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From Exploration to Re-Enactment: Instructional Uses of a Desktop Virtual Environment for Training Nuclear Plant Field Operators

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Abstract

Despite the growing use of virtual environments for training in complex industrial settings, we have little understanding of how these innovative settings transform training and trainers everyday work. This study investigates the instructional use of an industrial building's virtual environment by expert trainers during a training session for nuclear power plant field operators. Drawing from the course-of-action theoretical and methodological framework, field notes, continuous video-recording of the training sessions and verbalisations during post-training self-confrontation interviews with the trainers were collected and analysed. The results point out four typical instructional uses of the virtual environment in authentic settings: (a) showing the material elements and spatial layout of certain areas of the reactor building, (b) displaying safe and typical paths through the building, (c) explaining functional aspects to help trainees develop an operating model of the nuclear building, and (d) sharing salient experience through real-life anecdotes. These typical uses and their related learning dimensions are anchored in the re-enactments of expert trainer's embodied past events. The discussion develops the counterintuitive idea that from an instructional point of view, the intensified immersion of trainers afforded by the virtual environment seems less influential than emerging practice-based learning experiences. We conclude with new possibilities for improving learning *through* and *for* work thanks to re-enactment of expert trainers' past work practices.

Keywords Vocationnal training · Desktop virtual environment · Practice-based learning · Learning *through* and *for* work · Re-enactement · Real-life anecdotes

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Introduction

Longstanding research themes in vocational education and training (VET) have focused on how to bring school learning closer to real life situations and practices, how to facilitate the integration of conceptual knowledge and practical knowledge which is fundamental for the development of expertise (Tynjälä 1999; Tynjälä et al. 2003), and how work-based experiences for students can be integrated with learning in vocational education programmes (Billett 2014; Billett et al. 2013; Stenström and Tynjälä 2009). In VET, students are required to learn across different sites, as they alternate through experiences in schools and workplaces throughout their education and interact with different educators (trainers, tutor), and varied learning environments and tasks. The main theoretical, empirical, and practical concerns are to understand a) to what extent each place enables and restricts learning in the complex encounters between individual students and socio-material contexts, and b) “how people combine, modify and connect learning across places” (Tanggaard 2007, p.459). Concepts of boundaries and boundary crossing (Akkerman and Bakker 2011; Engeström et al. 1999) are recently called to address these issues and to reframe the problem of transfer (transcending the dualism between theory and practice). Some studies pointed how educators at school and workplaces act as mediators and boundary crossers in their collaborative interaction, and how they enact particular didactical practices in order to facilitate students’ learning across organisational or institutional boundaries (Wegener 2014).

Educational technologies (e.g., e-learning, mobiles devices, hyper-video, computer-supported collaborative writing, virtual reality) and technology-enhanced learning environments are designed and analysed as a way to “bridge the gap” between school and workplace learning (e.g., Guile and Griffiths 2001; Sappa and Aprea 2014; Tynjälä 2009). The aim is to use digital possibilities to enhance the integration of theoretical knowledge with the practical experience of participants. To follow up on our previous comments, educational technologies can act as “boundary objects” (as artefacts fulfilling a bridging function) (Star 1989) or “boundary zones” where it is possible to integrate different perspectives (Tuomi-Gröhn and Engeström 2003). Despite undeniably powerful digital possibilities for educational design, these technologies bring out many issues and challenges. As an illustration, in a review of e-learning at work based on theories of adult learning, workplace learning and organisational learning, Tynjälä and Häkkinen (2005) pointed that the success of e-learning is highly dependent on factors related to the overall work and learning culture of an organisation. E-learning at work deals with two main sets of issues: those related to learning in the workplace in general and those related to learning taking place in a virtual environment. More generally, educational technologies must be used accurately and incorporated into educational ecosystems (Dillenbourg 2008), which means being integrated within adequate activities that educators (at school or at work) orchestrate (e.g., Schwendimann et al. 2015). This is strengthened by the fact that many of the technologies available for educative purposes have not been designed specifically for learning and teaching, and thus the educator needs to understand the affordances and constraints of such technologies to creatively repurpose them for the educational context (Mishra and Koehler 2006).

Virtual reality (VR), concerned by our study, is now considered a mature technology appropriate for instructional uses, including VET. Yet empirical research investigating

whether and how the functionalities and features of VR are exploited is still lacking. Studying how trainers use VR in naturalistic settings seems necessary to determine whether their learning intentions can be invited, supported, or augmented by VR.

Virtual Environment for Vocational Training in Nuclear Sector

Virtual environments are the latest trend in the industrial sector, although their educational use is theoretically poorly supported. These technologies, such as VR, are considered as particularly promising training tools for complex and highly demanding maintenance and assembly tasks (Borsci et al. 2015; De Sousa et al. 2010; García et al. 2016; Gavish et al. 2015). VR refers to computer-generated environments that enable users to act virtually in a whole artificial world (or “interact” in a more technical sense). In a VR application, users are immersed¹ in and interact with a virtual environment in which they become the actors.

This study has been conducted in the nuclear industry. For the past several years, numerous training environments based on immersive technologies have been developed for maintenance purposes (Jiang and Long 2016; Matsubara et al. 1997; Matsubara and Yamasaki 2002; Sebok et al. 2002), and various studies have specifically focused on the use of VR for industrial safety training (Avveduto et al. 2017; Ródenas et al. 2004). Nonetheless, two main limitations are often formulated. First, too many training environments based on VR are designed along the lines of the “techno-push” model without conducting a thorough analysis of the related instructional issues. Second, little empirical evidence supports the benefit of these immersive technological environments in terms of learning outcomes or professional development (Leder et al. 2019). Sebok et al. (2002) studied two VR-based training systems and a conventional map-based to compare the learning of the path to follow in the reactor building to bypass its radioactive zones. The first VR-based system (called “guided”) displayed the paths to be followed by the subjects to learn how to find their way in this building, while the second VR-based system (called “non-guided”) only displayed the visualisation of the scene without any additional information on the path to follow. The results showed that the “non-guided” VR-based training offers the potential to provide a more effective way of teaching knowledge about the plant’s physical layout than conventional map-based training does. The comparison between the two VR-based situations revealed that the VR technology needs to be embedded in appropriate instructional schemes to make an effective training program. The members of the group receiving “non-guided” VR training rated their engagement significantly higher than the group receiving “guided” VR training because they felt more involved as they tried to find their own way through the reactor building. Involvement is known to be a key factor of inquiry-based learning and it seems to be strongly linked to the feeling of immersion, which is the core principle of the virtual environment. There is a clear need for further research to assess the efficiency and effectiveness of VR as educational technologies

¹ The notion of immersion is used in our study in the sense of “mental immersion” (Sherman and Craig 2003) or “sense of presence” (e.g. Slater 1999). Sherman and Craig define immersion as “the sensation of being in an environment; it can be a purely mental state or can be accomplished through physical means: physical immersion is a defining characteristic of virtual reality; mental immersion (is the) state of being deeply engaged; suspension of disbelief; involvement.” (Sherman and Craig 2003, p. 9).

