of these teaching units was the limited involvement of the teacher in the learning process. This aspect was necessary to evaluate the usability of the system and to explore the intuitive look and feel of the software interface.
The usability test scenarios, procedures and training materials are described in D52. The test took place in Bremen, Stockport, Leiria and Zurich between April and May 2001. A standardised test procedure (see table below) was used in order to obtain comparable results.

phase 1	*phase 2*	*phase 3*	*phase 4*
Usability test performed by each project partner with 6 test persons	Interim usability report contains data collected by means of a • Questionnaire • Observation • Interview	User requirement scoring by teachers and developers • User requirement data file	User requirement meeting • Implementation list for the final evaluation and the end of the project

Usability test procedure

A total of 29 persons consisting of employees as well as students and teachers participated in the trial. It turned out that the 3D handling mechanisms was not sufficient for efficient work with the electro-pneumatic circuitry. This concerns the navigation and especially the drawing of tubes and wires. However, more than 360 descriptions of concrete problems and ideas for improvements were gained.

Phase 2 – Communication and Collaboration Analysis

This phase of the evaluation took place in June 2001. It was dedicated to communication and collaboration. The three areas considered were tele-service, collaborative design and distance teaching. In this phase of the evaluation the user team explored the tool requirements for these tasks and tested existing tools integrated in the DERIVE system.
The evaluation was delivered in three scenarios:

- Tele-service – remote service of a system
- Collaborative design – among students dealing with the same problem
- Distance Teaching – teaching a lesson to students at different places

The test procedure contained two phases for each scenario.

phase 1: Process	***phase 2: Output***
Online observation using the FIT-system	Questionnaire registering system experience and personal technical background

Collaboration Analysis Design

The test settings were undertaken by students, teachers and industrial partners at different sites. Detailed observations of each session were carried out. The sessions were remotely observed by the evaluator of ETH Zurich (see picture below).

Online Observation Laboratory

The observer used a Palm to protocol the observation categories. The virtual interactions as well as the auditory information were presented by the PC and loud speaker as described in the picture above. The laptop showed the real pneumatics circuit of Bremen. Occurring problems were discussed immediately by phone. All unexpected events were noted on paper.
Each test setting lasted for 1.5. hour and 0.5 hours for the questionnaires. In addition one training session took place in the morning between 8-12 o'clock and one in the afternoon between 13.00-16.30.

Communication and cooperation results
Considering the results from both task analysis and online questionnaires (described in D53), the following conclusions can be drawn:

In summary, the DERIVE learning environment fulfilled the user requirements regarding tele-service. Concerning their usefulness all tools (in all scenarios) were rated as satisfying or at least "sufficient" or "good".

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!).

In the remote diagnosis setting subjects mainly solved the tasks with the real circuit, giving instructions and executing them (using nearly only the audio connection). Ratings in the questionnaires were all moderate or good, the usefulness of the tools was rated as being sufficient (FluidSim and whiteboard got the lowest rating). However, ratings were generally worse than in the other scenarios.

In the tele-teaching scenario lessons were delivered in symbolic and vivid depiction. Teachers and students mostly used audio supported channels to give explanations/instructions and ask questions, but other media were applied too. The usefulness of the tools was scored as being good.

The collaboration tasks were solved in symbolic and vivid depiction. Again, audio conferencing was most frequently used (the other media were hardly used) to give instructions/explanations and ask questions. In this scenario DERIVE received the best ratings: all tools were valuated "good" or "very good".

On the one hand all tools/media investigated were judged "sufficient" or "well". On the other hand only few of them were regularly utilised. One main criticism across all scenarios was the insufficient system stability (apart from the bad voice quality). This may have led to the reduced utilisation of the tools within DERIVE. The use of some tools may still be too complex and the user was not used to them. It should also be kept in mind that the subjects in the tele-cooperation setting, which received the best ratings, were students. Inversely, in the remote diagnosis scenario, where one of the subjects was an industrialist, received the most criticism. Therefore it should be considered to accomplish this teaching unit anew with other test subjects.

An interesting outcome was that the remote pointer was not used for pointing to objects to the degree it was previously expected.

