3D Simulators in Professional Training

Learning complex tasks overcoming material, economic, and human constraints

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***Abstract*—This paper is about the development of 3D simulators for supplementary instruction in professional training with complex learning tasks and material, human and economic constraints. We present a theoretical framework describing and explaining how a simulator can support the fundamental interaction dynamics in learning settings (interaction with reality, with others and with the learner himself. We describe the development of an actual 3D simulator (for installing the engine in an F-16 fighter aircraft) and present its next phases. We discuss how our theoretical framework fits and explains the development phases of a 3D simulator to meet the intended learning outcomes and how it can help in the development of simulators with similar purposes.**

***Keywords*—3D simulator; professional training settings; fundamental interaction dynamics; collaborative environment**

I. INTRODUCTION

The focus of this paper is the development of 3D simulators for supplementary instruction in professional training, when dealing with complex learning tasks and material, human and economic constraints.

We present a theoretical framework to describe and explain how a simulator can support the fundamental interaction dynamics in learning settings, namely the interaction with reality, with others, and of the learner with himself.

For further elucidation we describe how members of our team developed an actual 3D simulator (for installing the engine in an F-16 fighter aircraft) and present its next development phases.

We discuss how our theoretical framework fits and explains the developments phases of a 3D simulator to meet the intended learning outcomes and how it can help in the development of simulators with similar purposes.

The 3D simulator, presented in this paper, was developed in a joint effort of the Portuguese Air Force (FAP, Portuguese-language acronym) and the University of Trás-os-Montes e Alto Douro (UTAD), in support of the training of mechanical maintenance of F-16 aircraft engines, a quite extensive and complex process that involves several phases and procedures. The specific maintenance process chosen for the initial development of the 3D simulator was the installation of a Pratt & Whitney F100.PW.220/220E engine in the F-16 aircraft, a process that requires three skilled engine technicians to cooperate in the execution of a set of tasks.

The development of this simulator employed Open Simulator as a development platform [1], to lessen the resource requirements of simulation development and benefit from pre-existing networking and multi-user features of these platforms. The rationale is that this virtual world platform does not require licensing, is open source and thus enables the research team to modify it if necessary, and provides from the onset basic features such as content rendering, user login, immersive user interaction, object physics, collaboration (including awareness of the presence of other users), and a credible 3D representation – similar to real world scenarios.

The main purpose of the 3D multi-user training simulator is to provide trainees and trainers with more opportunities to conduct training, with the goal of allowing trainees to reach on-the-job training better prepared and thus to optimize the effectiveness of the resource-intensive training occasions with physical engines, enabling technician training to be enhanced with cooperation and context prior to the training phase with actual physical engines.

II. SIMULATORS IN PROFESSIONAL TRAINING SETTINGS – A THEORETICAL FRAMEWORK

A person learns whenever he or she interacts with the encompassing environment (objects, events or other people) or with him/herself [2]. In all learning environments the learner/trainee faces three fundamental interactions: i) interaction with reality, as defined by Mugur-Schächter [3] (evolving pool - everything that is available at a time - from which an individual can create, define, select object-entities of any nature), ii) interaction with other trainers or trainees; iii) interaction with the self. The articulation among these three

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interaction dynamics originates a given set of learning opportunities for learners/trainees that can lead to the intended learning outcomes (see Fig. 1).

