Immersive Serious Game-style Virtual Environment for Training in Electrical Live Line Maintenance Activities

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Abstract: This paper describes a virtual environment solution for the training of electricians in critical activities, namely, live-line maintenance, in electrical energy substations. The main concept of the virtual environment is the mapping between virtual reality technology and gamification methods with learning theories, in particular, Gagné's cognitive model. In order to explore the benefits of gamification, the system uses concepts established by the Flow Theory, the Magic Circle concept as well as the Player Experience of Need Satisfaction (PENS) theory. User Experience (UX) is used to assess how the system is perceived by the user. Non-player characters are modelled to assist the trainee in the learning process. However, they may use misleading information in order to induce the trainee to make mistakes and thus provide a means of exercising decision making in adverse conditions, which is an important stage in the learning process, especially in the context of critical activities. Additionally, an automatic feedback system based on the visualization of error patterns highlights not only the mistakes made in the virtual experience, but also the strategy for solving the proposed problem. Tests were carried out aiming at measuring several aspects, ranging from usability, perception of benefits and learning effectiveness. A trainee classification process is proposed based on the analysis of human error patterns during the execution of a task. The modelling of knowledge is based on the literature on human reliability and results from the application of tools such as task analysis and knowledge extraction from expert users when interacting with the system (expert elicitation). Clustering techniques applied to error patterns allows for the identification of prototypes of performance classes and their visualization in the form of distinct groups. Results of different assessment processes, based on the view of potential users, are presented, analysed and discussed. Future work includes the conclusion of the automatic evaluation process, based on the analysis and visualization of human error.

1 INTRODUCTION

Virtual reality, along with gamification, has played an important role in alternative learning in recent years, especially in the context of critical activities. This paper describes a virtual environment aimed at training electricians in power substation maintenance activities.

The general benefits of a complementary virtual process include a) safety, since there are no risks and, more precisely, there is no health and life related threat in a virtual environment, as opposed to the traditional maintenance activity; b) psychological effects, since trainees know there are no risks involved and they can concentrate solely in the learning process; c) logistics, because the actual

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training process requires special arrangements, favourable weather conditions, the involvement of a whole team of professionals and displacement of people and equipment, whereas the virtual process can be used at any time and can be transported easily; and d) the innovation of an effective learning through the mediation of the virtual reality technology involved.

The most important benefits, however, are related to the improvement of the training process, addressing the following issues:

a) the fact that the traditional training can only be performed sporadically, at specific occasions, due to the constraints implied in the process, which makes it very difficult for the trainees to recall learning, and thus reducing the effectiveness of the training process;
b) the use of methods, concepts, and cognitive aspects with great potential to improve the learning process; and
c) risk activities require a lot of attention, since they are by nature very dangerous. However, experienced professionals tend to rely on their muscle memory, when they have already mastered the activity to be performed. This may lead to accidents because of minor mistakes. In a virtual environment, error-inducing mechanisms are useful to bring the issue from the muscle memory back to the cognitive system. This way, professionals activate their attention in the activities, preventing mistakes which can lead to serious accidents.

The immersive virtual environment relies on a few concepts which address learning factors not normally and suitably addressed in traditional training processes. Thus, it provides an alternative learning experience capable of a greater degree of knowledge retention, exploring motivation as a key factor for learning. This scheme can ultimately result not only in better quality of services but also in human security.

It is also very important that a virtual learning system provide an adequate means of assessing the effectiveness of learning. However, learning evaluation is not a simple task, and it normally considers the progress the learner has made since the beginning of the training. Automatic evaluation should be presented to the user as part of the gamification process, since players admire scores and feel motivated to carry on until they reach the desired level.

Due to the professional nature of the critical activities training, knowledge modelling was carried out by means of human reliability tools such as task analysis and expert elicitation during training sessions. From the interaction data of expert users with the virtual system during the execution of a task sequence, error patterns of each user were mapped, allowing for the proposal of a trainee model. Trainee error patterns were grouped into performance classes using simple data mining techniques, such as K-means, implemented in the R language. The identification of performance classes provides a basis for developing a system of the evaluation of new trainees. This can also be fed into a more advanced evaluation model, capable of measuring how much the player has actually learned.