Phase 3 – Learning Benefit

This learning benefit evaluation (October to December 2001) is dedicated to the learning output of the DERIVE system, comparing traditional (bottom up – simple to complex) and modern teaching methods (complex case based – top down) and technologies. The benefits and experiences of the BREVIE evaluation have significantly influenced the design of the DERIVE evaluation. In BREVIE it was found that by careful control of the teaching scheme and lesson plans, it was possible for teachers at the different evaluation sites to execute lessons in a comparable teaching style. Since the DERIVE project is based on a more complex (and expensive) hardware of FESTOs' MPS, it was also considered as difficult to ensure that there would be sufficient working DERIVE prototypes at each training site. In addition it was difficult in BREVIE to organise different teaching scenarios when the system set up had to be changed for each scenario within one hour. Taking the different results into account it was decided to deliver phase 3 of the project with one different teaching method at each delivery site.

The table below shows the allocation of the teaching methods and learning technologies.

teaching method	***evaluation site***
TRADITIONAL TEACHING	ESTG – Portugal
DERIVE LIGHT	Stockport College
MPS	Festo Didactic Ludwigshafen
DERIVE	Bremen

As a development of BREVIE it was decided to add a fourth teaching method. The DERIVE light model involves the use of simulation and 3D visualisation only. Students have all the features of DERIVE without the hardware components. This scenario is of particular interest to schools as it may bridge the gap between using pure symbolic simulation tools and practical hands on experience. It was hypothesized that by using the 3D simulation students will more easily be able to transfer their knowledge to the real world.
In the design of this teaching unit it also was necessary to increase the number of hours required to execute the unit. As the incorporation of programmable logic controllers was a definite requirement of mechatronic systems, the time of 16 hours (sessions of 45 minutes) for the delivery of the unit would not be sufficient to evaluate these aspects effectively. The teaching lasted 20 hours (sessions of 60 minutes), which was an increase of 67% teaching time compared to BREVIE.

The research hypotheses were based on working memory considerations (Cooper, 1998), cognitive development (Piaget, 1991) and situated learning theory (Greeno, Smith and Moore, 1993).
Following hypotheses were developed in cooperation with our teacher colleagues.

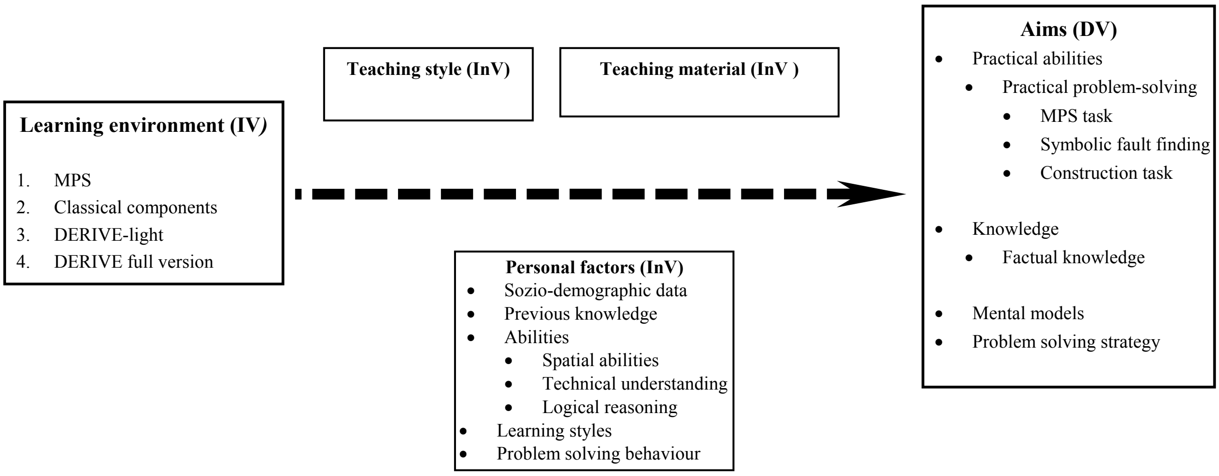
1. **The possibility to switch between different representations of factual knowledge in DERIVE supports the acquisition of factual knowledge, leading to comparably more factual knowledge in the DERIVE group.**
   Baddeley (1992) and Mousavi (1995) showed that the combination of different information formats leads to a reduction of the working memory load and supports the learning process.

2. **The learning output is affected by student´s cognitive abilities, previous factual knowledge and the learning environment.**
   Egan and Gomez (1985), Greene, Gomez and Devlin (1986) and Landauer (1997) showed the influence of cognitive abilities on learning output.

3. **MPS students will find more practical faults than other students.**
   These students are more familiar with handling real components (MPS group), followed by the DERIVE full version group and the classical teaching group based on the results of situated learning effects (Greeno et al, 1993).

4. **DERIVE students have a higher mental flexibility in switching between real and symbolic representations.**
   The combination of real and virtual 3D models fosters mental ability to switch between different representation formats.