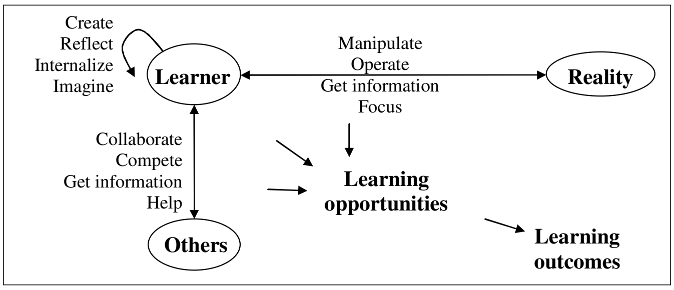

Fig. 1. Fundamental interaction dynamics in learning settings

A. Fundamental interaction dynamics in learning settings

In the interaction with reality (material or virtual) a learner/trainee can configure the reality (operate, manipulate, explore, change, etc.) and get information: (a) to have relevant sensorial, cognitive and/or emotional experiences; (b) to focus the attention on some aspect of the material reality. Those experiences support a given epistemic pathway, with specific epistemic practices [4]. This interaction can be improved if appropriated artefacts are used to mediate the "contact" with material reality.

The interaction with others is another important dynamic. In this dynamic the conversation is crucial. Through it the learner/trainee communicates his ideas, doubts, beliefs. Also through this interaction, the learner/trainee collaborates with others, gives or receives help, coordinates actions which need more than one person.

Finally, the interaction of the learner/trainee with himself is important so that he/she appropriates what he does in the other dynamics. Among other things, the learner/trainee internalizes, creates, imagines, represents, and elaborates mental models.

B. Caractering a professional training setting

In professional training settings the three fundamental interactions dynamics remain important. However, each dynamic has characteristics which are specific of these particular settings.

In a professional training setting the trainee often deals with material objects (a particular kind of reality). In general there are material, human, and economic constraints. Also the general social environment is characterized by a combination of collaboration and competition. Finally, the learning outcomes can be described as a set of skills, or a given level of performance in the execution of a task or sequence of tasks, where tacit and group knowledge [5] is often more important than explicit and individual knowledge.

The interaction with reality (material or virtual) in professional training settings is more focused on action or production instead of observation, description or comprehension. The interaction with others is influenced by the structure of social relationships and intended outcomes. That is, this interaction is conditioned by what is intended: collaboration or competition, autonomy and accountability or the need to execute orders. In professional training settings, the trainee, in terms of the dynamic of interaction with himself, has the responsibility to self-regulate his learning, and take some initiative to find what is relevant to learn in his work context.

C. The role of simulators in professional training settings

A simulator in professional training settings can enable the emergence of new features in each fundamental interaction dynamic.

First of all, a simulator can recreate the material objects and events in a "realistic" context, eliminating: (a) geographic and temporal barriers; (b) risks and costs associated with using the material reality.

A simulator can enable new features in the interaction of the trainee with the virtual environment. First of all, the simulator can work as a mediator [6]: (a) providing new or several perspectives of the virtual object at same time; (b) focusing specific parts of the virtual objects and showing them in more detail; (c) visualizing some virtual events when it is possible to see the results but not the process. The dynamic of interaction with the simulator may afford the opportunity: (a) to operate the virtual environment on the basis of strong interactivity (watching what happens with certain operations) and rapid, or more sophisticated, feedback; (b) to increase or decrease the time scale in which the events occur; (c) to take actions that are forbidden, unintended or unexpected, without the risks associated with doing so in the material reality; (d) to appropriate relevant information from the virtual environment (e) to generate representations that can help the elaboration of mental models; (f) to use a new range of manipulative mediators (e.g. haptic sensors) facilitating the interaction with the virtual environment (increasing the number of tools and diversifying them, to extend the sensorial information, and learning possibilities).

A simulator also can provide new features in the interaction dynamics with others. In particular, it may facilitate and/or structure the interaction among people. For example, the nature of the task may require the coordination among several people, with different roles. The simulator may allow particular ways of interacting (cooperation, regulation, competition, assessment, etc.), or new ways to access the knowing of colleagues. Finally, the simulator may incorporate "artificial" (simulated) colleagues able to answer to the actions or requests of the human trainee.

Finally, several sensorial, cognitive and even emotional experiences with the simulator may support the trainee in achieving a more effective interaction with himself (e.g., triggering reflection, mental modeling).

