An Application to Training in the Field of Metal Machining as a Result of Research-Industry Collaboration

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Abstract

This paper describes how a close collaboration between research and industry organized through a global network, enables new developments in virtual reality both in research and in companies. This collaboration will be described in the field of vocational training for adults. A virtual environment for training is dedicated to metal machining sector. It is currently being developed thanks to a close collaboration between several research laboratories and companies. It aims at solving expected training difficulties, and, thereby, at facilitating learning.

Key Words

Virtual Reality, Training, Design, Industry-Research Collaboration

Introduction

The development of close collaborations between research and industry has been a recent topic in the field of virtual reality. The French Ministry of research has funded a specific program in order to facilitate such collaborations between industries and research in virtual reality technologies. The assumption is that virtual reality may enhance company productivity and competitiveness by using new means that can accelerate the product lifecycle from design to maintenance. This program called Perf-RV is organized as a global framework in which different sub-projects have been developed. We will first present the Perf-RV context and the particular modes of contribution that emerged from those collaborations dealing with economical, sectoral and engineering issues. We will then reach the main topic of the paper, which is how those economical, sectoral and engineering issues are met during the design process of a virtual environment for training in the context of a research-industry collaboration. Therefore, we will develop and discuss the design process of a virtual environments for training called "Virtual technical trainer" (VTT). VTT is dedicated to the training of operator both on milling machines and technicians of industry. The VTT project will illustrate how those three crucial domains (economic, pedagogy, engineering) are articulated together.

Perf-RV

Major French companies[i] and laboratories[ii] involved in virtual reality are involved in Perf-RV program [ARNALDI, 2003]. Perf-RV stands for Virtual-reality platform. It is also known as the "Research and Development Department of the Future". The program supports both a network of partners, which can share means and knowledge, and a set of workshops focusing on particular projects organized in four topics:

- This first topic is focused on haptic interfaces and their applications in relation with large immersive visualization displays. One particular issue has been the acquisition of data when haptics and vision have to be coordinated.
- The second topic is focused on multimodal interfaces and cooperation between local and distant co-workers. It provides distant users with interfaces enabling multimodal interactive cooperation. Therefore, it integrates the topic of data exchanges between distant databases and distributed servers.
- The third topic is focused on manual assembling and fixing in companies concerned by production and maintenance activities. The project includes both direct manipulation using different kind of haptic devices, comparisons between real and virtual manipulations and simulations of manipulations based on virtual humans.
- The fourth topic is focused on applications of virtual reality for training. This aspect is further developed in the remaining part of the paper.

Over the entire project, it is possible to notice how haptics and multimodal coordination represent a key issue.

The three crucial domains encountered through industry/research collaboration

Contrarily to most classical approaches, which are centered either on research or on industrial problematic, this particular approach is organized as a crossway between those two worlds. Therefore, in the context of Perf-RV, the design of a new application is both driven by a strong interaction between research and industry and by considering different domains that impact industrial requirements. The design of an application is grounded on a set of requirements, which define what is expected to be produced, and how it is supposed to be used. Industry typically requires efficient and cost-effective products that may improve existing processes. Research is concerned with the production of new knowledge and innovative solutions within the engineering domain. Other impacts are encountered through three problem domains: economics, specific issue of the domain, and engineering. To make a development fit with economical constrains is a critical issue when commercial activity may be engaged using those systems. Due to their main activity, each industry encounters specific issues it has to deal with. Those issues are fully taken into consideration within each sub-project. Using virtual reality leads companies to face their lack of skills to design virtual environments and to deal with specific engineering issues. They have either to acquire new competencies or to collaborate with experts of the field. The design of a virtual environment for training gives rise to many engineering issues belonging to three distinct but highly interrelated areas in virtual reality: hardware, software, and ergonomics.