To test the hypothesis a quasi-experimental design was chosen. The intervening factors teaching style and teaching material were controlled via a workbook including behaviour instructions and the whole teaching material.



Evaluation Design, IV=independent variables, InV=intervening variables, DV=dependent variables

In a pre-test intervening variables such as cognitive abilities (logical reasoning, spatial abilities, technical understanding), learning styles and problem solving styles were measured. In a post-test practical abilities were analyzed with a practical fault finding task using a real MPS station, fault finding in a circuit diagram and a paper-based construction task. The factual knowledge was measured with an electro-pneumatic theory test given to the students at the beginning and the end of the course. After the practical and symbolic fault finding students had to fill in a mental process questionnaire about mental models and problem solving behavior.

Altogether 19 students' took part in the classical component group, 7 in the DERIVE-light group, 19 in the DERIVE full version group and 27 in the MPS group. The average students age was 18 years, SD=2.5. The classical group was significantly older (ANOVA, F (3,65)=13, p<.01), Scheffé (p<.01). All students had minor or no knowledge at all in pneumatics/electro pneumatics M=4 points, SD=4 (max. 79 points), again the classical component group had significantly (ANOVA, F (3, 68)=10, p<.01) more previous knowledge M=7, SD=4 (Scheffé, p<.01). Students cognitive abilities were comparable to a standardized group of vocational training students. Students described themselves as more heuristic problem solvers than algorithmic problem solvers. Learning styles did not differentiate sufficiently within and between students.

However the learning benefit analysis shows a significant difference (ANOVA, F(3,68)=7.6, p<.01) in the increase of factual knowledge between the DERIVE group M=26, SD=5, the MPS group

M=25, SD=6, the DERIVE-light group M=20, SD=5 and the classical components group M=19, SD=4, but 43% of the difference can be explained by technical understanding (beta=.44) and previous technical knowledge (beta=-.32) learning groups had no significant effect. Hypothesis one could not be verified whereas hypothesis two could be verified for all different learning output variables.
Significant differences (ANOVA, $F(3,68)=3.1$, $p<.04$) could be found in the construction tasks between the DERIVE group M=31, SD=17, the MPS group M=23, SD=15, the classical teaching group M=21, SD=7 and the DERIVE-light group M=14, SD=13, but still only technical understanding (beta=.37) can explain 23% test variance.

In the symbolic fault finding task DERIVE group M=5, SD=3 and MPS group M=6, SD=3 students had been better than DERIVE-light group M=3, SD=2 and classical teaching group M=1, SD=1. We identified a significant group effect (beta=.51) and a technical understanding effect (beta=.31) explaining 49% of test variance.
A group difference in the practical fault finding could be found (ANOVA, $F(3,68)=6.43$, $p<.01$). MPS students found significantly more practical faults in the MPS station M=4, SD=1 than the DERIVE-light group M=2, SD=2 (Scheffé, $p<.05$). The other groups found a comparable amount of faults, the classical teaching group M=3.5, SD=2 and the DERIVE group M=3, SD=2. 16% of test variance could be explained by technical understanding (beta=.36). Hypothesis three could be partly verified.

Looking at qualitative descriptions in the mental model questionnaire it has to be mentioned that in general students used mixed mental representations (real and symbolic) to solve the practical and symbolic fault finding. A higher mental flexibility in the DERIVE group could not be found. Students linked between two and three elements in their mental representation in order to find faults. Students with less MPS experience simulated mentally more by touching the components whereas the other students did their mental simulations just by looking at the MPS system. Many classical teaching students gave "trial and error" explanations to themselves to understand the circuit whereas DERIVE students, DERIVE-light students and MPS students gave "if ...then... because" explanations. It is supposed that this is based on the fact that they have not worked before with the MPS system. It had been difficult for all students to keep the practical task in mind and to simulate the circuit mentally but they had no problem in understanding the task. The symbolic task had been in general more difficult. In the practical and symbolic task pneumatic to electronic converter, one-flow control as well as the 5/3 solenoid valve caused most difficulties. The task difficulty averaged M=3, SD=1 on a five point scale. The problem solving strategies "trial and error" was found more in the classical teaching group. The heuristic and algorithmic styles had similar distributions within the other groups.