(regarding both instruction and pedagogy) compared with traditional training methods, particularly in authentic settings.

Another important limitation is the lack of knowledge about instructional uses of these VR environments by trainers in naturalistic (non-experimental) settings, and their impact on the transformation of their professional practices. With regard to this issue, Fréjus (Fréjus 1998) explored the potential of using virtual environments for training nuclear plant maintenance staff to detect valve defaults. She compared trainers' teaching activity during two training settings, one traditional with the support of slides and the other supported by VR technologies. The results indicated that the two training configurations had the same overall structure in so much as the trainer's activity was more opportunistic than planned for, adapting his job to the trainees' activity. The author also showed that slides were used to illustrate rather than explain, whereas the VR configuration had opened up a much broader range of use (e.g. ensuring the transition from one topic to another, resolving problems in understanding, providing clues for answers, developing or confirming a trainee's answer, illustrating from different angles, localising a component and its connections with another one, commenting on rather than explaining, etc.).

The aim of our study is to explore how expert trainers of nuclear field operators make an instructional use of a virtual environment. In this regard, we describe in detail how this virtual environment transforms their actual teaching practices, questioning the affordances and constraints of this VR-based environment for training. Like Dalgarno and Lee (2010), we use here the term "affordance" (a term also referred to workplace learning) in preference to "benefits" or "advantages" to emphasise the fact that it is primarily instructional strategies of the trainers combined with both the trainers and trainees practices supported by VR, rather than VR itself, that have an impact on learning. The use of a particular technology does not guarantee the achievement of specific learning outcomes or benefits. Affordance is a frequently used term in educational technology research, but also one that has been used with several different meanings. Kirschner, Strijbos, Kreijns, & Beers (2004) made a helpful distinction between technological affordances (related to usability of educational technologies), social affordances and educational affordances. Social affordances are defined as the properties of an artifact that act as social-contextual facilitators relevant for the learner's social interaction. Educational affordances refer to "characteristics of an artifact that determine if and how a particular learning behavior could possibly be enacted within a given context" (Kirschner 2002, p. 19) and whether the learning intentions of the user can be invited and supported. In other words, when technology mediates the social and educational contexts such that their properties induce and invite specific learning behaviors, mention is made of a technology affording learning and education. However, it should be noted that educational affordances always refer to the relationship between the properties of an educational intervention and the characteristics of the learners that enable them to acquire particular types of learning. Dalgarno and Lee (2010) argued that for a VR-based learning environment, an educational affordance analysis should be valuable during the design and evaluation processes. These authors identified five affordances related to 3D virtual learning environments (3D VLEs). They can be used to facilitate i) learning tasks that lead to the development of enhanced spatial knowledge representation of the explored domain, ii) experiential learning tasks that would be impractical or impossible to undertake in

the real world, iii) learning tasks that lead to increase intrinsic motivation and engagement, iv) learning tasks that lead to improve transfer of knowledge and skills to real situations through contextualisation of learning, and v) tasks that lead to richer and/or more effective collaborative learning than is possible with 2D alternatives. But to go beyond the educational affordances of 3D VLE, which deals with the trainees' learning, we also studied the instructional affordances, by analysing the trainers' activity.

The Course-of-Action Theoretical and Methodological Framework

We conducted the analysis of expert trainers' practice within the course-of-action theoretical and methodological framework (Theureau 2002, 2003), developed in the Francophone world and traditions. This framework has already been mobilised in numerous workplace studies in the nuclear sector - in relation with the design of artefactual, organisational, and cultural systems (e.g. Palaci et al. 2012; Theureau et al. 2001; Theureau et al. 2000), in numerous studies in vocational and professional education (e.g. Durand and Poizat 2015; Horcik et al. 2014), and in educational technology design-research (e.g. Leblanc and Ria 2014; Leblanc et al. 2001). Largely unknown in Anglophone literature, it acquired considerable visibility within Francophone research on vocational and professional education (e.g. Durand 2011, 2015; Filliettaz, Billett, Bourgeois, Durand and Poizat 2015). Most of the studies deal with both occupational practice (i.e. what needs to be done - and so, learned - for ensuring performance, health, safety, learning...), and professional development (i.e. what is learned, how it is learned, and how learning can be improved). Practical implications of course-of-action studies are their potential for bringing work practices in curriculum, improving pedagogical practices, and designing learning environments. These studies produced a vast body of concepts and methods related to: a) learning at work, for work, and through work; b) practice-based knowledge used or/and constructed in situ; c) pedagogical practices, mentoring, and interactions between trainers and trainees; or d) video viewing and professional development (Poizat et al. 2016).

As an activity-oriented approach, the course-of-action theoretical and methodological framework echoes with Cultural-Historical Activity Theory (CHAT) often referred to in international literature. However, the notion of *activity* is not specified in exactly the same way, even if there are many common points. The main differences with CHAT concern the unit of analysis and the hierarchical view of the structure of activity. The course-of-action framework does not adopt the activity-system model, nor an activity-systemic method (Engeström 1987). In the Francophone world, the understanding of the notion of *activity* was developed in a specific historical and cultural background, combining, in some studies, the influence of soviet psychology (e.g., Leontiev 1975) with a strong tradition of work analysis highlighting the distance between prescribed work and real work (more details in Daniellou 2005, De Keyser 1991). The course-of-action theoretical framework is rooted in this francophone tradition, insisting on the distinction between what must be done (tasks or functional description of the work process) and what workers actually do (actual work practices). The course-of-action framework focuses on *activity* – defined as enacted, situated, embodied practices – and more particularly on the level of activity that is meaningful for an actor. Activity, as enacted practices, could be broadly defined as everything that is done by an actor at a given time. This includes the flow of actions, thoughts,

sensations, perceptions, attention focusing, intentions, emotions, expectations, and interpretations that occur at a given moment. Viewed as a theoretical object, a course-of-action is “the activity of a given actor involved in a particular situation, where the activity is meaningful for this actor, i.e. he can show it and tell about it at any time” (Theureau and Jeffroy 1994, p. 51). The course-of-action method is then designed to provide a fine-grained analysis of actors’ lived experience (Dieumegard et al. 2021), and involves gathering two types of data: video-recording and verbalisation data gathered during self-confrontation interviews. This makes it possible to document “from within” working or training practices, and learning processes in naturally occurring situations.

