How is VR used to support training in industry?: The INTUITION Network of Excellence Working Group on Education and Training

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Abstract

INTUITION is the European Network of Excellence on virtual reality and virtual environments applications for future workspaces. The purpose of the network is to gather expertise from partner members and determine the future research agenda for the development and use of virtual reality (VR) technologies. The working group on Education and Training (WG2.9) is specifically focused on understanding how VR is being used to support learning in educational and industrial contexts. This paper presents four case examples of VR technology currently in use or development for training in industry. Conclusions are drawn concerning future development of VR training applications and barriers that need to be overcome.

1 Introduction

INTUITION is the Network of Excellence on virtual reality and virtual environments applications for future workspaces. It is funded by the European Union under the 6th Framework programme on Information Society Technologies (IST-507248-2). The network has 58 members from different backgrounds including large industrial organisations, small to medium sized enterprises, research institutes and universities across Europe. The scope of the network is organised into 11 areas of interest or “working groups (WGs)” that represent different applications of the technology (Aerospace, Training and Education, Construction and Energy, Medicine, Entertainment and Culture, Automotive and Transport) or are general related topics (Augmented Reality, Evaluation and Testing, Design and Engineering, Haptic Interaction, VR Technologies). This paper describes the activities and outcomes of working group on Education and Training (WG2.9), particularly with respect to applications in industry.

2 Use of VR learning in industry

Training is an important aspect of any industry as it is necessary that employees are equipped with the skills and knowledge required for their work, but also in order to maintain some competitive advantage. Investment in training can be costly and therefore it is important to consider solutions which are appropriate and flexible to change. In competitive environments there is continual pressure to minimise these costs and improve upon the training provided. Virtual reality (VR) and the virtual environments (VEs) they create have the potential to address this need. VR has attracted a lot of attention due to its potential to augment training programs and provide additional benefits to the learning process while minimising the overheads. In addition, as Brough et al. (2007) identified, due to increasing complexity of rapidly changing technologies it is important to maintain a competent workforce and that to achieve this, existing training methods can be improved in terms of cost, effectiveness, time expenditure and quality, through the use of virtual environments.

The variety of benefits that VR can provide to industrial training applications is wide. Firstly the use of a virtual environment can be designed in order to recreate a scenario that otherwise can not be recreated in a ‘real’ situation whether this be due to cost, risk or the task in hand being destructive or the availability of resources. The scenarios can represent real and abstract three-dimensional environments which enable training familiarization without risk to the trainee and at minimum expense. It can, in principle, engage the trainee’s different senses and therefore essentially affords the experience of the learning environment in a similar way to the real working environment. Virtual objects can be capable of behaving as they would in the real world; the trainee can activate them accordingly and can virtually practise the desired
skill and receive instant feedback on the consequences of their actions, serving to reinforce the training without anxiety or injury.

VEs have the potential to provide additional information that other more traditional training tools may not. It can support learning at different levels (novice to expert) by providing a number of VEs with varying degrees of complexity based on the trainee’s level of understanding. Importantly, VEs are not constrained in a pre-defined form as are video or animations; the trainee can try out different methods to reproduce the same outcomes. Progress can be tracked and automatic records may be generated to monitor progress and a system can be designed to provide feedback to the user during interaction.

Virtual environments can also provide the ability to display and visualise factors that are invisible in reality (e.g. forces and wind). This can enable the user to understand better why things happen and work has been undertaken in this area with particular interest to education for children (Cobb and Stanton, 2005; Roussou, 2004). Veltman (2001) describes how scientists are using the technology to be able visualise many intangible concepts. The ability to visualise invisible concepts can help in the understanding of the effect that they have and thus the understanding of how it affects a task in hand. The potential for learning using VEs may be great as specific skills can be practised and observed from different viewpoints, and the information learned may be presented in meaningful and concrete ways, and the experience itself can be the basis for group discussion in the classroom. Other ways in which VEs can support education are through self-directed activity, naturalistic learning and increased motivation (Moshell and Hughes, 2002; Winn, 2002).

