Training in Virtual Training Environments: Connecting Theory to Practice

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Abstract: Many institutions, such as the police, use virtual environments as part of their training and education programs. Typical scenarios that are being trained virtually are of high complexity, require intensive communication between team members, consist of situations in which individual human beings are in danger, and are not trainable in real-life situations. In this paper we describe the virtual training environment *VirtualPolice*. Its theory-based development process is explicated to show how theory was connected to practice. We present which specific needs were evaluated in order to define training goals. We introduce our theoretical base and argue why such virtual training environments can support the acquisition of knowledge-in-use, the ability of team members to take the perspective of others, and reflection of team performance. This makes it possible to identify those features of virtual training environments that enable successful training, and to point out how these may be implemented.

Introduction

Members of institutions such as the police force, fire department or rescue teams are often confronted with scenarios in the course of their work which could not be trained before because of the high costs, the danger, time or effort that such training would have required. Nevertheless, these members of such teams have to react adequately to their daily challenges. They have to act as real teams, solve complex problems, ensure their own safety and avoid dangerous incidences. They need adequate preparation for this type of teamwork that will ensure that they can handle their jobs efficiently, flexibly and safely. Many institutions have recognized the potential of virtual worlds and serious games as tools to train their teams for challenges which could not possibly be trained in reality. This has resulted in various virtual training environments (VTEs) that were developed for different training purposes, and which are often integrated into vocational education and training programs (Rose, Attree, Brooks, Parslow, & Penn, 2000). In the health care sector, for example, the use of virtual realities for training purposes is on the increase (Riva, 2002). VTEs have also been developed to train fire fighters (Julien & Shaw, 2003).

A Virtual Training Environment (VTE) allows people to experience difficult situations without taking any physical risks, and without the need of going to the limits of their physical strength. Any errors made during this training will not lead to negative consequences, and trainers have the flexibility to define different scenarios. Such typical scenarios that may be trained virtually are of high complexity and have no single "correct" solution. They are based on a specialization of tasks within a team, require intensive communication between team members, consist of situations in which individual human beings are in danger, and are not trainable in real life situations.

From the point of view of computer-supported collaborative learning, both theory and practice, these complex training scenarios and virtual training environments are very interesting. The focus here is not only on knowledge, but also on the members' experiences with complex situation that will influence the performance of the entire team. So the aim of a VTE is to combine the different knowledge and skills of the individual team member to a high-performing team. This leads to the three key aspects, which are the base of our goal to connect theory to practice:

(1) *Knowledge-in-use:* Team members need knowledge-in-use to handle complex scenarios. Knowledge-in-use is a combination of different types of knowledge that are necessary to perform a given task, solve a problem, or handle a complex situation.

(2) *Perspective Taking:* Team members have to learn to take the perspective of the others in a complex situation. They have to know about their own skills as well as the skills of other team members, and have to build a shared mental representation of knowledge that exists within in the team in order to respond adequately.

(3) *Team Reflection:* Performance of a team depends on its ability to integrate diverse knowledge and construct a shared understanding of complex situations. Teams need to reflect about own strategies, behaviour and performance. This requires a permanent exchange of one's own experience and the shared experiences within the team.

We argue that VTEs can support the acquisition of knowledge-in-use, the ability of team members to take the perspective of others, and a reflection of individual knowledge and team performance. This paper explicates the theory-based development process of a VTE, as part of our design-based research program. It

starts with a description of the specific needs of our target group, a federal state police department in Germany. We introduce our theoretical base and argue why such virtual training environments can support what we call the three key aspects: knowledge-in-use, perspective taking, and team reflection. We introduce the co-evolution model (Cress and Kimmerle, 2008; Cress, Kimmerle, & Held, 2010), which focuses explicitly on the interplay between individual and team learning, and use this model as a framework to integrate our theoretical assumptions. The paper concludes with some features of a successful VTE, connecting theory to practice, and presents the VTE *Virtual Police*, which was developed as part of our work.