2 RELATED WORK

This section describes the state-of-the-art in the areas which play a major role in the work, namely, virtual reality technology and applications, gamification, virtual modelling and learning evaluation.

2.1 Virtual Reality Applied to Training in Critical Activities

The attractiveness of virtual reality to training in critical activities is high due to several aspects. Trainees are able to train whenever they wish, for how long they wish. Real world problems do not represent any danger in a virtual environment, and this corresponds to a significant advantage in terms of psychological aspects. Gamification methods can also enhance motivation, a key aspect of learning. They provide means to deal with a problem which affects to a great extent the performance of critical activities, namely, overconfidence.

Works dealing with the application of virtual reality in the area of power systems tend to focus on providing the user with familiarity with an environment to each there is limited access, so that the user does not feel uncomfortable or even threatened when present in the real scene. Such is the case of the work by Cardoso et al (2017). The work by Velosa et al. (2018), with application to power substations, proposed the use of a virtual model to provide a way to introduce a beginner to the scene, so that safety distances can be assessed and dealt with prior to an experience in a real scene.

Other works deal with the feasibility of implementing a well modelled and fast enough environment capable of adequately simulating a power substation. This is the case of the work by

Fanqi and Yunqi (2010) and the work by Nasyrov and Excell (2018).

2.2 Gamification

Gamification is the application of game mechanics outside the context of games, stimulating the reward centre of the brain and creating a psychological positive reaction to keep the subject interested in the activity and, thus, to generate engagement and increase the fidelity of the subject in the activity implemented by the system.

The flow theory, central to the object of keeping challenge and engagement, was developed by the Hungarian-American psychologist Mihaly Csikszentmihalyi in 1990 (Csikszentmihalyi, 1990) and further explained in 1997 (Csikszentmihalyi, 1997), claims that the maximum motivation of the player occurs when the challenge is large enough, but not impossible to the point of generating either anxiety or frustration. In this situation, the player can spend hours playing without realizing the passage of time.

There must be a goal that can actually be achieved by the player when performing the activity, otherwise it will become pointless and the player will lose interest. Too easy a task implies boredom by the player. Analogously, too difficult a task implies frustration or anxiety on the part of the player. There must be a well-defined relationship between skill and challenge (Csikszentmihalyi, 1990).

In order to achieve a successful experience, the player should receive feedback. The brain uses the feedback as a means to predict performance, to assess the chances of not reaching the desired goal and, specifically in the case of a game, the chances of losing (Tom et al., 2007).

The magic circle concept, within the theories of Huizinga (1949), considered the pioneer of the study of the play activity, explores the intrinsic limitations of an activity, be it spatial, temporal, or even social, and creates a parallel universe to everyday life, a self-contained microcosm in which some rules are added or removed from the player's context, so that errors may have little or no consequence outside the magic circle. Finally, the use of the PENS theory (Player Experience of Need Satisfaction) can help create virtual engaging experiences, mapping three aspects that the player feels the need to have: competence, autonomy and relationship (Scott Rigby, 2011).

The discipline of neuroscience has also shown that the human mind is constantly subject to interpretations that may not correspond to reality. It is not difficult to deceive the human mind by inserting it into a fictitious scenario and at the same time convincing it that the scenario is real and that everything within it is real.

The characteristics reported above led to the conception of the learning virtual environment described in this paper as a serious game.

2.3 Virtual Modelling

The modelling of virtual objects is commonly performed using ontology, since they must interact with the user and also with other objects in the scene, that is, they must have a well-defined behaviour.

Zagal et al. (2005) developed a framework aiming at an ontological language for game analysis. Their model, called Game Ontology Project (GOP), is based on the following taxonomy: a) Interface – interaction of the player with the game; b) Rules – what and how events happen within the game; c) Goals – what must be fulfilled by the player; d) Entities – all interactable objects; and e) Entity Manipulation – actions by entities and the player.