The course-of-action analytical method is inspired by Peirce’s semiotics (Peirce 1978), wherein action and cognition are conceived of as a semiotic process. This semiological framework is grounded in the hypothesis that actors think (and act) through signs, and that these signs emerge from the interrelation between this actor and his environment. Describing and analysing activity is then viewed as reconstructing the flow or the succession of discrete units that are meaningful for the actor. The smallest unit of meaning for the actor are called elementary units of meaning (EUMs) and are assumed to be the expression of *tetradic signs* including four components: the “unit of the course-of-action”, the *object*, the *representamen*, and the *interpretant* (the last three of which are derived from Peirce’s semiotics). The “units of the course-of-action” can be practical actions, communications, symbolic constructions, interpretations, emotions, feelings, or self-talks. For a researcher, documenting an actor’s course of action consists at least in drawing up the chain of these EUMs. It should be noted that other research conducted within the CHAT framework (Ma 2014, 2017; Norros 2005, 2018) also draw on Peirce’s semiotics to reinforce and amplify the empirical analysis of *activity*, with a particular emphasis on habits.

Material and Methods

Characterisation of the Virtual Environment

VVProPrepa, the virtual environment (VE) used in this study comes under the category of “desktop virtual environment” (Vince 2004). It is not a learning technology in the sense that it has not been designed and scenario-based to meet learning objectives. Indeed, this 3D visualisation software was first designed to prepare the reactor building’s maintenance tasks during plant outage. As the reactor building is not accessible when the plant is in operation, plant maintenance personnel use this virtual environment to anticipate repair and maintenance work by visualising the spatial constraints arising from the building’s complexity.

In parallel to this use for maintenance tasks, trainers of the nuclear operation crew perceived the potential of this virtual environment to teach recently hired field operators. In their future work, these practitioners will have to carry out complex operational manoeuvres in this at-risk environment, which is only very rarely physically accessible to them. Thus, trainers took the opportunity of the development of this tool to use it as a complement to the usual professionalisation curriculum of the field operators. It is in

this context that we have studied how expert trainers made use of this visualisation software in classroom training sessions.

This virtual environment provides a highly detailed tour of a nuclear plant reactor building, the most complex 11-story industrial building at the heart of any nuclear power plant. This software is based on VR technology and digital imaging techniques combining 2D maps, 3D models and high-definition 360° spherical photos of the reactor building (Fig. 1). It was built through an elaborate process of acquiring, processing and fusing data of many different types (Hullo et al. 2015).

This virtual environment is similar to Google Street View (Anguelov et al. 2010) with a click-to-go navigation mode that lets users click their mouse on locations in the scene and be transported to the image nearest to that 3D location. Thus, users can move around in first-person views using the 3D models, similar to video gaming. They can browse from one spherical photo to another by clicking step by step on the icons indicating their location in the tool, and they can switch from a 3D model to the corresponding spherical photo (or 2D map), and vice versa. Last, they can take screenshots, annotate photos, take measurements, and calculate routes. According to Sherman and Craig's definition of mental immersion, this desktop virtual environment can be qualified as a "low-immersion" VE from a physical immersion point of view.

Participants

Two expert trainers volunteered to participate in the study. T1 and T2 have respectively 24 and 22 years of experience as field operators, and 9 and 10 years of experience as trainers. Their job is to coordinate training, prepare specifications and conduct training for recently hired field operators. Informed consent was obtained from both trainers and all the field operators trainees involved in the training situation under study.

Procedure

The teaching activity of the two trainers took place during a traditional and theory-driven classroom training session (Fig. 2) led with the support of the virtual environment displayed on a whiteboard. The session had a duration of two hours. The session's topic was the reactor building's setup (reactor vessel/pressure channels, containment



Fig. 1 Three display modes offered by VVProPrepa: (a) spherical photo with on top right a "radar", a small 2D plan in miniature inlay to orient oneself in relation to the view of the spherical photos; (b) 3D reconstruction; (c) 2D plan



Fig. 2 Photo of the training session

systems, reactor coolant systems, coolant pumps, steam generators, pressurizer, outage status, etc.). The teaching objectives according to the training's requirements of this course were: i) to give details about the locking/unlocking procedure of the reactor building, and ii) to characterise the primary system and the containment system. The twelve field operators participating in the training had all been recently hired to work in the nuclear plant, and some of them had other experiences in the company (e.g. coal-thermal plant, hydroelectric plant).

This session was the first involving the use of this virtual environment for training purposes. The trainers became familiar with the tool before the training session, namely during the preparation which consisted in identifying places, paths and components they wanted to show the trainees according to the theoretical content initially planned. They also decided to make a change to their usual animation mode (only trainer) to cope with the introduction of the device: both trainers shared the animation with one of them using the tool to illustrate the notions of the course explained by the other.

Data Collection

Three types of data were collected: (a) field notes, (b) continuous video-recording of the training session (two hours), and c) specific verbalisations collected during post-training self-confrontation interviews. Field notes were used to gain an initial understanding of the general unfolding of the training situation and were also a valuable support for the interviews. Video-recording of the participants' behaviours and communications during the training situation was accomplished using a digital camera with a fixed wide-angle lens that framed the trainers, the trainees, the whiteboard, and the projector screen. The recorded data served two purposes: (a) to provide behavioural and contextual information for identifying elements about the participants' unfolding activity, and (b) to provide a basis for collecting the verbalisation data. Considering the exploratory context of the study, only one camera was set up to video-tape the trainees and instructors in order to minimise the impact on participant activity.

Verbalisation data were gathered during individual self-confrontation interviews (Cahour et al. 2016; Dieumegard et al. 2021; Mollo and Falzon 2004; Theureau 2003), which is a method designed to account for the level of activity that is meaningful for actors through situated verbalisation. Two interviews of one hour each were conducted, one with each trainer. The self-confrontations interviews were held 4 to 24 h after the training session. During these interviews, the trainers, interviewed separately, viewed the recording of the training session with the researcher. Pausing the video recording at specific points in time, the trainers were invited to comment and describe step by step their own activity as they experienced it. They were asked to recount their thoughts and emotions by expressing what they did, felt, thought, and perceived during the training session. The self-confrontations were video-recorded so that the researcher could verify the correspondence between the verbalisations and the specific behaviours that were commented on. The researcher's prompts² were designed to obtain information about the actions, sensations, perceptions, attention focusing, intentions, emotions, expectations, and interpretations that accompanied the past activity: "What are you doing here?", "Are you perceiving something special?", "What is drawing your attention?", "Are you aiming at something particular?", "What are you feeling?", "What made you decide to do that?" and "Are you thinking about something?". Some prompts were also used to lead towards more detail on what had already been said while keeping the focus on the level of activity that was meaningful for the actors.