In addition VR technology has the ability to enable distance training, utilising networking tools or the internet, VR can bring equipment and working conditions to the user for unlimited access in any location. Thus it has the ability to remove costs associated with travelling as well as removing the need for access to expensive equipment and removing machine downtime for training. Remote distribution of the system can also enable training of large number of users, removing the need or at least reducing the need for one-to-one, classroom based, tuition, which should in turn result in lowering the incurred training costs.

One of the distinguishing features of VR is the concept of “Presence”. There is much debate in the academic literature on what Presence is, how it is measured, and how it supports learning (e.g. Slater, 2003). Much of the discussion has focused on the importance of fidelity of the virtual environment and visual ‘immersion’ of the user (e.g. by using a head mounted display or CAVE display system) and assessment of how well these support user performance in VR/VE tasks (e.g. Pausch et al., 1997; Bowman and McMahan, 2007). Applications of immersive VR for training employees in industrial processes have been reported in the literature. In Mavrikios et al. (2006) a VE has been developed to support training in manual welding processes using immersive VR, while Chryssolouris et al. (2000a; 2002) present a virtual machine shop as a planning and training tool for machining processes (e.g. machine tool setup, NC part program execution) and Chryssolouris et al. (2000b) immersive VE for training in manual assembly operations is discussed.

Collaborative training can also be facilitated for team tasks, again with the benefit of distributing the system across distance, enabling teams of users to train together. Training of scenarios such as emergency response where the task require the subjects to work together and communicate, including response to vehicle accidents or fires, are suited to utilise VR technology due to the risk of recreating the environment. The ability to use collaborative environments such as the one presented by Binsubaia et al. (2004) enable the environment to more closely match the real situation. Systems using this have also been to train leadership of teams such the system presented by St. Julien and Shaw (2002) for training fire-fighter team leadership.

Perhaps most importantly, VE training potentially offers an innovative, interactive delivery method and its value may lie in the fact it increases the motivation levels of trainees by providing an enjoyable training experience.

3 Working group on VR Education and Training

The scope of the INTUITION working group on VR education and training (WG2.9) is wide and varied, reflecting the interests and competences of its members. It is one of the largest groups in the network covering the range of learning from school children to adults, in mainstream and special needs areas. Education is generally an important issue to most societies and most industries are interested in training. Therefore it is difficult then to limit the scope of this group to particular technologies and domains, instead it is interesting for different groups, e.g. education theorists, industrial trainers, VE developers and researchers, etc., to come together and share experiences and knowledge.
One of the objectives of the working group is to understand the attributes of VR which support learning in order, ultimately, to develop guidelines and recommendations for successful design and application of VR technologies in education and training. The working group has defined six research areas that will help to meet these objectives:

1. Training needs and models of learning
   To develop appropriate learner centred pedagogy, theories and models for participation in and learning through VR/VEs.
2. Learning support methods
   To provide greater understanding of which characteristics of VR technologies and VEUs support which type of learning and training processes.
3. Design of training and learning environments
   To provide greater understanding of the degree of complexity required in a virtual learning or training environment to ensure satisfactory learning of concepts, skills or attitudes.
4. Training and education application areas
   To investigate new application areas for training and education and effective methods for developing applications for these areas.
5. Measurements of impact
   To evaluate the true impact of using VR/VEs for training and education, in order to achieve a greater uptake of VR/VE for educational and training purposes.
6. Delivery methods
   To investigate different forms of VR/VEs (e.g. level of immersion, visual fidelity, forms of interactivity) in terms of their adequacy for different areas of education and training.

The initial stage of research is data gathering and the working group seeks to identify where and how VR/VEs are being used in industry and education in order to begin to examine evidence for successes and failures and thereby to understand the value of these technologies for supporting learning.