Yusoff et al. (2009) present a framework for the development of serious games combined with learning theories. The model allows for the specification of technical aspects of the game as well as learning dynamics based on the ability to fulfil certain tasks and promote reflection on the player about the actions taken in the learning process.

A similar approach is used in the work of Tang and Hanneghan (2010), which presents a model for the automatic generation of serious games, based on the following models: a) Game Content Model, used for defining objects, attributes and relationships; b) Game Technology Model, used for presenting the game within a programmatic order; and c) Game Software Model, used for implementing the model on a specific platform.

The works listed above describe, in general, development aspects in the production of serious games. However, in the proposed virtual environment, it is necessary to describe the elements within the dynamics and story of the game, as well as their behaviour.

2.4 Non-player Characters

Non-player characters (NPC) have played an important role in virtual environments focused on social skill training. Moon (2018), in his review paper on social embodiment for design of NPCs in virtual reality-based social skill training for autistic children, stresses that NPCs are “believed to enhance the social awareness of users in simulated social worlds". They have three special roles in virtual training:

i. Serve as an aid to the trainee, giving hints as to how to solve a problem;
ii. Serve as a sort of companion, providing the learners with a desirable social engagement;
iii. Initiate problematic situations in order to expose the learner to situations likely to be experienced in real life.

Gamage and Ennis (2018) examined some effects of NPCs in serious games both in terms of learning and engagement. The results they obtained in their experiments show that NPCs can lead to significant positive effects on engagement and also that learners prefer to use virtual environments which contain virtual characters, which in turn leads to a positive effect on learning.

The works by Buede et al. (2016) and Balint et al. (2018) both address the issue of designing intelligent NPCs in order to enhance interaction with users of the virtual system and thus promote engagement.

2.5 Learning Evaluation

Learning virtual systems reported in the literature normally use experimental tests in order to validate results, but none of them comprises a module to actually perform the evaluation of how much the trainee has actually learned.

Shen et al. (2018) applied questionnaires to students to assess the effectiveness of the use of virtual reality in learning, by means of an immersive VR experience. Analogously, Sankaranarayanan et al. (2018) applied a questionnaire to a simulation group and to a control group to assess the difference in performance when training in a simulated operating room fire scenario, resulting in a better performance to the simulation group. Ekstrand et al. (2018) compared an immersive virtual reality-based training system with the traditional paper-based method in the area of neuroanatomy, where 3D techniques are essential for providing a better understanding of the brain. The aim of the work by Mavromihales et al. (2018) was to evaluate the benefits of games-based learning for the performance of mechanical engineering students, dividing them into two groups and then comparing their performance. Sreelakshmi et al. (2015) integrated a serious game with the nine events of instructions by Gagné, and evaluated its benefits. All these works, regardless of the discipline to which virtual reality and gamification technology have been applied, highlight the fact that measuring learning is still a scientific challenge.

Artificial intelligence techniques have also been used for two relevant purposes regarding learning evaluation: a) to map or to infer the knowledge state, current and future, of the trainee from data generated within the interaction with the virtual environment; and b) to be an auxiliary tool for the analysis of human error risks.

There are vast amounts of studies related to human error in the scientific literature. This work is based on some parameters that have been consolidated in the area of knowledge: First, as stated by Rasmussen (1982), back in 1982, every instructional proposal must offer the opportunity for trial and error experiments. According to Bateson (1973), as interpreted by Pereira (1983), error is a necessary consequence of any learning process and, thus, error is an indicator of change in knowledge.

The recurrence of error, regardless of the context, allows for identification of error patterns, which provide indications of critical issues anchored in the human-system interaction (Reason and Hobbs, 2003).

The virtual learning system described in this paper goes beyond demonstrating that technology can improve the learning process, providing a model for the evaluation of trainees as well as of the learning they achieve when subject to the training process. The concept of the model is based on the analysis and visualization of human error, and is the focus of ongoing work.