Data Processing

The data were processed in three steps: (a) constructing a two-level protocol, (b) labelling the elementary units of meaning, and (c) identifying typical uses.

Constructing the Two-Level Protocol

This step consisted in presenting the data in a two-column table (Table 1). Column 1 presented the researcher's description of the trainers' observable behaviours, the objective elements characterising the situation (e.g. behaviours of trainees, time, materials and spatial arrangement) and the systematic transcription of the participants' (trainers and trainees) communications in the training situation. Column 2 presented the corresponding verbatim transcriptions of the self-confrontations of each of the trainers.

Identifying the Elementary Units of Meaning (EUMs)

The second step consisted in identifying the elementary units of meaning (EUMs), which are the smallest units of activity that are meaningful for an actor. When actors are asked to comment on, show, and tell about their activity, they spontaneously break down the flow of their experience into discrete units that make sense for them. The

² Questions mentioned here are non-prescriptive and not predefined. They are mere, non-exhaustive examples of questioning prompts to aid actors in deepening the elicitation of units of meaning that they themselves have defined in the course of their experience. When adapted to the dynamics of the interview, researchers may sometimes use predefined questions to document various dimensions of the actors' experience.

Table 1 Excerpt of the two-column protocol for T2

Actions and verbalisations in the training session	Verbalisations in the self-confrontation interview
<p>T2: [...] you've seen this about the valves. The Sereg valves, do you remember how to switch a tight valve into automatic mode?</p> <p>Trainee: You have the nipple on top.</p> <p>T2: So, zoom in. T1. The famous spoon, doesn't that mean something?</p> <p>Trainee: Yes, it's on it, otherwise you have to do it the old way.</p> <p>T1: So if the spoon is on it, you have to do it with the spoon.</p> <p>Trainee: No, yes.</p> <p>T2: Yes, you have to do it with the spoon. Normally, they stayed on the spoons (T1 zooms in on the valve).</p> <p>T1: There it is (he uses a pointer to show the spoon on the valve).</p> <p>Trainee: If there is no spoon, it's two turns (the old way).</p> <p>T1: Yes, if there's no spoon. But normally you have to have the spoon. If there's no spoon, it's a work request. Because there's a paired spoon for each valve, with the number of the valve on the spoon as well.</p> <p>T2: You put the valve on automatic and how can you tell that it's really on automatic?</p> <p>Trainee: When you...</p> <p>Trainee: Yeah, the wheel has to...</p> <p>T2: No, there's another way, safer.</p> <p>Trainee: We're going to put...</p> <p>T2: No, you're not the one who's going to make sure that it's working correctly in automatic mode, it's the operator. You ask the operator to do it from the control room.</p>	<p>T2: We're talking to them about the spoon and then; there, we're at the heart of their job; that's interesting, it's their job, it's what they're going to be doing and I think that's why they are so interested. You know, sometimes you're talking about things, yeah, and they say 'why are you explaining this to us, it won't help us with our work'. If you really take them to the limit of the work, you kind of leave them amongst peers. But there, really, it's the job that they'll be doing tomorrow; they'll go to the reactor building, they'll put in the spoon to put the valve on automatic and so all that really interests them. We're really in the maintenance job now and what and how they'll be doing things and all that.</p>

EUMs were labelled on the basis of the two-level protocols cross-referred to the training session video-recordings, using an action verb followed by a direct object, an adverb, or another complement. Labels reflect the responses to a series of questions about the trainer's actions, interpretations, inferences, and feelings as they appeared in the recordings and self-confrontation data: What is the trainer doing? What is he thinking? What is he feeling?

Identifying Typical Uses

The analysis of the EUMs indicated several ways of using the VE during a training session. These different uses were grouped into four categories described as typical because they are based on similarities. Typicality here refers to two main attributes: a *frequency* attribute (i.e. the typical occurrence is the most frequently observed in the study sample) and a *meaningful* attribute (i.e. actors express a feeling of typicality when they are questioned about something during self-confrontation). The typical uses were

distinguished on the basis of three criteria: (a) the meaning of each category of typical use, (b) the same level of generality across the categories, and (c) labelling that was sufficiently discriminating to limit overlap. Each typical use was labelled in such a way that its general meaning was evident .

Trustworthiness of the Data and Analysis

Clear research conditions were established to ensure the reliability of the data and analysis. First, interviews were conducted. Second, the transcripts were given back to the participants so that they could ensure the authenticity of their commentary. Third, the data were coded independently by two investigators who reached a consensus on the number and labels of the EUMs. The initial agreement rate was 87% for the EUMs. Any initial disagreements about EUMs or underlying constituents were resolved by discussion between the two researchers until a consensus was reached.

Results

Four typical uses of this VE came to light in this first training session supported by this visualisation tool (Fig. 3): (a) showing the material elements and spatial layout of certain areas of the reactor building, (b) displaying safe and typical paths through the building, (c) explaining functional aspects and help trainees appropriate an operating model of the reactor building, and (d) sharing salient experience through real-life anecdotes. The order of presentation of these results ranges from the most anticipated uses before observation to the most unexpected. These typical uses were not mutually exclusive and sometimes overlapped. The overlaps reflected the multiple concerns that the trainers pursued simultaneously. The examples chosen to illustrate each typical use are also prototypical, from a descriptive viewpoint, in the sense that they present the highest number of attributes of the observed activity in the sample of actors and the situations under study.