What is the conclusion from these evaluation results? In general a strong personal factor, namely technical understanding and previous knowledge, could be identified influencing the learning output. These results had been found in previous studies (Grund & Grote, 1999, 2001). The differences in factual knowledge development are partly effected by the fact of group differences in previous knowledge. A better group standardization would be appropriate for further research. The ability to construct symbol-based circuits is less influenced by technical understanding. The impact of technical understanding is getting even smaller in the practical fault finding and the symbolic fault finding. The hands on experience with classical components cause major transfer problems on a symbolic fault finding task. An interesting result in problem-solving is the fact that the classical group found a comparable number of faults within the MPS task by using mostly "trial and error" strategies. In this case other strategies seem to be of less importance for test performance.
The evaluation could not verify the first hypothesis. What could be seen as a tendency over all tests is the fact that practical experience is important to solve practical problems. The transfer from pure

virtual training (DERIVE-light) on practical problems caused several problems. This conclusion has to be verified in future research because the DERIVE light group was too small to draw reliable conclusions on this data.

The close coupling of the technological development and the evaluation process has been fruitful for the development process because the pressure of time specific trials forced the team to a certain production discipline and reflection. But it was a burden for the validity of the evaluation results with respect to learning improvements.

DISSEMINATION, EXPLOITATION, OUTLOOK

Dissemination and exploitation of the DERIVE results have been an essential part of the work in this project and contributed essentially to its success. With regard to dissemination the activities comprised the preparation of dissemination material as well as continuous dissemination activities. The dissemination material that has been produced so far includes the creation of a common design, including logo, web page, flyer, poster and flash presentation. From a marketing perspective this unified design is important for a common identification of the project and of the product.

The work done in the work packages *Disseminnation and Use Plan* and *Preliminary Product Specification* is fundamental for exploitation. In addition, the project investigated IPR issues at the IPR Helpdesk and signed a Consortium Agreement.

Deliverable D62 (the preliminary product specification) reflects a clear common understanding of the product concept which is very important for the objectives the DERIVE project wants to achiev-e.
The project also finished the work on D61 (Dissemination and Use Plan). The document includes concrete *Product Innovation Charters (PIC's),* which are the initial basis for new products at FESTO Didactic. The tasks of D6100 (Dissemination and Use Plan) was to work out steps of how to disseminate the product idea and to create a use plan to identify the target market. In particular, the activities of all project members to get into contact with external experts and potential users provided a successful way of dissemination. We succeeded in winning a member of the Festo Training Department for the project. We are now able to use their marketing activities for the dissemination of DERIVE.

A homepage for DERIVE (http://www.derive.uni-bremen.de) was developed and will be continuously updated. Project flyers and posters as well as a flash presentation were created.

The exploitation strategy of project results was discussed (Karras, Ernst). Several meetings were organised at Festo in Denkendorf , artec in Bremen and IRF in Dortmund to make sure that all different aspects are taken into account for product development.

Exploitation of the DERIVE technology will be done by FESTO Didactic together with the new start-up company ***Bendit Innovative Interfaces***, which is a spin-off from partner a*rtec*.