4 Understanding VR in education and training

One of the aims of INTUITION was to develop a tool to support the integration of knowledge and activities of the VR community. A wiki-based online tool has been developed to enable the community to gather and share information and their knowledge of VR and virtual environments (VEs). Based on the software which generates the on-line encyclopaedia “Wikipedia.org”, this site is dependent on the community to populate it and drive its evolution. Current content derives from the many outcomes of INTUITION and it aims to provide a discussion forum for the wider VR community. Please visit http://kb.intuition.eunetwork.net and join our on-line community and add to the body of knowledge in this area.

Separate pages for each of the INTUITION working groups are provided in the knowledge base and WG2.9 includes a review of knowledge about how VR/VE is used for learning in mainstream and special needs education and in industry. This paper is focused on industry applications. Four case studies, provided by industrial or VR developer partners in WG2.9, are now presented highlighting use and lessons learned of VE training in industry. Each case presents a description of the application (VE content and VR system components), rationale for using this system for training and outcomes.

4.1 Case study: Use of VR for training in SNCF

4.1.1 Application description

SNCF have developed two VR training applications – FIACRE and SIMURAT. FIACRE is a simulator used to teach train drivers how to check and to handle switch blades on the tracks, and SIMURAT is a newer simulator used to train employees of the company to control freight wagons to warrant the transportation security. The main control points are the essential mechanical organs of the wagon (brakes, wheels...), the freight position, weight, stacking, etc.

FIACRE is a high immersive simulator (see Figure 1) composed of:
- a 2 meter high by 3 meter wide screen;
- a treadmill which help the trainee to evaluate and to feel the distances and the time in the virtual environment; and
- a data glove to interact with different elements of the VE.

We have spent a lot of time to convince people that it is not a luxurious game, but finally we have been able to show that our prototype was a valuable pedagogical tool.

Figure 1 - FIACRE
speed lines but there are plans to expand to all kinds of lines with the final version. It was awarded a prize at the Laval Virtual congress in 2000.

SIMURAT (see Figure 2) is composed of:

- a dual screen system with 2 high resolution projectors (to a total of 1280x2048 pixels), with the point of view tracking;
- a wifi Linux tablet PC to interact with the wagon by gluing labels on it; and
- a lamp for night training.

**Figure 2 - SIMURAT**

The system offers a vision on a full scale wagon (5 meters high) in a normal class room (typically 3 meters high). It has been successfully tested with trainee and trainer and will be made in about 8 units for initial and continuous training. This simulator received an award in 2005 at the Laval Virtual congress. It is planned to perhaps train people from other companies who have similar control systems.

### 4.1.2 Rationale

FIACRE was developed for train drivers as there were a number of problems with the existing training including:

- danger of the real tracks;
- limited time devoted to training;
- complex logistics;
- dependency on good weather conditions;
- dependency on traffic fluidity; and
- the need for a TGV train to be used in some training centres.

VR was chosen as an alternative to improve quality by enabling the trainee to spend a longer time in training, to reduce the cost, and to reduce hazardous events which can cause the cancellation of the training.

SIMURAT was developed as the existing training for this task was based on the use of a train composed of wagons on which other wagons with defects were placed. This training is expensive to maintain as it uses a real train and is also costly to transport. The number of wagons is very limited and they always have the same defects. The change in the laws regarding the training of security tasks, required us to rethink how we train. VR was, among the possible solutions, the best one in terms of pedagogical efficiency, content comprehensiveness, cost and ease of use compared to the existing method.

### 4.1.3 Outcomes

During the development of these systems, limitations of the technology were already being observed. Some aspects of the pedagogy cannot be addressed by the VR application, in particular related to force feedback. These limitations imply a reduced set of functionalities. If it is not critical for the application, limits must be kept in mind in order to adapt the pedagogy. Functions which cannot be addressed have to be considered in another way. Realism in all the dimensions is not always a good approach and often not necessary. Limits are then seen as a simplification of an application. This simplification is always a good idea in pedagogy as it helps the trainee to concentrate their attention on the task. Thus, sometime, limits of VR systems may be used profitably as advantages. For example, in FIACRE, touching an object will activate it. As the pedagogy is oriented towards procedure acquisition, studying the correct gesture is not an objective. If gesture had been one of the learning objectives, this system would not have supported the required training adequately.