Field: Virtual Training for Police Officers

Police officers are confronted with a variety of problems every day. To be prepared for difficult and dangerous situations, they need permanent and constantly updated training, regardless of their level of tenure, education and experience. So the police of the German state of Baden-Wuerttemberg has adopted a broad training and education concept. It is based on an education and knowledge management system that is run by the state Ministry of the Interior, a system which integrates and coordinates different educational provisions, ensuring a continuous improvement of the skills of police officers in the state. This knowledge-management platform combines conventional education with training sessions and e-learning, and the virtual training environment *VirtualPolice* is, so to speak, an extension of this platform.

VirtualPolice makes it possible to train operations, which were previously untrainable, such as the interaction between officers on the ground with a helicopter crew. Due to the specific requirements of using helicopters (for example, availability, organizational effort, keeping down costs and noise), such operations can only be trained restrictively. So far, only so-called Special Forces have been trained intensively for such cases. But all police officers (22,000 in the state) might be confronted with a helicopter call, so such training is relevant to all of them.

The development of *VirtualPolice* is part of a design-based research program, and based on strong cooperation between partners with different backgrounds. The technical development of *VirtualPolice* is carried out by TriCat, a software company specialized on programming complex virtual environments. Police trainers from a local training and competence center and the helicopter crew are involved in the development of *VirtualPolice* as domain experts. Our part within the project is to accompany the development of *VirtualPolice* as researchers and connect theory to practice.

The first step of our development process and goal to integrate theory and practice was to become acquainted with the specific training needs of our field partners, the police force of Baden-Wuerttemberg. Due to the high complexity of the tasks that were to be trained and in the absence of tested and standardized work routines, we decided to use non-standardized interviews and expert workshops to identify current problems and training goals. Officers, police trainers and members of helicopter crews were interviewed about their experiences, and corresponding operations were staged and analyzed. Subsequently, specific training needs were identified, based on the outcome of the analysis, which we had conducted. These training goals may be assigned to the three key aspects, which are listed below.

Knowledge-in-use: Specific courses of action, which are required in dangerous operations, need to be trained. Police officers have to react adequately and fast in every situation. A sense of danger should evolve and be retained in every situation. At the same time, the presence of the helicopter leads to greater stress, due to the noise produced by the helicopter, to which the police officers are not adapted. Their teams have to decide under enormous pressure, even if the available information is sparse.

Perspective Taking: Many problems resulting from interaction between officers on the ground with a helicopter crew are due to a lack of knowledge of what a helicopter and its crew are really able to do. Police officers may, for example, misjudge what the helicopter crew can see from above. In addition, both the team on the ground and the helicopter crew need to adjust their communication style to the situation. The helicopter crew will, for example, need to be informed about intended actions on the ground.

Team Reflection: One central need is to make individual experiences available to other team members. If team members have finished an operation, it should be ensured that problems that occurred and their successful solution are communicated to the other members. This should lead to individual learning and, at the same time, a higher performance of the whole team. The same is true of the integration of experiences of helicopter crews into the training of ground forces. Integrating such different experiences makes it possible that the entire team is able to reflect on their knowledge and team performance. As helicopter crews, so far, have not been trained together with officers operating on the ground, the opportunity of training together will improve learning at an organizational level.

The next step of our design-based research program is to find theories that provide insights in how these training goals may be achieved.