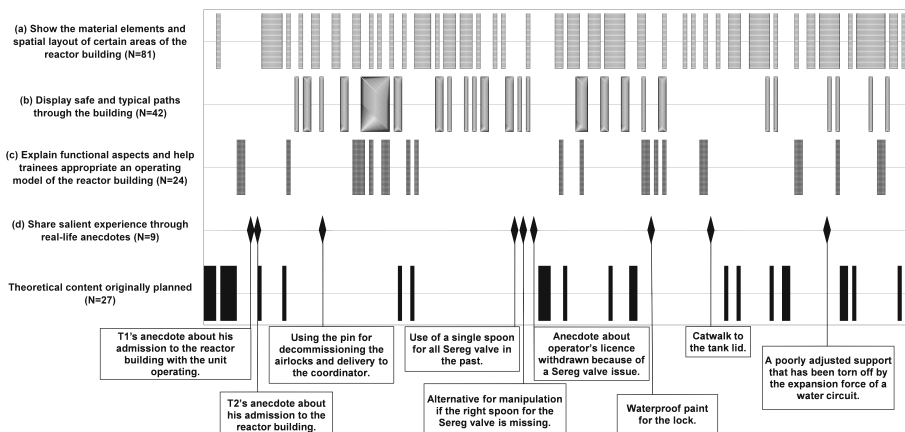


Fig. 3 Distribution and number of occurrences of the typical uses during the training session

Show the Material Elements and Spatial Layout of Certain Areas of the Reactor Building

The first typical use of the VE was the trainers' presentation and the trainees' viewing of the reactor building's elements. The typicality of this use is related to its frequency of occurrence. With 81 uses observed, this is the most repeated use during the training situation. Trainers used the built-in spherical photos to (a) give an overview of certain areas, (b) show selected components, and (c) show specific details of certain components.

The VE being interactive, it was possible for T1 to navigate from photo to photo looking up and down at 360 degrees, thus enabling the trainers to give the trainees a global, peripheral and dynamic vision of areas in the reactor building that were of particular interest for their future work activity. The trainers chose angles of view that would have been difficult to obtain during an actual visit (a view from above the reactor building's pool, for example) and that gave the trainees an overview that would help them to locate and orient themselves more easily in the real reactor building.

The trainers also used the tool to show the trainees specific equipment that would be difficult to access or even see in an actual visit (because it is high up or located in areas with a risk of radiation exposure). Depending on the case, the trainers tried to show the location of a piece of equipment (so the trainees would be able to access it more easily and quickly at the end of training) or its general characteristics. T1 explained in the self-confrontation interview: *"it's interesting to show a particular area. T2 wanted to show them the pressurizer expansion loop, so that's the piping that goes from the loop to the pressurizer. And there, we almost never go to these places, so it's interesting to see it and to help trainees understand how it's set-up in real life. It's something they would never see without the VE! In fact, they will never really see it"*. Last, the trainers were also able to zoom in some photos to show something specific in greater detail with no loss in image quality because of the HD resolution. Essentially, the trainers were no longer limited to showing a piece of equipment in its general environment, but instead they were able to bring specific material to the trainees' attention. Focusing on a particular element was usually the trainers' choice (T1 or T2), but it was sometimes also a response to a trainee's request. By way of illustration, while the trainers were presenting photos of the *reactor building pool* and the *fuel loading machine* (Fig. 4), a trainee asked if it would be possible to put three fuel assemblies into the machine. To illustrate his response (only one assembly can be transported), the trainer zoomed in on the photo so that the trainees could see in greater detail where the fuel assembly being transported would be positioned.

It should be noted that the detailed presentation of the *fuel loading machine* was not part of the initial lesson plan for the training session. Instead, the trainees' ability to view the elements that the trainers were covering in their oral presentation led one of them to ask a question about something that was not directly related to what the trainer was talking about. From this point of view, the spherical photo offered an opportunity for learning that neither the designers of the VE nor the trainers had foreseen: emergent learning. In other words, by providing an explanation of the handling of the components, the content addressed was various and more detailed than initially planned. According to the trainers, this content was closer to the actual work of field operators



Fig. 4 Left: view of the fuel-loading machine before the trainer zooms in on it. Right: view as the trainer gives an explanation

and to their professional culture. Because the trainees were able to both hear and see, they became even more active in their own learning.

Display Safe and Typical Paths through the Reactor Building

The second typical use of the VE concerned the trainers' demonstration of and the trainees' viewing safe paths through the reactor building as well as the typical routes between the different components. The typicality of this use by the trainers is also primarily frequency: it was frequently observed in the collected data ($N=42$ occurrences).

In their future work, the trainees are expected to stroll in the reactor building in order to carry out operational manoeuvres efficiently. This building has a complex layout: it has eleven floors with different types of organisation, underground levels, and access by stairs but also by ladders, etc. In addition to the traditional occupational hazards (risk of falling, electrical risk, etc.), it also has areas with a risk of radiation exposure. These two characteristics – complexity and risk – drove the trainers to provide the trainees with recommendations on the most efficient paths through the reactor building – that is, the quickest and least risky paths.

The trainers used the VE to illustrate these recommendations with “simulated” tours. For example, they showed the trainees the most efficient way to carry out the *tank venting* procedure, an operation that is both rare and difficult because of the risk of radiation exposure. *“The tank compartment, you’ll certainly access it, to open the tank vents. The tank’s vent valves, which are there, I have two on the tank, I have one there, with a tag-out. So that means going down into the tank compartment, using this ladder, and opening both valves. [...] And the access to this catwalk here, you get there with another smaller catwalk, on the other side, I have a catwalk that brings me to the tank lid, in fact”*. This verbatim also shows that the trainer did not restrain himself to display a path from point A to point B, but was also able to explain in detail all the material elements present, especially explaining the typical work situations in which the future field operators would have to follow these paths.

The frequency of the use of indexical expressions in the above verbatim illustrates the interest of using a visual medium to present the pathways. The older generation of visual display tools could do this, but the VE goes further, offering trainers a double opportunity for thoroughness: by viewing the building and zooming in on its details (see previous section). This feature opens new possibilities for exploring space in general and pathways in particular.

Explain Functional Aspects and Help Trainees Appropriate an Operating Model of the Reactor Building

The third typical use of the VE is related to the trainers' explanations to help the trainees better understand the operation of certain pieces of equipment, especially the valves, which are numerous and complex in the reactor building. The typicality of this use was primarily based on the meaningfulness of the occurrences ($N=24$): during the session, the trainers had insisted at great length (23 min/120 min) on how to handle some of these valves. In the self-confrontation interviews, the trainers explained that the impact of these explanations on learning was amplified by the virtual environment.

An important part of the work of these future field operators will be manipulating valves to ensure proper *valve alignment* for the safe functioning of the reactor. Some of these valves are manually operated and others are remotely controlled from the control room with automatic switch-on devices that field operators need to know about and monitor. These valves and pipes are components of several *primary systems* that ensure the essential functioning of the nuclear reactor, and they have to be closely monitored by the field operators.