Research/industry collaborations in the design of virtual environments for training

This paper will not develop a state of the art on how virtual reality has been used in training and educational sectors. For a review on virtual reality for training and learning purposes, see e.g. [Bevan, 1997; Mellet-d'Huart, Mellet-d'Huart et al. 2001; Mantovani, 2001; Burkhardt et al. 2003]. Advantages and limits of virtual reality for training have been discussed elsewhere [e.g. Winn, 2002a; Lourdeaux et al., 2003]. The following part is essentially focussed on the Research/industry collaborations for the design of training virtual environments.

There are few research/industry collaborations documented, since the seminar Motorola's training application [Adams et al. 1995]. In fact, most of the developments adopt a research orientation. For example, STEVE [Rickel, 2001], a virtual agent, is now used in a virtual environment in order to prepare lieutenants from US Army to peacekeeping mission [Marsella et al. 2002]. In this research context, no economic requirements are met. Developing the most accurate virtual environment supported by the best technology has been the essential focus. However, educational requirements were based on industry needs.

The following table shows the respective efforts and contributions of industry and research partners. It shows how, in classical sponsored research projects, industry takes mainly the position of sleeping partners defining the goals to be reached, and then waiting for results.

	Research	Industry
Economics	No	No
Pedagogy	Integration of emotion as a structuring component of virtual environments	Learning to act in stressful situations
Engineering	Emotional agents Architecture enabling evolving scenario Integration of components Immersive environment	No
Design process	Scenario oriented development	No

Research/industry distribution of efforts in Mission Rehearsal Exercise Project

On the opposite side, recent applications have been developed with a strong influence of industry-based requirements. For example, WAVE[iii] developed by AFPA and CS, is dedicated to helping learners to acquire basic welding schemes. WAVE has been designed with a close collaboration between educationists, experts at welding, and developers on the computer-science side. As far as WAVE is dedicated to be disseminated in training centers, very strong economical requirements have been met. For example, the savings realized by not using real welding devices and material, must enable training centers to buy the workstations. WAVE can be reimbursed on a two-three year period of use.

The table, in this particular case, shows that, although technologies may be very recent, in a perspective of industrialization, the development is fully realized by industrial partners.

	Research	Industry
Economics	No	Strong economical requirements
Pedagogy	No	Solving training difficulty about welding schemes acquisition
Engineering	No	Usability
Design process	No	Co-conception: Education Technical expertise Computer sciences

Industry/industry distribution of efforts in WAVE Project

Very little interactive cooperation between research and industry has been described in literature regarding the development of virtual environment for training. The following section will describe a project in which both research laboratories and companies play an active role.

The Virtual Technical Trainer project

In the context of Perf-RV, the Virtual Technical Trainer (VTT) is a virtual environment dedicated to the training of operators and technicians using metal machining. Partners coming from industry and research have collaborated on the VTT project, in the context of PERF-RV. Industrial partners are CLARTE, AFPA, and SimTeam. CLARTE initiated the project, provided technical means, and supported the developments. AFPA as a vocational training organization has been a natural end-user, but has also contributed actively to the conception of the virtual environment for training. SimTeam implemented initial software developments. Research partners are INRIA, LEI and ESIEA. ESIEA supported the development of a new haptic device and provided a large software support. INRIA supported both the whole process of Perf-RV and the particular developments to experiment and adapt the concept of pseudo-haptics to the particular project. LEI has contributed by providing ergonomics expertise through the whole project. University of Le Maine/ISTIA, University of Bourgogne and ESIEA provided the project with trainees who contributed to different phases of the project.