Theory: Knowledge-in-use, Perspective-taking, Team Reflection

Current constructivist approaches assume that active construction of knowledge required active collaboration, using real or digital objects as epistemic artifacts. This has led to a plethora of theories that deal with situations in which groups use some shared digital artifact to construct knowledge. The knowledge building concept (Scardamalia & Bereiter, 1994) addresses how a community of learners will manage to develop knowledge jointly. This approach focuses, to a large extent, on using computer technologies to form a knowledge building community. A knowledge building community acts like a scientific community, with the aim of constructing new knowledge and developing some theory to understand the environment. The knowledge creation spiral (Nonaka, 1994; Nonaka & Toyama, 2003) mainly focuses on the building and transfer of tacit knowledge (Polanyi, 1966). Most knowledge is contained in the experience of individuals, and can only be expressed verbally and transferred to others with some difficulty. The authors describe four processes, which dynamically build on each other: socialization, externalization, combination, and internalization. The knowledge building model of Stahl (2000) describes how social knowledge building and personal understanding take places and influence each other. It also highlights how cultural artifacts that are used in activity influence personal comprehension and learning. The knowledge creation metaphor (Paavola & Hakkarainen, 2005) focuses on a mediated process of knowledge creation, where shared objects of activity are developed jointly. The mutual creation of new material and conceptual artifacts leads to an advancement of knowledge, discovery and innovation. The idea of knowledge maturing (Schoefegger, Weber, Lindstaedt, & Ley, 2009) describes how knowledge matures in the course of time from expressing individual ideas, collaboration on shared artifacts, standardization in documents, to a creation of learning objects and standardized training programs. During this process, knowledge will develop, be more and more integrated in an organization, and shared between all its members

These theories, which were outlined here very briefly, all share the idea that the development of knowledge takes place within communities and that epistemic objects (digital or real world objects) will support this development of shared understanding and community knowledge. These theories are also a good base to understand how training in a virtual environment leads to a connection of different knowledge and skills of single team member to achieve a high-performing team. To connect theory to practice in our present context, we focus on the three key aspects knowledge-in-use, perspective taking, and team reflection. These are the basis of the features of the VTE, which we developed.

Knowledge-in-use

Theoretical assumptions: To solve complex situations and difficult tasks, the team as whole and its individual members need a great deal of experience from similar situations. This experience results from practice and well-tested sequences of action during team members' work. Knowledge of the type that is meant here may be described as knowledge-in-use (De Jong & Ferguson-Hessler, 1996). Knowledge-in-use is a combination of different types of knowledge that are necessary to perform a given task, solve a problem, or handle a complex situation. Knowledge-in-use may be defined as knowledge about activities or tasks that are performed frequently and therefore well established in the action routine of a person. Knowledge-in-use is embedded in daily challenges and in most cases implicit, because it is based on experienced work routines, which are often carried out unconsciously (Smith, 2001). Knowledge-in-use is highly *situated* (Greeno, 1998), as it is tied to specific contexts, situations or circumstances. Individuals build *situational knowledge*, that is, a relation between a situation that requires certain knowledge and the knowledge itself, about "situations as they typically appear in a particular domain" (De Jong & Ferguson-Hessler, 1996). This relation helps to identify relevant features of a current problem, to build an adequate representation of the problem, and to retrieve additional (declarative, conceptual or procedural) knowledge to solve a problem. In contrast to declarative or conceptual knowledge, it is not easy to transfer knowledge-in-use from one person to another. The larger part of knowledge-in-use consists of implicit knowledge about sequences of action (Polanyi, 1966). Members of an organization have to be aware of their individual work routines and experiences. They have to draw general conclusions from situated knowledge-in-use, which can then be presented as abstract knowledge and transferred to other situations and contexts. Others than have to internalize this transferred knowledge and integrate with own experience in order to make it adaptive.

Adoption to VTE: VTEs are a good means to support the development of knowledge-in-use. The VTE is a tool to simulate real situations. This should help a trainee to draw the relation between a specific situation and the relevant knowledge-in-use, which is necessary to respond adequately. This will not only lead to an appropriate reaction in the trained situation, but also allow a transfer of knowledge-in-use to similar real situations. The observation of what other members of a team are doing will also lead to a form of learning through socialization (Nonaka, 1994). Experiences are shared and tacit knowledge can be communicated from one person to another only through direct experience. So experiences can be transferred through observation and imitation, and, as a result of this transfer, the observer acquires knowledge, but this will also remain tacit.

A VTE provides opportunities, close to real experience, to acquire new knowledge-in-use by observing other users. Team members can observe strategies and actions of other members and learn from their success or failure. Even if trainees are not part of a current scenario themselves, they will benefit from their position as outside observers. They can adopt the observed strategies as part of their own knowledge, and give feedback to others from a third-party position. It should be emphasized here that learning is a socio-cognitive process. Different strategies of team members to handle a specific situation or to solve a problem may conflict with each other. To become a well functioning team, they have to find a common understanding of the situation and develop adequate strategies. A VTE can serve as a cognitive tool to highlight different strategies and provide possible alternative solutions to conflicts, which may occur by training together. In this way, a learning team will be formed in which all members with different backgrounds and experiences can bring in their own knowledge to the benefit of all.