Thus, during the sequence about the reactor building containment, the trainers used the software's spherical photos to explain the procedure for putting a pneumatic control valve into automatic mode. "Well, so here you can see the reactor building, with the mechanical crossing valves. So, does this type of valve mean anything to you? They're called 'Sereg valves'. Do you remember how to switch a 'Sereg valve' to its automatic mode?" The use of these photos to support their explanations resulted in increased interactions between trainees and trainers compared with the training sessions without the VE. In the self-confrontation interviews, the trainers expressed their satisfaction with the trainees' active participation. They took advantage of the virtual environment to point out not only spatial knowledge, but also functional knowledge. The tool thus offered the trainers a way to transmit the "essence of the trade": they were able to contextualise theoretical information by visually engaging the trainees.

Share Salient Experience through Real-Life Anecdotes

In addition to these three typical uses, the results showed that the VE encouraged the expert trainers to produce spontaneous and opportunistic anecdotes about their previous work experiences. Indeed, the typical uses described below were identified mainly on the basis of the significance of the occurrences ($N=9$), and the trainers had chosen these uses with the end goal of presenting essential reactor building elements to the trainees, taking them on a tour of the reactor building, and deepening their understanding of it. But while doing so, when a photo from the VE reminded them of an episode from their past experience which they considered to be of interest for the trainees, they took the opportunity to tell about it. This fourth typical use materialises into the production of stories. It cuts across the three typical uses already identified.

As an illustration, after explaining the operation of the *Sereg-type control valve* (see section above), T2 told the trainees an anecdote about something that had happened to one of his colleagues several years earlier: he had failed to pick up an error that a trainee had made on this *control valve* and his Operator's licence had been taken away. This serious consequence of the withdrawal of professional accreditation, a rare but dreaded

event, has made this anecdote highly significant to the trainees in terms of educational potential (Table 2).

Another example of a work anecdote is told by T2 when he notices, during the navigation of T1 in the visualisation tool, a particular metal support. At the view of this anchor point, T2 remembers an event that happened to him when he was a field operator several years before.

Table 2 Excerpt of the two-column protocol for T2 with anecdotes and elementary units of meaning

Verbalisations in the training session	Verbalisations in the self-confrontation interview	Elementary units of meaning (EUMs)
<p>T2: So you put the valve in automatic mode and how do you know it's really in automatic? How can you be sure it's in automatic?</p> <p>Trainee: When you...</p> <p>Trainee: Yeah, the wheel should...</p> <p>T2: Ah, eh, no, there's a better way, safer.</p> <p>Trainee: We're going to put...</p> <p>T2: No, you're not the one who's going to check that its working correctly in automatic, it's the operator. You're going to ask the operator in the control room.</p>	<p>Researcher: And so here? What were you thinking about?</p> <p>T2: Yes, there I was thinking that I'd have to send a really strong message here, which was; since I had in mind what had happened and I know the risks when the valve is poorly adjusted, my goal was to get the message out, so that was to tell them they had to get the operator to manoeuvre the valve because I know this is the only way to be sure that the valve is on automatic. So I say that so they can protect themselves. To protect themselves and be sure they put the valve on automatic before there's any safety issue. Sometimes the messages are really important so it's true, I realise that I sometimes get the message out in a brutal way, a little blunt, huh? Well, there're sometimes messages like that so I'm blunt. It's not to disturb them, it's so that it's really taken into account and that there's no other way to do and that is how they have to do it.</p> <p>T2: But I think that there, well, I insist, that time we talked about Sereg valves, we really had all the elements to give a good explanation.</p>	<p>EUMn: Listening to the trainees' incorrect answers, T2 feels that it is essential that the trainees know how to operate a Sereg valve.</p> <p>EUMn+1: T2 realises that there are all the visual elements in VE to explain to the trainees how to operate a Sereg valve.</p> <p>EUMn+2: T2 remembers a work anecdote he had experienced concerning the withdrawal of a colleague's authorisation following the mishandling of a Sereg valve.</p>
<p>T2: Just a little story here. At one time there was a guy in training just like you here. So he was in the field with an authorised person who said 'go take care of the Sereg valves, go align the Sereg valves'; the guy went to align the Sereg valves and then at some point they did a periodic test. They took away his operator's licence. Not from the trainee, but from the person who was in charge.</p>	<p>T2: I told them about someone who let a trainee do the alignment, and it was not correctly done and they could see that the valves were poorly aligned. The withdrawal of the nuclear operator's licence that I explained. So those are the facts, it's the reality and it ought to put them on alert. In any case, if I don't align correctly I can lose my operator's licence, to do it. So that was the experience and I shared it with them.</p>	<p>EUMn+3: T2 realises that by telling this anecdote to the trainees, he could get the message across to them about the importance of operating the Sereg valves with the spoon.</p>

He had experienced a situation where this same metal support was torn off due to an inappropriate adjustment of the tightening clearance by the field operator in charge of the work. During the plant restart, the pipes of the circuit were dilated by the high temperature of the water (over 300 °C). The force of the expansion was so great that it pulled the support off the ground. The trainer tells the trainees about this experience, which shows the strength of the expansion phenomenon. He also insists on the importance of adjusting the “clearance” when the support is screwed down. T2 did not intend to tell this anecdote before visualising the support on the virtual environment. But he shares it spontaneously because he believes that this incident is very illustrative to account for the expansion phenomenon but also to explain why it is necessary to leave a “clearance” when the pipes are fixed on the supports. T2: “When I saw the metal support, I said to myself: “Well, that too is something I experienced at the start of the plant.” It wasn’t planned in the course at all, but I decided to show them. It’s something the trainees can’t even imagine, the expansion force of a pipe. Concerning the theme of the course itself, it doesn’t bring anything. It is just a matter of making a small cut, it’s not really related to the theme, but I said to myself... here, I’m going to explain to them what happened when I was on the job and I improvised.” The re-enactment of lived experience is initially independent of anecdotal practice. For instance, the trainer explained to us that, while visualising the reactor building in the virtual environment he remembered other anecdotes. However, he chose not to recount them either because he did not have much time left in the course or because he would have had to go into too technical explanations on topics that were not yet covered in the training.

The work anecdotes described in this training situation have the characteristic of emerging through the trainers’ immersion in the virtual environment. These anecdotes are related to the visualisation of the reactor building settings rather than to the theoretical content of the training. Contrary to other media that can be used in training or during informal moments of exchange (Marchand 2011) in which there is no visual support, with this VE the trainees can actually visualise what they are discussing. Beaujouan and Daniellou (2012) show that stories about professional interventions that are accompanied by dynamic visual aids significantly increase the professional story’s appeal and the trainees’ recall of its key steps. In the work anecdote about the anchoring torn off due to the expanding of the pipes, it is by visualising the imposing size of this metal support that the trainees become aware of the extent of the phenomenon. The trainer told this anecdote not because the course was about dilation but because he viewed the metal support in question.