The initial problem requirements

As a vocational training organization for adults, AFPA uses a pedagogy based on learning by doing in job-like situations, solving, thereby, the major educational question of transfer of learning. It enables former trainees to go and work directly and efficiently in companies. The pedagogical approach is based on concrete work situations. The trainee learns while completing the activity he/she is asked to complete. Nevertheless, learning is a complex process that needs to be progressive and to be adequately structured. One has to be sure that a learner knows all the basics that will be expected to know in order to complete a new task. This is quite easier to complete when a process can be observed, corrected or stopped when necessary. Not every job situations make it possible. Theory is only provided when required to complete a particular task. Furthermore, theory is always delivered in the context of a concrete activity, since AFPA's trainees usually do not feel at ease with abstraction. Although this pedagogy may be efficient, some learning difficulties remain [Michel, 1996] and new ones do appear essentially due to the introduction of new numerical interfaces in job situations. The "dematerialization" of work situations introduces new educational difficulties as we might see further. In this context, AFPA was interested in applying virtual reality to solve learning difficulties that were met in training centers by its trainees.

After we had considered what already existed and made a state of the art, the starting point of the project was a survey realized within the training center of Laval in order to bring to light significant learning difficulties. Several significant learning difficulties were registered through different sectors such as building, industrial maintenance, and metal machining. The last sector was retained for three main reasons. The problem analyzed was characteristic of effect of "dematerialization" of work situations. It might require haptic devices (this was whished by the all partners for research and development purposes). Trainer's motivation was high. They could imagine at once how virtual-reality-based training resources could open up new perspectives and new pedagogical developments. Once the topics had been defined and the team constituted (the team was composed by trainers, educationists, computer scientists, professionals from industry, and researchers in electronics, computer sciences, ergonomics), the project focused on analyzing and developing hypotheses about how to solve a foreseen difficulty in the metal machining sector.

Laval based AFPA training center offers two training courses developing skills involving metal machining. The first one is a training course for operators who will conduct numerically controlled milling machines. The second one prepares future technicians specialized in the design of industrial moulds for manufacturing plastic objects. Most of those moulds are produced by metal machining process. Therefore, even if they do not directly use machines, trainees have to know perfectly well what is possible or not with machining process. For the operators, the training period currently proposes a first training period, when exercises are done on traditional crank machines. By manipulating these old machines, the trainees gradually discover, how the machine works and reacts and how much effort the machine should produce in order to complete the process. Those efforts depend on variables and choices made by the operator. During a second period, trainees operate on numerically controlled machines. This progression is due to teaching difficulties resulting from characteristics of numerical control. In fact, the generalization of numerical control on machines gives rise to new pedagogical difficulties. Indeed, numerically controlled machines do not let a learner have perceptive feedback of the process; neither can he/she modify the process once it has started. Such machines are fast, well protected, and require to be programmed in advance, implying that no corrections are allowed in the course of the process. If, up to now, training organizations have been using old crank machines to train new learners, it might soon not be possible anymore. Such machines are about to disappear because they are hardly manufactured any more. In order to anticipate the future situation where no more crank machines will be available, AFPA along with the other partners of the project decided to deal with this particular topic.

Pedagogic working hypothesis

Before designing any solution, an important step consists in making hypotheses about how learning could be facilitated. Then those hypotheses will be evaluated on both educational efficiency and feasibility. One important criterion focuses on the re-organization of the perception-action loop that supports the activity in order to support learning, and the involvement of body actions [Winn, 2002b]. As old crank machines provide the operator with sensorial returns that inform him/her about the current efforts of the machine, a simulator of such a machine could have been developed. This was hypothesis 1. Hypothesis 2 was oriented to an unknown solution that could provide a learner with a more direct haptic feedback. How could we make the learner feel how the modification of variables may impact the strength the machine has to develop in order to machine the piece of metal? This question was answered through a metaphor. The effort engaged by the machine is mainly due to the activity of the tool on the metal piece. In order to feel it, the learner could come as close as possible to that point. Therefore, he/she will be holding, moving, and pushing himself/herself the cutting tool in order to machine. By doing that, the learner might be in a better position to predict efforts required by the machine depending on values fixed for the different variables. Using VTT, he/she could control his/her predications. Another expected educational topic will focus on the exploration of the limits of values that can be used to machine and the observation of what may happen when the user goes past those values.