3 METHODOLOGY

The work involves multiple areas of knowledge aiming at providing an effective solution for the virtual learning process. The most important areas involved are geometric modelling, virtual reality, which can be categorized as technological, and gamification and learning models, which can be categorized as cognitive sciences.

In addition, this work addresses two special aspects. The first consists of the application of virtual reality technology and gamification aiming at enhancing the learning process, making special use of the role of human errors in learning. The second consists of conceiving an automatic evaluation model, which is a very challenging task, since measuring learning is rather difficult and methods to accomplish that are still incipient.

3.1 Using Errors for Learning

Beyond the work towards the development of a realistic virtual environment for learning purposes, the first research topic addressed in the project attempts to answer the question on the effectiveness of gamification on learning, especially in the context of critical activities. The system should make use of all gamification scheme which bring benefits to the learning process.

The first thing to do is to map the methods mentioned in the previous section onto a mechanism of learning, which in turn is represented by a suitable learning model. Due to the nature of the activities addressed in the virtual environment, namely, "live line maintenance of electrical substations", which englobe very rigorous protocols, the learning theory adopted was Gagné's learning model, with its nine events of instruction. For further details on the Gagné's learning model, the reader must refer to the seminal paper by Gagné, Briggs and Wager (1992).

After carefully identifying how each of the nine events of instruction proposed by Gagné et al. relate to the physical (standard) training process, it was possible to analyse which of the gamification schemes previously mentioned had potential of application aiming at enhancing the learning process.

Apart from the geometric modelling challenges involved in the development of the learning environment, some important decisions had to be made to ensure a satisfactory learning experience. One of them was that the experience in the learning environment should be of the type "single player", which implies that only one electrician is trained at any particular time.

The second modelling challenge is to make every agent (also known as actor) in the scenes behave appropriately, according to the type of relationship they have among themselves. For this purpose, an ontology scheme was adopted.

For the modelling of behaviour and relationship patterns of agents (whether they be simple electric components or maintenance tools), seven requirements were defined: 1) to take into consideration the social relationship dynamics present in real world practice, namely, subordination and cooperation; 2) to convey to the player a sense of the need for reaching a specific goal so that a larger goal is achievable; 3) to consider that a specific problem in this domain can have multiple possible solutions; 4) to verify whether the player is able to make a decision considered correct in activities such as choice and use of maintenance tool; 5) to consider possible consequences of not executing a specific procedure; 6) to consider the nature of fortuitous violations of good practices; and 7) to consider possible adverse conditions which could jeopardize or even prevent activities from being performed.

Logging user interactions with the system while performing a task enables detection of different types of errors. According to the taxonomy presented by Reason and Hobbs (2003), based on Rasmussen's Skill-Rules-Knowledge hierarchical scheme (Rasmussen, 1982), these errors assume the following forms of observable behaviours:

- Task not performed due to action omission;
- Inaccurate performance;
- Action performed in the wrong order;
- Performance outside the expected time;
- Incorrect action;
- Wrong action performed on the correct component;
- Correct action performed on a wrong component;
- Action performed at the wrong time.

Given the critical nature of training activities, the role of error in assessing learning goes beyond its pedagogical character. Often used in instructional planning and learner classification (Bloom et al. 1983), human error is the central element in human reliability studies and, therefore, was defined as the fundamental parameter for mapping the trainee's learning level.

These mechanisms help in the determination of errors performed by the trainee. They can also dynamically provide suitable feedback so that they can estimate their performance and attempt to prevent failure.

It is assumed that there is a projection of the state of knowledge of the trainee in the form of behavioural patterns. A pattern is a reflection of shared beliefs that influence the performance of an individual. Thus, the recognition and analysis of a critical situation, or the execution and validation of a proposed solution, must correspond to a certain level of performance in relation to the knowledge of rules and procedures as a strategy for problem solving and decision making in critical situations. Data knowledge discovery techniques have been successfully applied in instructional systems to either statically or dynamically infer the trainee's state of knowledge or to map patterns of user interactions. The purpose of analysing and visualizing such patterns is to reveal a dynamic image that allows for the identification of changes in individual performance and its classification in relation to the proposed learning objectives.