D. Learning outcomes and knowing achievable with simulators

The simulator allows a new kind of articulation of the three fundamental interaction dynamics in professional training settings. This articulation may: (a) diversify and increase the learning opportunities (more information in several media and different semiotic registers); (b) diversify and increase the possibility for learning attempts without the fear of "censorship"; (c) facilitate and/or structure the contact between other trainees and trainers, strengthening the dialogic component of the relationship among participants; (d) allow different learning approaches depending on the subject epistemic profile.

In synthesis, a simulator may afford the reformulation of the interaction dynamics, content, actors, processes and, finally, the limits of what is a learning/training environment, as we try to explain in the following sections.

III. DEVELOPMENTS PHASES OF THE SIMULATOR

A. Description of the simulator in present state

The 3D simulator presented in this paper was produced to respond to the needs of the FAP on mechanical training. It aims to provide trainees and trainers with more opportunities to conduct training, reducing the resources needed and the risks and costs associated to this process.

At the moment the 3D simulator status is that of functional prototype. The 3D environment is a realistic representation of the scenario of an hangar, the setting where the mechanical training and subsequent use of competences takes place (Fig. 2). The aircraft, the engines, and the tools used for the installation process are represented in a faithful way, so the trainers can visualize and easily identify them when training with physical engines. The simulator is running on a server (which for testing purposes was a simple laptop) and each trainee uses a networked computer to enter the virtual world of the simulator (one computer per trainee). With this setting, trainees can see themselves represented as avatars within the virtual hangar, and they can also see the avatar representations of the other trainees and interact with them. Communication can be embodied (i.e., avatar positioning, gestures, and motions) or verbal (remote text chat or remote voice chat). If the trainees are using their computers within the same physical room, they can also communicate verbally by simply speaking audibly while witnessing the visual representation of the virtual worlds on their screens. Furthermore, a trainer, facilitator, or monitor can participate or witness the training session by entering the virtual world with his own computer and avatar. If a larger group of other trainees wishes to witness the actions of the trainees using the simulation, they can either enter the virtual world with their own computers and avatars, or (if in the same physical room) simply witness a wide-screen projection of one of the participants.

The installation process of a Pratt & Whitney F100 engine in an F-16 aircraft is extensive and complex. The on-the-job training phase evolves several technical procedures that need to be executed by a team, with several procedures requiring the simultaneous cooperation of up to three technicians. Plus, a specific role in the process is that of process checker, which may be played by one of the three technicians, or lead to a fourth person being involved for that specific role. These interactions require at least two types of interaction mentioned above: interaction with others and interaction with the virtual environment.

Installation of the engine inside the aircraft fuselage is the first procedure being implemented in the prototype. This process follows an ordered sequence of tasks, being subdivided into four jobs: JOB1, JOB2, JOB3, and JOB4. Currently the prototype supports the simulation of JOB1, which comprises the sequence of tasks to insert the body of the engine inside the aircraft frame. Cooperation is crucial to the success of JOB1. This job entails several tasks that cannot be performed by a single individual, requiring the simultaneous involvement of all technicians. The prototype already allows the simulation of these tasks, and enables trainees to practice the cooperation process [7] (See II-C).

Fig. 2. Engine technicians operating within the virtual space

One task included on JOB1 requiring cooperation between the trainees in the role of engine technicians is the raising of the engine to align it with the empty hull of the aircraft fuselage. This job requires all three technicians to interact simultaneously with the simulator: two on the left side of the engine, and another one on the right side. When the technician playing the role of process checker gives the command, the three technicians will operate screw driving machines in concert to lift the engine simultaneously and co-ordinately, keeping it levelled, using speech as a means of synchronization. In the current prototype, once all preconditions are adequate (such as having steadied the bearing cart and having adequate tools in hand and fitting for the tools in place), the engine lifting can take place [8].