Discussion

The results are discussed from two perspectives: (a) the emergent and typical uses of the VE and their work-related learning affordances, and (b) the re-enactment of expert trainers’ past experiences.

The Typical Uses of the VE and their Work-Related Instructional Affordances

The analysis identified four typical uses of the VE during the observed training session: (a) showing the material elements and spatial layout of certain areas of the reactor building, (b) displaying safe and typical paths through the building, (c) explaining

functional aspects and help trainees appropriate an operating model of the reactor building, and (d) sharing salient experience through real-life anecdotes. The first two uses have already been noted in the literature in training contexts such as 3D virtual field trips or the identification of hazardous elements (e.g. Burkhardt et al. 2005; Mikropoulos and Natsis 2011; Martínez-Graña et al. 2014).

If some of these uses were forecasted by researchers, others were not. Viewing related uses such as paths and locations/displays of equipment were expected. According to the literature, location visualisation and virtual tours can be used to illustrate complex theoretical concepts (e.g., Dede et al. 1996), often complementing another medium (e.g., trainers' slides) with "interest points" specific to areas of great interest along the route (e.g., Martínez-Graña et al. 2014). The unanticipated uses concern the link between visualisation and the trainer's mimetic experience as well as the emergence of work anecdotes. The last two typical uses were less expected because they were more related to the integration of the virtual environment into a training situation and because they had not been planned by the two expert trainers themselves.

Initially, the training session was dedicated to the presentation of the reactor building layout related to its main operational features. The trainers had planned to address two prevailing items: (a) the reactor building *locking/unlocking*, and (b) the description of two main plant systems: the *primary system* and the *containment system*. However, the pedagogical opportunities emerging from the use of the VE prompted them to spontaneously broaden their focus to other facets of this building: typical paths to walk from one component to another and clarification details regarding the manipulation of valves. Far from deviating from the initial training objectives, these professional basics are nodal points of the nuclear field operator's job. Accounting about these key work features contributed to draw the session on the reactor building components closer to the real work (Boccaro and Delgoulet 2015; Durand 2011; Durand and Poizat 2015). The results bring out also that the VE was not merely used to illustrate the theoretical content (provided by the trainers), nor was it limited to being a support for spatial learning, although this has been shown particularly important (Dalgarno et al. 2010). More than anything, it helped the trainers to share practical knowledge about the functional dimensions of operating a nuclear facility. Previous studies conducted with nuclear control room simulators have shown the importance for trainers to develop and build on an action-oriented operative model (e.g. Béguin and Pastré 2002). From this viewpoint, the VE not only offers trainers with opportunities to address some fundamental operational aspects, but also encourages professional debates with the trainees about work-related typical situations and experiences. For this purpose, the "trainers-VVProPrepa" system supports the development of trainees' reactor building operative model by the means of a crucial typification process (Schütz 1962) – that is, the construction, extension, generalisation or collective appropriation of types that are never completely decontextualised because they are actually typical forms of attention, perception, action, communication, or interpretation, partly (but only partly) shared and shareable by field operators. For instance, the typical paths proposed by the trainers are those actually used by experienced field operators given the constraints of their everyday real work, even though these proposed paths are not indicated in the procedures. It should be noted, however, that when analysed through trainers' lived experience, virtual technology offers only "favorable opportunities" for valuable work-

related instruction for trainers. That means that trainers may or may not make them a reality according to their current personal dispositions and the other characteristics of the training situation. This observation has two consequences: a) there is no determinism in the relationship between the use of the virtual environment by trainers and the emerging modality of instruction (but it is always the case, not only with virtual environments), and b) some training configurations that emerge with the support of virtual technology could have emerged with the support of much less elaborate visualisation tools (such as photos and videos), but with a much lower probability. Virtual environments such as VVProPrepa appear therefore to be a valuable complement to apprenticeship and workplace learning. However, more research is needed to investigate trainees' practical and work-related knowledge construction during VR-supported training sessions.

Our study also invites reflection on affordance-based design for training and learning. Typical uses and opportunities for action – i.e., affordances (Stoffregen 2003) - are emergent properties. These affordances are not properties of the user (here the trainer), as such, nor properties of the artifact (here VVProPrepa), as such. They are rather relational properties of the user–artifact system (e.g., Maier and Fadel 2009a; Stoffregen et al. 2006; Stoffregen and Mantel 2015) and differ qualitatively from the properties of trainers, as such, and from the properties of the VE, as such. In addition, the landscape of affordance during training sessions, such as the one observed, is not limited to the “user-artifact system”. This focus on “user-artifact system” does not adequately capture the entirety of the trainers' ecological niche and the whole spectrum of abilities available in their socio-cultural practices. In fact, typical uses and opportunities for action are emergent properties of the “user-artifact-environment” systems (e.g., Mantel et al. 2012), or in other words, of the “trainers-VE-training environment” systems. This has several implications regarding design (Maier and Fadel 2009b): a designer of VR artifact must focus on the design of the whole system, and must take into account the active nature of human perception and the critical role of exploratory activity in users' understanding of and ability to exploit the landscape of affordances. This calls for further studies on affordance-based design and on learning affordances (Dalgarno and Lee 2010) of the “learners- virtual environment-wider training environment” system.

The Re-Enactment of Trainers' Past Experiences

From an instructional point of view, the most promising element for learning and professional development is not so much the intensified immersion afforded by the VE (even though this plays a role), but the re-enactments of expert trainer's embodied past events produced. The results pointed that the VE encouraged trainers to tell anecdotes about practice-related experience during the classroom training session, and yet this aspect was far from “anecdotal”. Narratives and storytelling are primary mechanisms through which humans construct reality and make sense of the world, and they are worthwhile activities in training situations (Rantatalo and Karp 2018; Wylie 2019; Zucchermaglio and Alby 2016). However, in safety research for example, it has been noted that storytelling effects have always been underestimated and underused in training sessions (e.g. Colville et al. 2012; Sanne 2008; Weick 1987). It is important to make here a clear distinction between episodes in which trainers report past events

and those in which they re-enact them. Re-enactments involve re-presentations and are distinct from narratives, which are basically descriptive (Sidnell 2006). It is a recommitment of past experience in a living present reality, which is neither mere recollection, nor narrative, nor even reliving the past situation. When trainers engage in re-enactment, they make use of, dramatise and revitalise selected events, episodes or even atmospheres of the past (Daugbjerg et al. 2014). The trainer's experience is not that of reactivating a past experience or rethinking a past thought, nor of performing a thinking-act that is identical or similar to the first. Instead, it is a "re-casting" of past experience that proceeds in the "as if" mode. Re-enactments are embodied descriptions and demonstrations of past events (Tutt and Hindmarsh 2011) in which past and present co-exist through a vivification of the past (Nichols 2008). As highlighted by Daugbjerg et al. (2014) "*the re-enacted past upholds a complex temporality: it is not entirely present or completely constructed in the here and now, but neither does it, obviously, allow access to an unmediated past*" (p. 682). The re-enactment thus outlines the contours of an embodied and doubly living history: actuated and present. It enables to interweave collective history into individual stories by engaging them in the present time. This blurs the ties to the past event. As commented by Schneider (2011), the re-enacted past is not the past, but "*not not the past*" (p. 43).