In a similar way, it would have been difficult to use SIMURAT if the training required that the trainee had to handle some elements of the wagons. Fortunately this is not the case, and if we choose not to permit errors in this domain, the simulator is correct. However if we allow the trainee to make all the possible errors, we will have to find a way to consider the training on this particular point if it is critical.

Generally speaking, limits are always referring to interactivity and force feedback. Except for applications such as those used by AFPA that are dedicated to train to professional gestures (e.g. the Virtual Technical Trainer, Crison et al, 2005), we consider the use of force feedback in application training to be a huge problem as it mixed two different spaces.
4.2 Case study: Virtual Training Environment to prevent chemical risk in workshops (INRS)

4.2.1 Application description
INRS has developed an application using virtual reality methods in the field of occupational risk training. In this case, training involves "instruction-action" applied to the chemical risk prevention field. The teaching aim is to have learners acquire a methodology for building up a prevention strategy, which can be applied in companies. The methodology involved in the training requires development of investigative, data retrieval and structuring capabilities to generate a prevention strategy. This training should enable the learner to:

- identify main activity phases of varying complexity,
- identify chemical products implemented in each activity phase,
- conduct first-approach analysis of room ventilation characteristics,
- assess suitability of specific metrology,
- interpret metrology results to refine risk assessment,
- define prevention means allowing risks to be eliminated or reduced

The virtual environment allows learners to reproduce all cognitive processing implemented in the company-based chemical risk analysis, right from perception to decision-making. Our choice fell upon a simulator, which enters deliberately into a work situation transposed from a real situation. The case study retained is that of a varnish ing shop. The virtual application looks like a PC game. During the time dedicated to the study case, the trainees have to fulfill a table supporting the methodology by acting in the Virtual Environment (by moving, observing, asking, picking some objects, etc.).

The learning is split into four stages: Identification of different worker activities; Identification of dangers; Risk assessment; Proposal of prevention measures in accordance with a prevention strategy. Each stage comprises a theoretical course, an exercise in Virtual Environment and a debriefing.

4.2.2 Rationale
Virtual Reality offers a number of advantageous characteristics in response to teaching problems due to the specific nature of this skills area.

- VR enables a learner-user of this method to be active and to develop, as naturally as possible, activities within a virtual environment. This operative immersion through diagnostic activity allows the learner to develop his/her skills in building up a mental image of a work situation and its associated risks.

- VR offers the possibility of overcoming field constraints.
- In common with all computer learning aids, Virtual Reality allows recording of learner action-related data, personal monitoring organisation and learning session replay ensuring error analysis during debriefing sessions.
- VR allows safe observation and analysis of risk situations and it provides extensive data representation flexibility. The learner can act and perceive based not only on methods identical to the real situation, but also on original methods offering "impossible" perception modes. It renders accessible the unobservable in a work situation (rare events, incidents, pollutants, etc.) and thereby facilitates conceptualisation of the chemical risk.

4.2.3 Outcomes
This first experiment convinced us that this type of environment is not easy to design. The design phase requires a relatively wide range of skills exceeding by far those of most instructors. Moreover, teaching skills should be complemented by artistic talents, such as those of graphic designers, as well as the technical know-how of computer scientists, ergonomists and psychologists.

Cultural diversity leads to rapid appearance of common language problems, making it difficult to establish a common operative reference and this is aggravated by totally different viewpoints. A collaborative-type methodology should be set up to make effective this cooperation. Furthermore, lack of accessible references does not facilitate implementation of different forms of experience feedback in the field of Virtual Reality-based training.