B. Description of the simulation technical platform

The current simulator prototype was developed using a virtual worlds platform (OpenSimulator) to provide a 3D online user interface and multi-user interactions, and a backend Web server to control the overall simulation operation and state control – a software architecture described elsewhere [1][8]. There are many choices of development platforms and kits for multi-user simulations, and we devised this separation of concerns between visuals/interaction and knowledge/control with the goal of retaining the possibility of changing the technological base of the visuals if necessary, as the project evolves. For this prototype development phase, we elected a virtual world platform instead of a typical game development engine, because virtual world platforms provide several features ready to use, such as multi-user logins, 3D object editing by non-programmers, and concurrent user-to-user interaction via avatar positioning and chat (text and voice). Also, the pre-existing software client for end users provides several features out-of-the-box which may contribute to the learning process during training, such as the possibility to zoom and pan over areas or objects, focusing on some specific object, seeing it in detail to better identify it or perform precision fine actions during a task. For example, when aligning the engine with aircraft fuselage, this feature is very useful for the process checker to verify if the engine's position is correct and give orders to the other three mechanics if some rectification is needed. Likewise, it is possible to zoom out the camera and get one's bearings, similar to what one could do by looking around in a physical setting, moving away or towards locations or other avatars, among other possibilities. These three functions are very useful to get different views of the space organization and location of objects and other trainees' avatars, and also to support cooperation with embodied positioning and team movements, contributing to the cooperation process through training.

The implementation of these features using game development engines is much more resource-intensive and lengthy, which is why we elected to use a virtual worlds platform for this. OpenSimulator was chosen because it is free to use (no licenses required), it is open source (and thus we had the potential of changing its code if we came across unexpected situations), and is for the most part compatible with Second Life, meaning we could leverage all previous local know-how at UTAD and a large worldwide pool of development information, know-how, and resources available both for OpenSimulator and Second Life. If we looked strictly at the development tasks, and not at this overall context, we might have developed the simulator with another platform, such as Open Wonderland, Open Cobalt, or yet others.

As a limitation, the benefits that OpenSimulator offers for rapid prototyping imply that we have to adapt to its existing client software alternatives ("viewers"), which may not be adequate for large scale deployment. For instance, OpenSimulator viewers assume that each user has the ultimate decision-making power over its interface behaviour. As a consequence, we cannot have the simulator automatically change a trainee's perspective without an authorization prompt being presented to the trainee. Our architecture splitting the simulator between an interface and a back-end server with the actual control code is part of a larger effort that aims to provide software architecture support for using the rapid prototype advantages of virtual worlds for streamlined development and at a later stage simplify the process of moving the simulator to a different visual interface environment (more details on this effort are provided in [10].

The current simulator has been tested with intended users, including trainers at the Portuguese airbase where F-16 aircrafts of FAP are stationed [8].

C. Subsequent phases of the development of the simulator

Whereas completing the remaining three jobs is necessary to move this simulator out of development/trial and into full usage at FAP, several other aspects are undergoing consideration in view of their impact in the training environment and in the feasibility of its use. These include the need to improve the visuals of the detail level of some mechanical components, in order for users to be able to identify them more readily, and thus be closer to intended physical situations, where such readily-made component identification is required. Also, user interface decisions need to be thoroughly tested in terms of their suitability and effectiveness. For instance, visual cues on selection of tools, different levels of indications depending on the readiness and contextual support of the learners employing the simulator.

However, the most challenging future development is rendering the simulation use more flexible: currently, the full team of three mechanics needs to be present to perform the activities. If some could be replaced by intelligent computer agents, the remaining (human) mechanics could practice and explore the simulation even without a full team of learners available. Some early proof-of-concept has already been developed in this regard [9]. It remains to be seen, though, whether such intelligent agents could be parameterized, in order to intervene not always, but rather in specific roles of cooperation: e.g., leading the initiative to the human participants; taking on the initiative; cooperating as much as possible; cooperating only when the human participants take inadequate actions, etc.