This double negation echoes mimetic experience as defined by Willerslev (2004). Mimetic experience is part of a range of experience in which the commitment of actors to situations is complex and composite. It cannot be described univocally. The study of Horcik et al. (2014) showed that trainees in simulated environments exhibit a specific mimetic experience. Mimetic experience is similar, but non-reducible to another experience, with simultaneous feeling of likeness and difference. The authors then paraphrased Willerslev (2004) by suggesting that experience in simulation is "*not work but not not work*" and argue that this double perspective is promising for learning and should be encouraged in numerous training environments. What we are dealing with is a strange fusion or synthesis of work and not-work into not-not-work. Our results suggest a mimetic trickle-down effect. The VE supports a mimetic experience among expert trainers and the re-enactment of past events. This leads them to share work-related anecdotes and embodied practical knowledge, which in turn could encourage trainees' mimetic experience "*not linked to their work and not not-linked to their work*". That is why we assume that the VE supports practice-based learning experiences and opens possibilities for improving learning *through* and *for* work. We must, however, emphasise that it is important to distinguish between a mimetic environment (reproducing the environment) and a mimetic experience. Indeed, if environments such as simulators or VEs are efficient emulators of mimetic experiences, the latter is never guaranteed (in its form, its nature, its permanence) and depends on the coupling between the actor and the environment. Moreover, powerful mimetic experiences can be observed in environments and practices that are not at all inciting, thus showing the importance of imaginative dimensions. Further studies are to be carried out to examine trainees' experiences in relation to trainers' re-enactments of past events, but also re-enactments of past work practices. Studies should also focus on gaining greater insight into the effects of anecdotes, narratives and storytelling for training field operators and how they articulate with virtual environments.

Lastly, it is noteworthy that VE, through the instructional uses made of it by trainers, becomes a boundary object. By becoming a boundary object, VE enables trainers to

address elements in the training situation that relate to the substance of the job, in other words, the practical (or concrete) side of a field operator's work. The VE is a potential boundary object not "by definition" but by the conjunction with the actors' experience: it is the trainers/trainees who bring into the VE, almost without their being aware of it, a part of what is at stake in the real world.

Conclusion

This study focuses on a virtual environment, and its actual instructional use by two expert trainers during theoretical teaching sessions for power plant field operators. Our results show how this virtual environment has been integrated into trainers' practices and how it has enabled new instructional affordances. Some of our findings are in line with previous research on the use of virtual environments. Trainers take advantage of the features of this virtual environment to enhance learning about operational equipment and spatial layout. In doing so, they guide the trainees in developing an operational model of the reactor building.

This study gives rise to new results that need to be confirmed in future research. Thus, we make the hypothesis that the most promising means of learning are not those provided by the immersive nature of the virtual environment, but rather by re-enactments of expert trainers embodied past events. It is this process of re-enactment, coupled with mimetic experience that supports practice-based learning experiences and improves learning *through* and *for* work. This re-enactment process helps trainees to make sense of their day-to-day work practices. More fundamentally, we postulate that it is these two processes, re-enactment and mimetic experience, that ensure "from within" (i.e. in trainers/trainees lived experiences) the connectivity between different knowledge, between past and present, between various learning contexts and between work experiences (including early work practices for trainees) and training. They are therefore central to the development of integrative pedagogical approaches (Tynjälä 2008).³

The limits of this study are linked to the methodological, theoretical and practical choices that have been taken. The data collection is based on the video recording of a single camera with a panoptic view from the rear of the classroom. The use of two cameras, one oriented on the trainer and the other on the trainees would have allowed to: i) avoid that during a self-confrontation interview, the trainers see the trainees on the video, which leads them to be more attentive to (re)discovering the trainees' reactions rather than explaining their own experience; ii) provide data filmed with the trainers in close-up to account for their gestures and mimics.

The course-of-action theoretical framework used in this study aims to account for the significant activity of trainers in natural training situations. It is a question of taking into account the elements with which the trainers are coupled in their entirety. It consequently is difficult to pinpoint the role of each distinct characteristics of VE in the instructional affordances presented here. Indeed, the deliberately global approach chosen to analyse the coupling between trainers and their environment would make it risky to attribute one result or another to a single VE attribute. The scope of this article

³ Here, connectivity refers to processes that contribute to close relationships and connection between different elements of learning situations, contexts of learning and systems to promote learning.

is focused on trainers. It therefore does not account for the learning of the trainees who participated in this training situation. This study continues by analysing the experience and learning of trainees during training situations supported by a VE.

Practical perspectives have emerged regarding the VE and its use during training sessions for field operators. Exploratory activity is crucial in a user's ability to exploit affordance, including learning affordance in the case of trainees. Learning affordance does not exist as an attribute per se but is the result of the actors' active exploratory involvement and interpretation activity. In this sense, training systems based on exploratory activity encourage the capacity of trainees to exploit learning affordances.

To the extent that trainees are not passive receivers of information, the design process should take into account the fact that user–artifact–environment systems include the user's exploratory activity. It is essential to design for exploratory actions and to propose training scenarios supporting this activity. For this, the designer cannot design only artifact (here the VE) but have to focus on the design of the whole system. Training design experiments are being implemented (a) to enable the trainees themselves use the VE to navigate in the reactor building (unlike the situation we analysed where a trainer uses VE), and (b) to enhance exploratory actions and inquiry-based learning (De Jong 2006).

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Compliance with ethical standards

Informed consent was obtained from all participants. All names in this paper have been replaced with pseudonyms and identifying information has been removed. The ethical aspects of this study were approved by the University Research Ethics Commission (CUREG) of University of Geneva. The data associated with this research may be made available upon request and under certain conditions. This research has been co-funded by the University of Geneva and EDF R&D.

Conflict of Interest The authors declare that they have no conflict of interest.

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