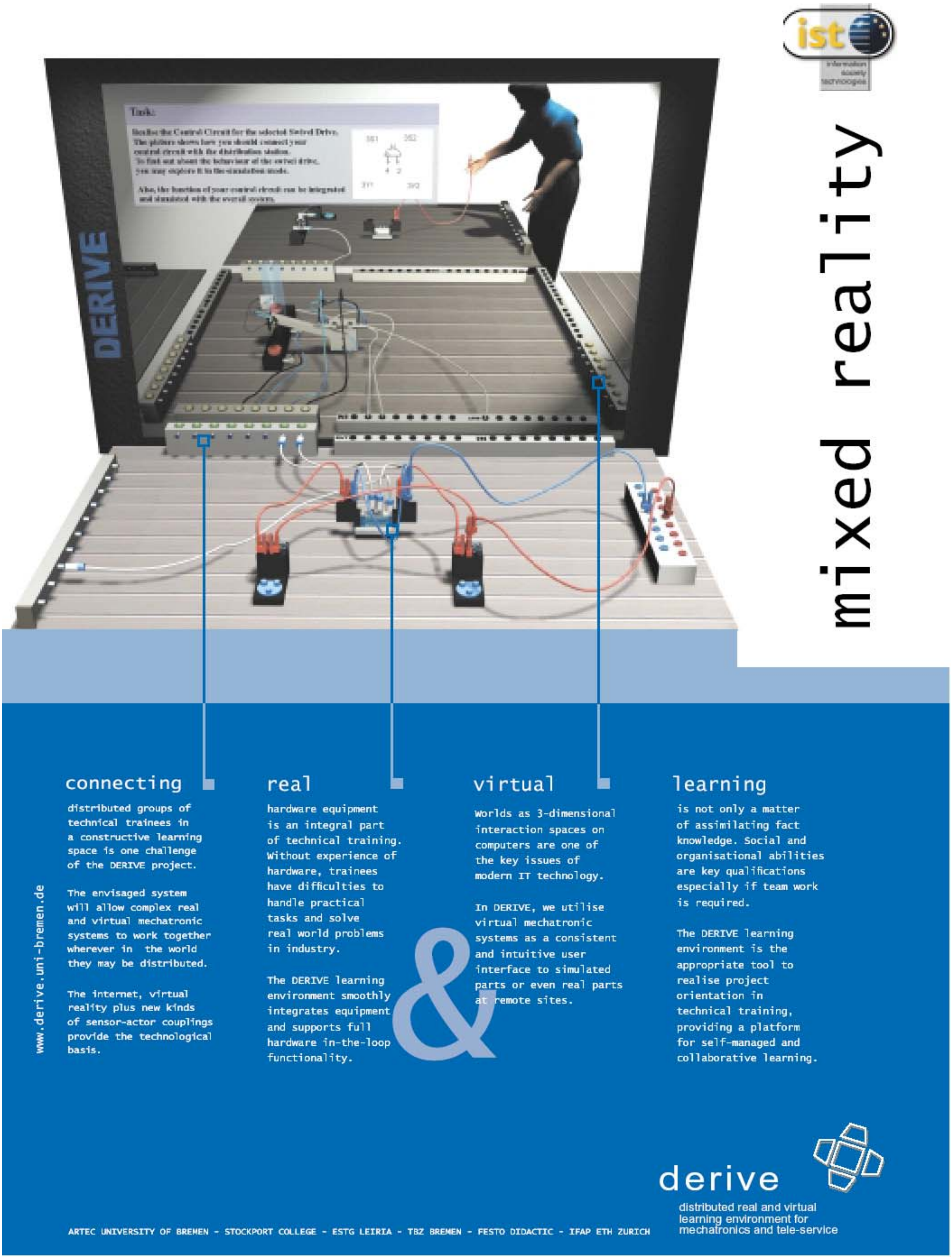


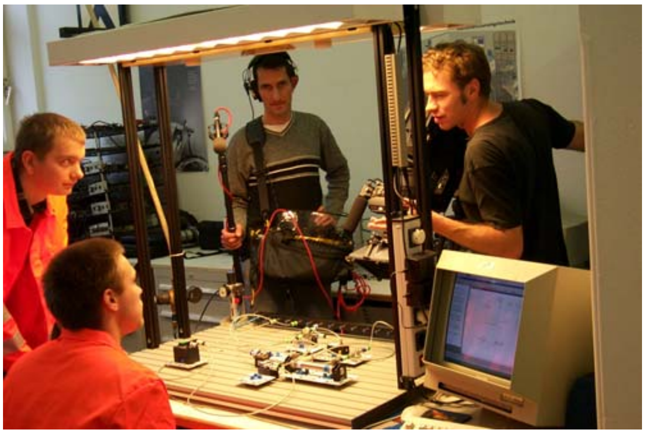
Figure 18: Derive Poster

DERIVE has been presented and discussed at several occasions:

- Project presentation at the first meeting of the Virtual Learning Communities Cluster in Bremen
- Project presentation for a representative of Festo's training department

- Project presentation in a workshop session at CVE2000 (Third International Conference on Collaborative Virtual Environments, sponsored by: ACM SIGCHI, SIGGROUP, and SIGGRAPH) in San Francisco
- Poster presenting the related FP4 project BREVIE at CHI2000 in Den Haag
- Project Presentation on the Conference "Network Event Lernnetzwerke und Wissensnetzwerke 2000" in St. Gallen/CH (09.08-31.08.2000)
- A lecture on a mechatronic workshop was held on 24th May at the Chamber of Handicrafts in Bremerhaven /DE
- Beyond Europe our project was introduced during a one week summer school seminar at the Korea University of Technology & Education in Cheonan (South Korea).
- In Bremen, an introduction of the BREVIE/DERIVE projects was produced for the German TV programme *"Nano"* on channel 3SAT.