Finally, and as an enticing prospect, this virtual cooperation could be extended to enable external experts to participate in the process, thus acting as remote advisors or tutors of the learners. In fact, the virtual environment might even be seen as available on mobile devices and be used as a mediator between mechanics operating on a physical engine and experts on remote sites, which could demonstrate a procedure on the virtual counterpart – an idea of merging virtual training and physical actions imagined earlier for other subjects, but which could see new application contexts here [10].

D. User testing and results

In order to evaluate the simulator, two test sessions were performed, which included 3 FAP trainers each, chosen on the basis of being potential future users [8]. The team identified their satisfaction as users, and their expectations regarding subsequent development – particularly issues related to technical challenges, pedagogical affordances, and human-computer interaction details. Both sessions were similar: inside of a room with two group tables with chairs, a projector, a whiteboard, and four computers (three for the users and one as an OpenSimulator server).

The sessions consisted in a brief introductory presentation with the virtual environment projected and the work plan for the session. During the simulation session, the whole dynamic was being projected onto a screen, from the perspective of the computer whose user (a development team member) played the role of supervisor for the engine installation simulation. The session began with an activity for acquainting users with the platform, aimed at the acquisition of basic skills for moving in the virtual world and interacting with objects. During the engine maintenance simulation, trainers were asked to employ the think aloud protocol throughout the process, communicating their thoughts and feelings. After completing the simulation process, final group interviews took place for analysis - in an attempt to measure users' satisfaction towards the system, and to collect suggestions and recommendations for improvement.

The tests confirmed that the selected technology was feasible for use by the FAP trainers involved in technician training. The procedure analysis needs to be fine-tuned, taking into account tactical know-how and systemic aspects (such as the safety of certain avatar positions or the importance of using specific accessories such as the toolbox for better team coordination). Expanding the simulator to support mixed teams of human-controlled avatars and artificial intelligence agents, to support training even if only some of the human trainees are available, was also mentioned as another future improvement.

IV. Discussion

As explained before, a simulator may enable new features in the interaction of the learner with reality. The functional prototype of 3D simulator described works as a mediator, since it provides new or several perspectives of the objects (engine and aircraft) at same time. It also allows focusing specific parts of the objects and showing them in more detail. This particular prototype affords strong interactivity in a very realistic environment (operators may watch what happens with certain operations) and quick feedback. The time scale of the process being modeled (JOB1) is accelerated (it takes less time than when dealing with the correspondent material reality). Obviously, it is possible to try actions that are forbidden, unintended or unexpected, without the risks associated with doing so in the material reality.

In future developments of the 3D simulator other features may be added or enhanced in the interaction of the learner with reality, as the ability to appropriate relevant information from the reality or to generate representations that can help the elaboration of mental models. Another possibility would be to to use a new range of manipulative mediators (e.g. haptic sensors) facilitating the interaction with reality (increasing the number of tools and diversifying them, to extend the sensorial information, and learning possibilities).

A simulator can also provide new features in the interaction dynamics with others. In particular, it may facilitate and/or structure the interaction among people. The 3D simulator described is an example in which the nature of one task requires the coordination among several people, with different roles. In this case, the 3D simulator allows the cooperation and interaction of several technicians, using visual using visual data or through voice communication. Providing help is also possible in the 3D simulator, especially through the action of the process checker. In the future, the simulator may incorporate other possibilities for interacting or new ways to access the knowing of colleagues. One feature already planned for futures development of the 3D simulator is adding “artificial” (simulated) colleagues, which are able to answer to the actions or requests of the human learner.

It is expected that all the sensorial, cognitive and even emotional experiences with the 3D simulator may support the learner in achieving a more effective interaction with herself/himself (e.g., triggering reflection, developing mental models and growth in professional knowing).

V. Conclusions

As discussed above, the theoretical framework presented is able to explain the characteristics and learning affordances of the functional prototype of 3D simulator described here. It is also shown to be a valuable guide for future developments in the 3D simulator, in terms of the three interactions dynamics and in terms of the learning outcomes and knowing that we expect to achieve, given the potential already revealed in the tests with actual users.

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