We have evaluated potentialities and limits of such tools to overcome difficulties encountered with traditional training aids such as slides, video, etc. Our experiments show that the method we have implemented validates effectively the significance of the Virtual Environment for Training (VET). Performance characteristics recorded with this type of environment are indeed as good as those observed using the conventional methods we used as reference. Conducted in a real training situation, this experiment allowed us to reveal that the VET was considered the most relevant aid for this training course, independently of the training content itself. It is therefore reasonable to believe that the relevance of this kind of pedagogical tool could influence learner motivation, which we otherwise know plays a leading part in training.
4.3 Case study emergency training

4.3.1 Application description

An application has been developed to support training for emergency services personnel comprising the integration of innovative technologies: Virtual Reality, Intelligent Agents and Shared Mental Models. The main objective of the system is to improve effectiveness and reduce cost of training systems that promote learning by individuals, teams and organisations involved in the handling of emergency situations. The purpose of the was not to substitute the existing training methods (mainly drills), but to compensate known drawbacks of the existing trainings and complete the current trainings.

The following is the description of a training situation in the railway scenario. Four trainees and one trainer are seated in front of their PCs. The trainer selects the scenario, the situation, the role of the participants and the current conditions of the training before the session starts, the trainer can also start, stop and pause the session and even introduce external events during the session. A representation of the system communication network is shown in Figure 3.

![System description](image)

Figure 3 - System description

Every trainee enters in a 3D environment where a detailed representation of his workplace is shown (see Figure 4). Every participant in the session is represented by an avatar in the VE, including real users and agents. The users interact with the environment to perform their task during the emergency situation, performing mainly two kinds of actions: equipment manipulation and communication with other participants. The main communication devices are simulated by the system (telephone, talk channel, megaphone, train-ground system, etc.). The system includes also a pedagogical agent, the assistant. This agent is in charge of monitoring the participant actions and giving advice and assistance to the trainees.

![Trainee user interface](image)

Figure 4 - Trainee user interface

4.3.2 Rationale

The main goal of the developed VR-based tool was to extend practice with the simulations to allow the development and integration of skills which would not have been possible from previous drill approaches. From the evaluation point of view the objective was to know if distributed agent and team based training with virtual reality interfaces are likely to help users with their training. Both objectives have been achieved and the evaluation results demonstrate that the proposed approach represents a well integrated set of learning approaches and technologies.

4.3.3 Outcomes

So far the system has been tested via pilot studies of two demonstration prototypes and has not yet been included in the training activities of any real end users. It has been tested by two end user groups in Spain. The first one, Metro Bilbao, tested for training people involved in the emergency situation caused by a fire on a train in the underground section of the railway resulting in the need to evacuate the train and call in the fire and medical
services. The second one, Iberdrola, focussed on the constitution of the emergency response team during a nuclear power station emergency.

The benefits of the training tool were seen in the enhanced practice environment, the sense of realism created by the VR and agents, the pedagogy with assistance in team training and in reflective learning. In terms of functionality the demonstrators have achieved an acceptable balance between realism and limited functionality (and cost) in both the virtual reality and in the simulated agents. The system managed to produce a feeling of anxiety in trainees, and the feel that they were involved in a real emergency. While communications were not as easy as in the real workplace they were found to be "pretty similar".

The barriers to integration were thought to be primarily cost and attitudes. Cost of computer hardware may reduce with time, and new computer software may result in cheaper development costs. There is still a substantial gap between the current demonstrator and a usable training application. Potential was also recognised in that the ideas are seen as extendable within an organisation and also transferable to related emergency response training.

4.4 Case study: Validation of a mixed reality system to train X-Ray machines

4.4.1 Application description

This case study was conducted on request of the company PANalytical (http://www.panalytical.com/), Almelo, The Netherlands. Among other apparatus, PANalytical develops X-ray fluorescence spectrometers (XRF), which are used for semi-automatic characterization of materials. The materials that have to be analyzed are manually placed in the XRF and, subsequently, analyzed. Placing samples of material in the XRF is a delicate process that requires sensitive handling of the containers of materials by human operators. So, in addition to the development of complex X-ray techniques, the usage of the apparatus by human operators has to be taken into account. Traditionally, the former has received the most attention; however, more recently, the latter aspect is taken into account. This has three consequences for current XRF design: 1) The requirements imposed by usability issues have to be taken into account in the development of next generation spectrometers as well as the other way around, 2) Validation of envisioned setups has to take place in practice, and 3) Operators have to be trained on the final new design, before using the XRF apparatus in practice.