The expectations in the field of metal machining are not only to develop an efficient alternative to the use of crank machines, but also to introduce an added value by improving training method and enhancing learning facilitations. A critical issue would be to help the learner develop adequate mental models of the process. An other one focuses on apprehension of limitations and risks by developing their understanding and experiencing them in virtual environment. The management of resources and economical factors is also an important issue for future skilled workers or technicians. The adaptation of the tool for different publics (such as operators, technicians…) is important. The software development will offer future trials to those questions.

Description of VTT

A force feedback device is used so that the user may directly handle the turning part of the tool, make it move, and feel the reaction of the machine. VTT system is made up of a regular screen monitor as visual display where the milling process is represented, and of a force feedback device. Three types of haptic interaction have been implemented within VTT using first a generic haptic device, secondly a dedicated device designed for VTT, or, more recently, a simple input device combined with a pseudo-haptic feedback.

Tests and design process

The VTT project has been conducted now for some four years. It is still under development. Up to now, three prototypes have already been developed. Each one implemented a different solution regarding haptic feedback.

First prototype: PHANToM Desktop solution

The first prototype used a on-the-shelf haptic interface that was a PHANToM Desktop solution from SensAble Technologies. Before going further and implementing educational hypotheses, the usability of the device was to be checked. Therefore, it was tested by three different groups of trainees. Group A was made of 5 novice trainees who knew nothing about machining, and currently trained in some other domains. Group B was composed of 11 future operators on numerically controlled milling machines. Group C was made up of 12 future technicians who will not directly operate on a machine, but have to know what can be processed using machining and what cannot be processed using machining. The three groups were asked to answer a questionnaire in order to evaluate their pre-acquired knowledge on machining. The five trainees of group A and three trainees of group C were effective novices. After that, they interacted with VTT. They were given a limited period of time to explore the system, and then, were asked to complete a machining process on a virtual metal parallepiped. They had to remove one quarter of the metal and comment on their action. The trainees-VTT interactions were videotaped for 12 of them. An informal analysis of the collected protocols enabled us to draw the following main results.

VTT: PHANToM Desktop solution

The pre-acquired knowledge about machining did not have significant effects on the performances. For the three groups, the results were mainly identical, except for Group B, which had more precise and more efficient gesture. Only non-novice trainees of Group C made changes in parameters by themselves (*e.g. modification of rotation speed of the tool*). The force feedback device was globally appreciated, although the trainees reported that the modification of variables (*dept of machining, speed*) was not perceived as strictly being reflected by a variation of the force feedback. The force feedback did not always fit with their expectations, being either too strong or too weak. The trainees' arm get rapidly tired by being continuously obliged to handle the Phantom. The 6 *dof* provided by he Phantom were unnecessary, adding complexity to the task, since 3 or even 2 *dof* were actually required. Thus, handling the stylet induced circular movements that were difficult to correct when linear trajectories were expected. As the computer over-loaded, the quality of the force feedback declined and the device started vibrating and jumping (*some trainees experienced up to 9 times such "jumps" during their trials*). Finally, the Phantom quickly reached saturation and an alarm signal had to be implemented in order to stop the trainee's push. As a conclusion, we decided not to go further using the Phantom device. Obviously, it did not fulfill the necessary requirement for educational developments because of a lack of discrimination, and ergonomical constraints, which did not fit with the task. Either another interface was to be developed or experiments were to be abandoned. CLARTE decided to design a new haptic interface for the project and software enhancements were provided thanks to those pre-tests (*modification of the viewpoint, simplification of the scene, an upper view is provided in order to precisely locate the tool in regard with the piece, implementation of different tools and different shapes of metal…*).

Second prototype: a dedicated haptic interface

ESIEA research laboratories went on along with CLARTE to design and develop a new force feedback device. An ad hoc device has now been developed to fit with the *dof* and constraints related to the learning task. It is a dedicated 2 *dof* haptic interface. The prototype provides linear movements, enables light or strong force feedback, and is robust and very cheap.