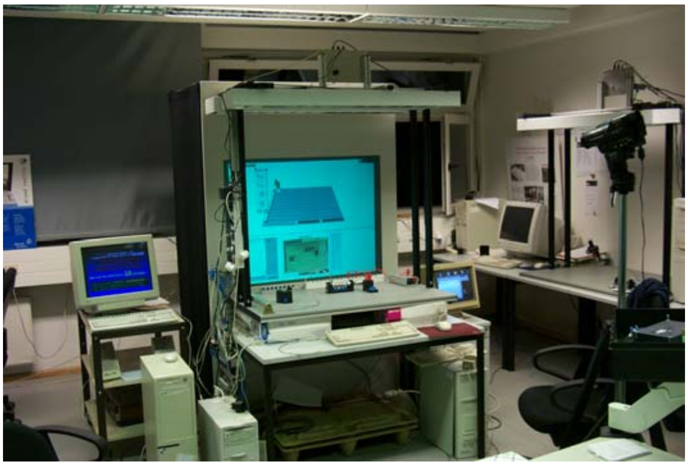
- BREVIE Evaluation: Lessons Learned presentation at the Concertation Meeting 8 – 9 January 2001 in Luxembourg
- BREVIE Research Result presentation and a one day DERIVE exhibition at the 12-14 February Online Learning 2001 Europe in London
- Multimediales Lernen: Wie wichtig ist die Gegenständlickeit? including a publication and an four day DERIVE exhibition together with Kai Schmudlach, University Bremen artec on the Mensch & Computer 2001 5-8 March 2001.



- DERIVE information event on the 8th December 2000 in Zurich with 52 companies, 16 vocational training schools and 8 ETH Institutes from all over Switzerland.
- 18th - 21th July 2001: Project presentation and exhibition at the International Workshop on Tele-Education in Mechatronics Based on Virtual Laboratories, Weingarten
- 3.-4.9.01: Project presentation at the IST Concertation Meeting in Luxembourg
- Summer 2001: Project presentation at the ARTEC research day in Bremen

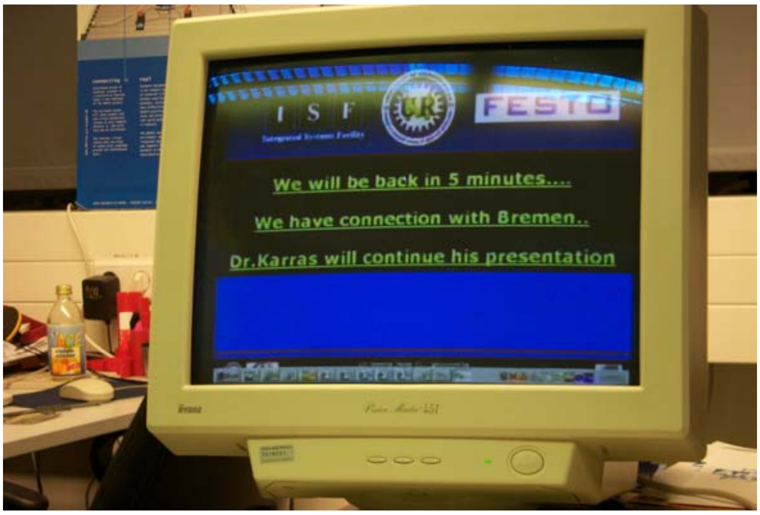
- 24. 4. 2001: Presentation of DERIVE at the I3-Spring Conference Porto (I3= Intelligent Information Interfaces) with two talks
  - "Learning in mixed Realities"
  - "Web-based cooperative Teaching and Learning of Mechatronics in vocational Education - New Forms of mixed Realities"

- April 2001: Publication Hyperbonds - Enabling mixed Realities, artec-paper 82
- 23. 6. 2001: Presentation/Exhibition of DERIVE at the Open Research Day of Bremen University



- June/July 2001: Presentation of DERIVE at the KUT in Korea
- 20.09.2001: Presentation of the DERIVE - Principles at the World-Skills-Competition in Mechatronics in Seoul Korea
- 9. 10. 2001: Presentation of DERIVE at the IFAC (Int. Federation of Automation Control) Conference on low cost automation
- 11. 10. 2001: Presentation of DERIVE at the 12 Years Anniversary Workshop of ARTEC about "Good Work? Good Technology? Good Environment?"
- 16.10 2001: Presentation and Online-Demo with ARTEC at "Real and Virtual Learning Environments for Integrated Manufacturing and Automation" at the University of Missouri-Rolla (USA)
- 19.10 2001: Presentation and Online-Demo with ARTEC at "NFPA's Educators' Summit" in Cleveland, Ohio (USA)
- 24.10.2001: Presentation and Online-Demo with ARTEC at FESTO USA in New York
- October 2001: Presentation of the DERIVE - Concept by Eva Hornecker at
    - Institute of Lifelong Learning - University of Boulder Colorado (USA)
    - Massachusets Institut of Technology (MIT), Tangible Media Group (USA)

- 30. 10. 2001: Presentation and life demonstration of DERIVE at the Supercomputing 2001 Conference in Denver, invited by the NSF in cooperation with NCSA and the EU-US steering group on e-learning Cooperation.