Summary: Knowledge-in-use is an essential outcome of this form of training. Team members have to acquire knowledge-in-use to integrate different types of knowledge and solve a given task. A VTE should support this acquisition of knowledge-in-use.

Perspective Taking

Theoretical assumptions: The concept of perspective-taking describes the "process of imagining the world from another's vantage point or imagining oneself in another's shoes" (p.110) (Galinsky, Ku, & Wang, 2005). From a social psychology point of view, perspective-taking results in an overlap of a mental representations of the self and the other and leads to a decreasing of stereotype expression and in-group favouritism (Galinsky & Moskowitz, 2000). What is relevant in the context of knowledge-in-use acquisition is that perspective-taking will also influence interaction and coordination within a team. Perspective-taking leads to higher similarity of the group members' behavioural strategies and fosters the coordination of social behaviour (Galinsky et al., 2005). A team member has to build a mental representation of his or her own perceptions, strategies and competences and those of the others. The team as whole will then develop a shared understanding of complex situations and strategies to act as a team. This shared understanding does only include knowledge about the others' expertise (cf. the concept of a transactive memory system (Wegner, 1986)) but also knowledge about how to act together and handle a complex situation. This team knowledge is an important part of knowledge-in-use that is required to solve a complex task. Taking the perspective of other team members will also help to prevent communication failures. Members who know about different vantage points within a team (e.g. the different perspectives of helicopter and ground crews members) are able to improve their interaction strategies in an adequate way. They adapt their communication to the perceived knowledge of the other members (Krauss & Fussell, 1991). This supports the common ground (Clark, 1996) within a team and is an important condition of success even in hazardous situations.

Adoption to VTE: We argue that a VTE can support perspective-taking within a team by simulating the perspective of other members. A team member is in a position here to experience the virtual world from the perspective of another member who has different tasks and commissions. The VTE enables the team easily to swap positions, equipment or viewpoints in order to build an understanding of the others' perspectives and of the whole situation. As a result, the team will build a shared mental representation, which can be used in similar situations in real-world settings. Moreover, VTEs provide the opportunity to review finished virtual training sessions several times from different perspectives. One team member can experience the training session from the vantage point of another member. Then a trainee builds a mental representation of the whole situation and integrates the different perspectives and tasks of single team members into his or her own knowledge-in-use.

Summary: The ability to take the perspective of others is an essential outcome of successful training. Team members have built a shared mental representation to perform as a team. A VTE should support perspective-taking by providing the opportunity to switch between different perspectives.

Team Reflection

Theoretical assumptions: There are two relevant outcomes of training: Individual learning and team performance. Both outcomes influence each other because integration of different experiences leads to reflection on one's own knowledge, and enables a development of the whole team. The VTE acts as an epistemic artifact that can visualize the actions of the team members and support reflection processes. This mutual evolution of the individual and the team is described by the co-evolution model, as proposed by Cress & Kimmerle (2008). This model refers to the work of Scardamalia and Bereiter (2003, 2006), but points out, at the same time, that individual learning and collective knowledge building are two parallel and equally important processes, which support each other. Individual learning describes the internal processes that take place during collaboration and lead to better understanding of the environment and greater conceptual knowledge. Knowledge building, on the other hand, as a collective creation of public knowledge, is regarded as an improvement of ideas or the development of new ideas, not as a search for a perfect or true solution. It is as a discourse-oriented process in the sense of joint problem solving. Shared digital artifacts can support knowledge building, as they enable

participants to contribute their own theories, models, examples, visualizations, notes, and other epistemic artifacts. The shared digital artifact initiates a dynamic and self-organized process, in which ideas are formulated, discussed, revised, or rejected. The co-evolution model regards the exchange of knowledge as an interplay between individuals and a community.