The VR XRF consists of a haptic simulation and a visual simulation, which were synchronized and is shown in Figure 5.

Figure 5 – VR XRF used for training in sensitive handling of dangerous materials

4.4.2 Rationale

A VR XRF was envisioned to reduce costs and time in both training of operators and development of new XRF apparatus. The feasibility of this idea was explored through group interviews of designers and engineers. They supported the idea to apply VR technology to facilitate the design process of and training on XRF apparatus. The VR XRF had to satisfy a number of requirements: 1) it has to be relatively low-cost, since it has to be used by small and medium enterprises, 2) preferably, the VR XRF had to be easily maintainable, and 3) the users' behavior has to resemble their behavior with the real apparatus.

4.4.3 Outcomes

To enable a good comparison between the simulated environment and its real counterpart, an experimental task was designed that had to be performed with both setups. Measures were taken of mental workload and user experience of spatial presence, realism, and involvement. The 16 participants had a similar task performance, mental workload, and involvement but differed in experienced realism and spatial presence. All participants quickly learned to use the XRF apparatus (real or SE modeled) appropriately. No difference was found with respect to learning in either of both setups. Moreover, it can be expected that the experience through training can be transferred without any loss of importance to the other setup, in particular from SE to the real setup.

The VR XRF was both used and partly experienced as being similar as the real XRF and we conclude that it is a valid replacement for the real XRF.
apparatus. This VR XRF can be used for training and education purposes as well as for designing new XRF apparatus in a cost and time efficient manner. The limitation in experienced spatial presence should be subject for further research, since the cause of this effect is not fully understood. Moreover, the initial VR XRF should be further developed and a manual for it should be created. Last, we would like to stress the importance of validating a VR setup against the real setup it should replace.

5 Discussion

Although the potential of VR for training and education has been discussed for more than a decade (Caird, 1994; Psotka, 1995; D’Cruz, 1999), there are still few applications that can be purchased off-the-shelf beside other training methods available to industry. In all of the case examples presented in this paper, bespoke systems specific to the training scenarios and learning objectives required by industry had to be developed. This is time consuming and costly, and results in development of non-standardised technologies that may be difficult to reconfigure and integrate with other system components.

Nonetheless, the outcomes of these case studies are encouraging. VR/VE simulations do appear to be able to successfully replicate the activities required for training tasks and, where systems have actually been used for staff training, they are motivating for trainees and produce performance outcomes that are comparable to other training media. It is interesting to note that these case examples did not make use of immersive VR displays; projection screens were used to display a full-size image, but not to visually displace the user from the VR training room. Of greater concern to the training providers in these examples, was the need for supporting appropriate physical interaction (e.g. gestures) and behavioural interaction (e.g. communication) rather than just relying on the user clicking on virtual objects in the VE to represent a behavioural activity. This raises an important question: are ‘presence’ and ‘immersion’ really important for industrial training or is it more important for the user to conduct their training in a multi-sensory system that allows them to perform task activities in a naturalistic manner? Perhaps it depends upon the type of learning skills required. Certainly, learning of skills requiring manual performance, such as materials handling, required use of a haptic interaction device. It has been suggested that multi-sensory interaction with VEs, providing complementary feedback to the user via different sense, may be more effective in supporting learning than presence alone (Burkhardt et al., 2003). An example of a successful multi-sensory system for vocational training is the Virtual Technical Trainer (VTT) for machine operation (Crison et al., 2005).

6 Conclusions

While the costs of VR/VE equipment have reduced in the last decade and the capabilities of the technology have increased, barriers to development and implementation still exist. The expense and complexity of developing VR training applications is prohibitive and there are only a few examples of use in industry from which we can draw lessons learned. It is hoped that, by sharing these examples and experiences between VR system developers and industry users, we will be able to inform future research and development studies in order to deliver effective, useful and usable systems for industrial training. The intention of the INTUTION knowledge base is to provide a forum for information exchange between industry, academia and research institutes so that we can move closer towards this goal.

7 References