This dedicated device is currently being pre-experimented. Its pre-experimentation is industry-oriented rather than research-oriented. It intends to provide some trends but no scientific validations. Research-oriented experiments will take place later on. The pre-experimentation is submitted to 6 trainees who entered a training course for operators on numerical controlled milling machines (cf. Group B in the previous experiment). Three informal tests are performed. The data analysis is in progress but we may already say that it should confirm our hypothesis about having a training resource available for beginners that provides them with haptic feedback correlated with the effort of a machine depending on chosen values for the basic variables. VTT would thus fulfill the expected requirements for further educational developments and thus it may be used to support effectively training sessions.

VTT project: a specific haptic interface developed by CLARTE with ESIEA

Third prototype: a pseudo-haptic solution

The third haptic interface is a simplified solution using isometric input devices and pseudo-haptic feedback in order to simulate haptic sensations without haptic interfaces [Lécuyer et al., 2000; Lécuyer, 2001]. This interface is still under development and will combine visual and audio data with haptics. It will use either a spaceball or a spacemouse as a haptic interface. The correlation between action on the passive interface to move the tool and modification of speed of this move depending on resistance of the metal as seen on the visual display is supposed to generate an illusion of perception. That is still to be experimented during the research-oriented experiments. The aim pursued by industry is to check whether this concept of pseudo-haptics might be pertinent and efficient in the context of learning activities.

The three crucial domains in VTT

In training organizations, industrializing requires dealing with three major problem domains: economics, pedagogy, and engineering.

Economical issues

Training organizations require numerous virtual-reality workstations for their trainees if they want to use them on efficient bases (clearly, this is not the case in the context of research labs or even in R&D departments where only one or a small number of Virtual Environments are usually necessary). Even if learning was supported in a more efficient way with Virtual Reality than with other existing resources, such systems would not be generalized since they are as expensive as large full-scale simulators. The economical model could be effective only if virtual environments for training:

- enables direct savings on training costs, and if the savings may cover the cost of the systems.
- increases training efficiency by reinforcing learning or speeding up training processes.

Up to now, virtual reality may have suffered from the reputation of rising high costs. However, computers for virtual reality are now cost-affordable. Furthermore, even if most haptic interfaces and large visual displays remain expensive, one issue of the research/industry collaboration is to elaborate on economics together with pedagogy and engineering concerns. Lowering the cost of interfaces, and especially of haptic interfaces, remains as a necessary issue in the use of virtual reality for training. Actually, vocational training often prepares to activities including a large range of behavioral schemes including gestures and body movements. Furthermore, the available haptic devices are currently very expensive. Therefore, the project will especially focus on efficient and affordable haptic solutions for training. Lowering the cost of interfaces, and especially of haptic interfaces, remains a fundamental issue in the use of virtual reality for training.

Because of the fact that the cost of expendables for training in the field of machining is not that expensive, it means that little saving may be done and that the final system will have to remain cheap although it may use haptic devices. A consequence in terms of economics requirements is that the cost of the complete system should not go over five thousand euros. Fitting with such requirements, VTT system might be used in all training courses dealing metal machining. In terms of engineering requirement, the previous economics frame implies that current haptic interfaces of the market cannot be used. The current developments encounter those requirements.

Pedagogy

Pedagogy is a specific and major issue for AFPA. As a training organisation, it has to cope with two main classes of issues:

- training problems that have not been optimally solved yet, for example in terms of efficiency or cost;
- new emerging problems, for example when new technology and new skills are concerned.