Adoption to VTE: The co-evolution model offers a framework to describe the mutual development of individual knowledge and team performance during virtual training. The co-evolution model does not explicitly focus on knowledge-in-use, but knowledge building will, of course, also take place if learners handle authentic real-life problems that require knowledge-in-use. A VTE can support this co-evolution of the members' individual knowledge and team performance by providing a platform for mutual action. This form of joint training within a VTE leads to a permanent exchange of individual and shared experiences within a team. This leads to an integration of diverse knowledge, and constructs a shared understanding of complex situations. Unlike real-life training, it is possible in a VTE to record a complete training scenario and replay it later from different perspectives. Team members can review and observe their own behavior and identify failures or potential for improvement. The VTE provides a form of objective feedback on one's own reactions and strategy, for example, by measuring reaction times, replaying communication behavior or visualizing strategic components. This supports and validates the subjective feedback of trainers or other team members, and will certainly improve individual development. The team performance will also be developed further through such mutual training and the possibility to review training scenarios. This can help to detect communication failures, misconceptions or conflicts during the collaboration. Deficits can be identified and different viewpoints integrated into shared team knowledge. This also leads to learning at an organizational level, because the different experiences that were made during virtual training scenarios can be stored and retrieved later. Thus, experiences made by other teams are available to others, who can review their own behavior and connect it to their own knowledge-in-use. This facilitates the integration of different experiences and the collective creation of knowledge-in-use at the organizational level.

Summary: The mutual development of individual knowledge and team performance is an essential outcome of training. Team members reflect about their own behaviour and develop individual knowledge, at the same time team performance will evolve during the virtual training. A VTE should support this co-evolution by providing the opportunity to switch between different perspectives, record and replay finished scenarios.

Connecting Theory to Practice

Coming back to the specific needs of our partner from the field, we can connect theory to practice and formulate those features of a VTE, which provide ideal conditions for training complex and dangerous scenarios. We use the three key aspects to structure these features, bearing in mind most of them are relevant to more than one key aspect.

Knowledge-in-use: A VTE supports the acquisition of knowledge-in-use by providing a flexible and reviewable training space.

(1) Training is possible even if training in reality would be too dangerous or too expensive.
(2) Specific courses of action demanded by typical operations may be trained many times and with different team configurations, in order to acquire some routine and flexible reactions.
(3) The difficulty of a task may be modified, for example, by starting with a reduced scenario and increasing its complexity.
(4) The VTE can provide additional scaffolds to support trainees at an early stage of training, and this support can be faded out later.
(5) Training may pause at any time, to reflect on the current status, define possible problems and re-adapt a strategy.

Perspective Taking: A VTE supports perspective taking within a team by simulating the perspective of other members.

(1) A VTE can simulate the vantage point from which other team members view the situation.
(2) Team Members can see their own behavior from the perspective of others, e.g. by seeing the helicopter crew's view of the ground.
(3) Team members can take the position of an outside observer, looking at scenarios from a wider perspective. This supports the acquisition of strategic knowledge.

Team reflection: A VTE supports team reflection, which will enhance individual learning and team performance.

(1) Completed training scenarios are stored and can be retrieved later.
(2) Team members can learn from others' experiences by reviewing them later.
(3) Recorded communication, e.g. between helicopter crews and ground forces, may be analyzed to detect communication failures.
(4) Data on the performance of team members can be aggregated to visualize, for example, navigation routes and resulting dangerous situations.

The VTE *VirtualPolice*

The virtual training environment *VirtualPolice* was constructed to train both ground forces and helicopter crews, although the integration of fire fighters, emergency medical services or other emergency services in a police operation can also be implemented, making this VTE highly adaptable. *VirtualPolice* simulates 150 square kilometres of accessible terrain, with villages and towns characterized by individual townscapes (see figure 1). Some building structures are accessible, and open areas in the countryside and woodlands exist as well. Day and nighttime in the simulation can be influenced and weather conditions be set, so that training scenarios can be adjusted to specific training needs. The trainees are represented by avatars, dressed either like police officers or suspects. Each participant perceives what is going on visually and with sounds through his or her own ego perspective, and can move freely through the VTE. Furthermore, the scenario can be populated by autonomous agents, guided by artificial intelligence. In addition, police patrol cars and normal vehicles are available.