- 27. 2. 2002: Presentation at the workshop on Mixed Reality of the IFAP-ETHZ
- 12.-20.03.2002: Presentation of DERIVE by Bendit GmbH on the Bremen booth at the CeBIT, Hanover
- 11-12.03.2002: EU Concertation Meeting Luxembourg
- 15.-21.04.2002: DERIVE presentation on the Industrial Fair of Hannover at the stand organised by a consortium consisting of Festo, Bendit and others, Hannover
- 20.04.2002-22-04.2002 : EuroChina2002, Peking
- 23.-26.04.2002 : DERIVE booth (12qm) on Festo Didactic's booth at the World Didactic, Zurich

A conclusion of these activities drawn up by the industrial partner Festo is: There was an excellent feedback and numerous persons were very impressed. However, the market for such an innovative product must be further prepared first.

Feedback on the scientific level has been very positive. Beside the general scepticism of non-experienced scientists and novices in automation technology, who often rise the question: “Why do we need this complicated coupling of virtuality if we have good simulations?”, we have many supporting comments and astonished visitors who believe that this is a revolutionary concept, having the potentiality to change learning and working in the direction of a closer relation between Theory and Practice, the Abstract and the Concrete.

Benefits for Project Partners

Partner ARTEC benefited from the project in the development and partial implementation of the Hyper-Bond concept. This new, easy to use universal technology to merge real and virtual systems will open a new research and development field in

education, entertainment and work

related to research fields as embedded systems, mixed reality, distributed simulation, mobile computing, technology enhanced learning, integration of work-school-home.

ARTEC plans to participate in future EU research projects. MARVEL - Virtual Laboratory in Mechatronics: Access to Remote and Virtual e-Learning (EU-Leonardo), Lab@Future - School LABoratory anticipating FUTURE needs of European Youth (EU-IST), MobileCampus (BMBF) are first successful project follow ups. For the EU 6th framework programme, ARTEC is involved in several expressions of interest and will participate in coming calls.

Together with its Spin-off company BENDIT, ARTEC will promote the market penetration of this new technology.

Three parallel projects about “Mixed Reality Caves” at the University of Bremen are initiated by ARTEC and will investigate further applications of this new concept. National cooperation with the Fraunhofer Institute, as well as international cooperation with Stanford University -USA, KUT – Korea and first contacts with China (resulting from the EU-China Fair) will complement the European dimension.

Partner Festo benefited from the project in the development of the innovative concept of Hyper-Bond interface to create a mixed reality learning environment for mechatronics. Furthermore, Festo benefited extremely from the dissemination and marketing activities for the new concept of DERIVE during the project. These results gave Festo a very important feedback of customers to integrate the new technology provided by DERIVE into the further product development.

The school partners benefited from the project, in that the European dimension of learning in mechatronics, cultural similarities and differences in teaching and learning could be experienced. New modules of mechatronics-learning are now available and technologically supported. Remote access to complementary laboratory equipment is now possible.

IFAP benefited in the development of new evaluation methods and tools and a better insight into action oriented learning processes.

EUROPEAN ADDED VALUE

The new Learning-Environment will enhance the user-friendliness of the information society in a double sense:
a) mechatronic- and service-engineers will play a key role in supporting the usability of future information systems. Developing advanced training systems for these vocational groups is a prerequisite for user-friendliness,
b) the work place of future mechatronic- and service-engineers will be improved by user interfaces oriented towards concrete objects, providing a more natural use of computerised artefacts.

The improvement of quality of the individual's working life and the increase of competitiveness of small and medium enterprises (SME) are supported best, if key jobs, influencing future working conditions, are well supported with far reaching educational and technological concepts. Our new technology and tool for mechatronics will help to build secure, scalable and customisable technical systems and learning environments. In addition, it will also be supporting first encounters with the field of tele servicing. The tool itself will bridge different culture and language backgrounds, different levels of abstractions, different simulation traditions and the real and the virtual. This will have a strong impact on socio-economical and technological issues.