As far as technological issues often over-influence pedagogical aspects, one may consider two main issues for the training sector. Firstly, educational issues have to be taken into consideration as soon as the design process starts. Secondly, setting up pedagogical scenarios (bridging objectives with methods and contents) is a major topic. It will precise how the system should be used as well as the roles devolved to learners, trainers and virtual environment for training. Those developments will reinforce the pedagogical accuracy of the system. If those developments were missing, the virtual environment for training may even be of no help for learning. A particular pedagogical problem is tied with the heritage of simulation in virtual reality. The logic in which simulators have been developed remains imitation and substitution to real equipment, which cannot be used because of risks or cost. In this sense, they are not actually designed to solve pedagogical problems, that is to support the learner when learning is especially difficult and when other existing training resources are missing to support learning difficulties. Very recently, developments tend to be less and less reality-like oriented but to focus on how to reorganize virtual environments as a specific space, where action and perception are reorganized around key concepts that have to be learnt.

Minimal educational requirements would be to replace with the same efficiency the learning function previously supported by the old crank machine during the first steps of learning. Regarding virtual reality technologies, more is expected that simply replacing old learning situations. VTT is expected to reach a higher level of efficiency in facilitating and supporting the learning process. VTT offers opportunities to test virtual reality based solution in order to support learning and trainers' strategies. The pedagogical issues involve the development of adequate situations of use for virtual reality to facilitate learning. Some more software developments have to be done. Nevertheless, main aspects are twofold. First, training organizations are interested in getting knowledge about the real efficiency of virtual environments for training. Secondly , they wish to acquire appropriate design methods in order to solve learning difficulties with virtual reality.

Engineering

Engineering a new training resource will lead to face different kinds of hardware, software questions as well as ergonomics. In this particular project, the focus has been orientated toward (1) haptic issues; (2) integration of ergonomics concerns and methods during the whole design process; (3) integration of training and educational requirements and feedbacks during the whole design process. The design of a virtual environment for training gives rise to many engineering issues belonging to three distinct but highly interrelated areas in virtual reality: hardware, software, and ergonomics. Training organizations are not familiar with these approaches and have to be helped by experts.

Regarding hardware, the focus has been put on haptic device, and how to lower the cost, increase efficiency, as well as limiting functionality to what has been required for educational purposes. Throughout all the steps, hardware had been tested and evaluated by end-users (trainees and trainers), reorienting the project when necessary. The software approach has been complementary and is still under development. First requirements were to reach a satisfying level of usability for the interfaces. As far as this criterion is reached, software developments will now support pedagogical requirements. New tests and evaluations with learners enable the design team to adjust the functionalities until a correct level of enhancement of learning might be reached. The visual interface has to be simplified in order to help users to focus on important data. Some other data were reinforced or reified [Winn, 1993].

Ergonomics was mainly concerned in VTT with the following three aspects: (a) user model and needs; (b) context of use and usability; (c) methods and criteria to design requirements and to evaluate the system at the various stages of the project development. Although these aspects are related to existing ergonomics and human-factors methods and knowledge [Burkhardt, 2003], current practices have been mainly developed in other areas than virtual environment, i.e. for WIMP-based interactive systems. Furthermore, ergonomics usually deal with expert users having the goal of performing their well-known task with the new tools to be designed. Ergonomics methods and empirical validations related to systems supporting learning and training activities remain far less developed today. The specificity of VTT as a virtual environment for training explains that the ergonomics intervention was also strongly oriented to address the corresponding research issues, for example specific adaptation of methods and criteria to fit with the design of a Virtual Environment for Training. This is an important point, since it means that each new result from research provides directly the industry with a step forward within the innovation.

Discussion

Interaction between industrial requirements and research developments constitutes the key topic of VTT projects. If an effective training resource based on virtual reality supports the development of the project, wider issues (haptic interfaces, design methods…) are treated meanwhile. The following table shows in the particular case of VTT, how collaboration between research and industry takes place, and how the design process is approached as cooperation. Effective requirements may orient research development and these new developments are immediately integrated in system that are tested and evaluated in real training situations.