Figure 1. Screenshot of *VirtualPolice.*

The available helicopter is represented with realistic pictures and sounds, as seen by the participating ground forces, and can be navigated either by trainers or helicopter pilots. A helicopter pilot in the simulation can choose between natural day/night view, use image-intensifying glasses at night and an infrared camera in order to provide a heat image of the scenario (figure 2).

Figure 2. Helicopter Perspective within *VirtualPolice* Using the Infrared Camera.

The training participants use headsets to communicate through spoken language. Trainees, trainer and helicopter pilots can use a simulated two-way-radio, and when they are close enough to each other in the VTE, they can hear each other without the need to use this transmission. This simulates real-world conditions in which the ground force team talk to each other face-to-face, but have to communicate by radio with crews further way or with the helicopter pilot. The trainer's monitor can show any position in the scenario and switch between different trainees' views and the helicopter view. He or she can communicate with the simulated police officers, with the suspects, or with all of the participants at the same time. This allows the trainer to give additional support, providing scaffolds or interrupt the training. The trainer can re-arrange the training scenario by placing any participant, the helicopter or the suspect into any position within the VTE and re-start the training.

VirtualPolice is designed to train up to 12 participants simultaneously, and the system requirements of the software are low, so it will run on standard computers with no need for further equipment - only a keyboard, mouse and headsets are required. The VTE is part of the organizational network of the state police and can be used online. The trainees can remain in their local police stations or departments, but train together with other teams. *Virtual Police* provides the option to record the entire training scenario and replay it later from different perspectives. The trainer can set markers and written comments during the training in order to highlight relevant situations, for example, communication failures or dangerous behavior of the trainees. These markers can used to provide a structured feedback after the virtual training.

Application of the Training

The training concept of *VirtualPolice* consists of a preparatory stage with theoretical information, a practical stage using the VTE, and a feedback phase, which also integratesthe VTE. During preparation, the trainer first explains to the participants the content and the importance of this training. To underline this point, videos of real operations with dangerous developments are introduced and discussed. Then, information on appropriate behavior during such operations is provided and discussed. Finally, the training goals are defined explicitly, pointing out the focus of the practical stage. In this stage the participants are first instructed how they have to to use the VTE and how to navigate within it, and are given some time to acquaint themselves with the VTE. Subsequently, the prepared training scenarios are executed. The trainees are seated in single cabins in front of a 24-inch monitor and wear a headset with integrated microphone, as an attempt to isolate them as widely as possible from environmental influences (figure 3).

Figure 3. Police Officer Trains Using *VirtualPolice.*

After each scenario, a feedback phase is conducted. The scenario is discussed and every action can be replayed from different perspectives, allowing all participants to take the others' perspectives and to see their own actions from others vantage points. After the practical stage the participants receive feedback from their trainer depending on their performance and progress during the training. Newly acquired skills and knowledge-in-use can be discussed and real-world applications can be illustrated.

Summary

This paper explains our theory-driven approach to the development of a VTE for police officers, focussing on knowledge-in-use, perspective taking and team reflection. We consider these as key factors for efficient virtual training, and try to highlight the importance of sound theoretical foundations and assessments when applying VTEs. But the theoretical basics should not only be kept in mind when designing and developing a training environment. There should also exist, at least in the early stage of implementation, a feedback loop between trainers, trainees, psychologists and software developers. In our example *VirtualPolice,* we conducted after each newly released version of the VTE a training stage to test and explore the training environment, and we also arrange regular workshops involving police trainers, helicopter crew members, ground forces, psychologists and software developers, to discuss future improvements of the VTE. During our training and workshop sessions we discovered, for example, the necessity to have personalized avatars and identifiable streets and city areas. With such feedback loops, we intend so secure a high standard of training, permanently refresh our assessment of training needs, encourage communication between trainers, ground forces and helicopter crews, and connect theory to practice.

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