More and more European companies are imbedded in pan-European relations by either being distributed over several sites or by maintaining international business contacts. This also concerns SMEs. Though the technical sides of mechatronics are based on international standards, the pedagogical curricula and teaching concepts differ widely in the various regions of the EU and lack a standardised common basis, that would allow European mechatronically skilled workers and technicians to more easily cooperate internationally. These abilities are fundamental requirements for pan-European working mobility. This project aims at providing harmonised European courses in mechatronics, that are based on the user-demands from schools in several different EU countries. This would not be feasible in national projects. The courses contain one teaching unit of two modules to support the development of a European standard in teaching mechatronics.

The integration and convergence across information processing, communication and media will be supported by our learning environment, in that it integrates different levels of information about production systems (from topology to abstract control languages to technology assessment) with distributed means of communication between experts and users and extends the media notion towards graspability and concreteness.

DELIVERABLES

ID	Title	Date of Delivery (Planned)	Date of Delivery (Prev. Report)	Date of Delivery (Current Estimate)	Status (Actual or Expected)
11	Project Handbook and QA Plan	30.4.2000	05.05.2000	05.05.2000	A
21	User Req. Spec.	31.5.2000	12.07.2000	18.07.2000	A
14.01	Periodic Management Report 1	30.6.2000	07.07.2000	07.07.2000	A
13	Project Presentation	31.8.2000	02.10.2000	02.10.2000	A
14.02	Periodic	31.8.2000	06.09.2000	06.09.2000	A
31	Courses Req. Spec.	31.8.2000	02.10.2000	02.10.2000	A
41	System Req. Spec.	31.8.2000	02.10.2000	02.10.2000	A
51	Evaluation Req. Spec.	31.8.2000	02.10.2000	02.10.2000	A
62	Preliminary Prod. Spec.	31.8.2000	21.12.2000	21.12.2000	A
12	Consortium Agreement	30.9.2000	24.11.2000	08.12.2000	A
61	Dissemination and Use Plan	30.9.2000	07.2001	08.08.2001	A
22	Organisation Concept	30.9.2000	21.12.2000	21.12.2000	A
14.03	Periodic Progress Report 1	31.10.2000	20.11.2000	20.11.2000	A
14.07	Cost Statement 1	31.10.2000	04.05.2001	04.05.2001	A
14.04	Periodic Management Report 3	31.12.2000	26.01.2001	26.01.2001	A
42	System Des. Spec.	31.1.2001	07.2001	18.09.2001	A
14.05	Periodic Management Report 4	28.2.2001	29.03.2001	29.03.2001	A
32	Courses Des. Spec.	28.2.2001	07.2001	08.08.2001	A
52	Evaluation Des. Spec.	28.2.2001	22.06.2001	22.06.2001	A
63	Exploitation Plan	28.2.2001	08.2001	02.11.2001	A
14	Annual Report	31.3.2001	27.06.2001	27.06.2001	A
14.06	Periodic Progress Report 2	31.4.2001	13.08.2001	13.08.2001	A
23	Consolidation, Valid. and Verification	31.3.2001	07.2001	08.08.2001	A
14.08	Cost Statement 2	30.4.2001	09.2001	04.10.2001	A
15.01	Periodic Management Report 5	30.6.2001	16.07.2001	16.07.2001	A
15.02	Periodic Management Report 6	31.8.2001	18.09.2001	18.09.2001	A
33	Courses Development	30.9.2001	02.11.2001	02.11.2001	A
43	System Implementation	30.9.2001	02.11.2001	02.11.2001	A
53	Evaluation Development	30.9.2001	02.11.2001	02.11.2001	A
64	Market Strategy	30.9.2001	02.2002	11.06.2002	A
15.03	Periodic Progress Report 3	31.10.2001	02.11.2001	02.11.2001	A
15.07	Cost Statement 3	31.10.2001	03.2002	25.06.2002	A
15.04	Periodic Management Report 7	31.12.2001		09.01.2002	A
34	Courses App.	31.12.2001	03.2002	16.05.2002	A
44	System Inst. and Refinement	31.12.2001	03.2002	20.06.2002	A
15.05	Periodic Management Report 8	28.2.2002	20.03.2002	20.03.2002	A
54	Evaluation Appl.	14.12.2001	19.03.2002	19.03.2002	A
55	Evaluation Anal.	28.2.2002		20.06.2002	A
65	Technology Impl. Plan	28.2.2002		09.2002	E
15.06	Final Report	31.3.2002		18.12..2002	A
24	Final Project Analysis and Presentation	31.3.2002		20.06.2002	A
15.08	Cost Statement 4	30.4.2002		18.12.2002	A
15.09	Periodic Progress Report 4	30.4.2002		21.06.2002	A

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