	Research	Industry
Economics	Development of low cost interfaces	Low cost interfaces requirements
Pedagogy	Integration of pedagogical data in the system	Introducing of pedagogical components based on learning activity analysis and testing.
Engineering	Integration of ergonomics, software and hardware developments	Development of prerequisites for pedagogical usability
Design process	Development of an integrated design process	

Research/industry distribution of efforts in VTT Project

VTT is a project oriented towards innovation. In this context, the contribution of ergonomics was complementary with the other participants, so that ergonomics expertise could be exploited "in real time" during the evocation of possible innovative scenarios. When the various design alternatives were elaborated and discussed, each participant elicited its specific viewpoint, i.e. economics, pedagogy, hard and software engineering, ergonomics, etc. An interesting consequence was that, in the case where a solution was argued as feasible from a specific viewpoint (e.g. economics), then alternatives were provided and complemented by other viewpoints, and the resulting solutions were clearly generated from a complex combination of these different viewpoints. What the sharing of each viewpoint during design provided is threefold. First, the state of the art and the specific constraints of each crucial domain were explicitly shared between the various participants; second, concrete scenario of how the system may be used by trainees and trainers, together with the resulting constraints were anticipated simultaneously from each viewpoints to get a coordinated and consistent image of the possible system; third, the constraints of evaluation were also explicitly shared and a rapid agreement came about the different levels (and viewpoints) of evaluation that should be distinguished and carried out during the design lifecycle.

Conclusion and perspectives

This paper shows how close collaboration between research and companies may lead to new solutions and maybe to efficient products. Particular progress has been realized in the training sector thanks to such collaborations. Particular difficulties were met on the design process and on the force feedback devices. On those two topics progress have been accomplished. Experiments are going on three more topics: ergonomics tests of the new dedicated force feedback device, usability of pseudo-haptics applied to training, and educational use of virtual environments for training to support learning. As an industrial company, AFPA would surely not have tempted on its own to use virtual reality for training, using modalities where haptic devices would be required. Only a longer-term perspective and a close collaboration between industry and research have allowed such a challenge. Based on both pedagogical and economics requirements, research partners developed an haptic interface that, although it is still under tests, seems to be perfectly relevant to the application and to the economical context. The design of the new interface was oriented by data issued by ergonomics experts and trainers' expectations. Important economical improvements have been completed toward the capability of developing low cost virtual environments, which are required in order to assure the future and the usability of these technologies in training centers. Finally, VTT is expected to open up a generic frame of reference in design methodology of virtual environments for training. We hope to learn about how to deal with specification of interfaces, ergonomics adaptation, pedagogical developments and uses.

Industrial partners are now expecting to learn from the VTT project about how to reach a good compromise between simplification of the virtual environment and of the interfaces, and the facilitation of learning in vocational training environments. The current teachings focus on two topics. The first one concerns the system design process (making pedagogical intentions explicit, choosing metaphors, reference to a real scene or distance taken with realistic representations, taking into account ergonomics…) and emphasizes the importance on interdisciplinary collaboration and on close cooperation between practitioners and researchers. The second point focuses on the choice of interfaces and how adequate they have to be in order to make the intended uses possible or not. We reached the limitations of the Phantom in the context of VVT project. The development of an alternative interface was a condition to pursue the project. The new and current step in the development of VTT consists in implementing and testing pedagogical uses. Three goals will be developed:

- The understanding of the main qualities of the machining process and the development of basic mental models of the role of each variable on the global result.
- The understanding and experiencing of limits and dangerous situations that cannot be approached in real situation.
- The integration of economic components of the practice of machining (taking into account the wearing of the tools…).

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[i] *EADS, DASSAULT Aviation, RENAULT, PSA Peugeot Citroën, ALSTHOM, HAPTION, CLARTE, IFP, INRS, GIAT Industrie, ADEPA, EDF, and AFPA*

[ii] *INRIA, CEA List, ENSAM, LaBRI, LRV, ENSMP, CNRS LIMS, and Orléans University*

[iii] *http://vr.c-s.fr/wave/*