3.2 Evaluation Process

The evaluation of learning has always been a challenge, since there is no definite method which is able to clearly state how much somebody has learned from a particular experience or activity. One of the clearest reasons is the subjective nature of scoring, since every evaluator uses an internally conceived scale and therefore different from that of any other possible evaluator.

Evaluation processes in virtual learning systems are performed on a learner model consisting of state variables based on user interaction with the environment. The trainee modelling was carried out using tools and models to analyse human reliability and, in particular, the study of human error in critical activities. In this perspective, the state of knowledge of a trainee corresponds to the likelihood of certain types of errors occurring during the execution of a task.

The trainee model is based on the probability of violation or negligence towards implicit semantic rules. Learning measure, as well as the measure of the efficiency of the virtual environment, is based on a) the ability by the trainee to respond to the requests made by the system; and b) the evolution of this ability.

Table 1: Error categories and types.

General category	Error type
Choice of procedure (P)	P1- incomplete P2 - incorrect P3 - superfluous P4 - absent P5 - unnecessary
Execution (E)	E1 - omission E2 - replication E3 - inclusion E4 - sequence E5 - intervention at some inappropriate time E6 - incorrect operator position E7 - incomplete action E8 - unrelated or inappropriate action E9 - right action on wrong object E 10- unintended action
Recovery from error (R)	R1 - too late R2 - late R3 - immediate

Performance metrics of a trainee in a virtual environment allow for the categorization according to:

a) Trainee's current level of knowledge;
b) Aims of the training;
c) Interactive processes with the system;
d) Risk associated with human error.

The categorization of human error, in turn, allows for a) the identification of critical situations; and b) the definition of preventive and corrective interventions.

Error categories analysed in this paper were selected from the work by Sherer et al. (2010) and are presented in Table 1.

4 DEVELOPMENT

The immersive virtual learning environment was developed using a game engine, Unreal® Engine 4. A real electrical substation was digitalized, first using laser scan and then a geometric modelling tool. Details of objects, such as day and night cycle, dust in the air and on insulators and 3D modelled gravel, enhance realism and thus the sensation of immersion. Figure 1 illustrates the modelling of a power substation.

Figure 1: Image showing the modelling of a power substation and tools used in maintenance activities.

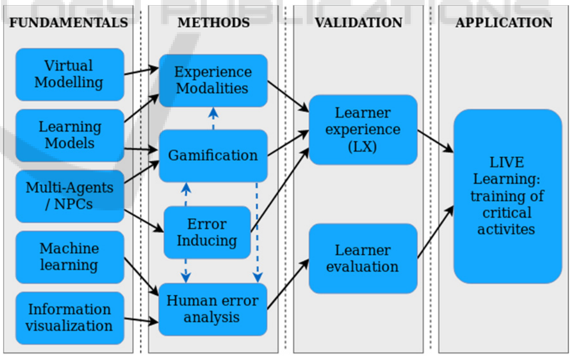

Figure 2: Conceptual diagram showing an abstraction of components of the live learning virtual environment in four domains (fundamentals, methods, validation, and application) along with their relationships. Continuous arrows indicate direct relationship, whereas dotted arrows indicate abstract relationship.

The concept of the system can be thought of as the interaction between several different components. Figure 2 attempts to represent, in terms of methodology and technology, how the virtual learning environment was conceived and developed.

4.1 Virtual Learning Modelling

The system provides five modalities of virtual training:

a) demonstration modality: the system shows the procedures to be performed using a movie-like animation, causing effects on the components which must be moved or acted upon.
b) instruction modality: the system takes one step further, showing to the trainee how the procedures must be carried out. In this modality, the trainee is already inside the virtual scene, but does not perform anything.
c) interaction modality: The trainee is now responsible for carrying out the procedures in their logical sequence. In this modality, errors begin to have a role.
d) game modality: The system now provides functionalities that make it resemble entertainment games, including scoring. This modality attempts to explore the motivation to play and, thus, to learn.
e) unexpected situations modality: The last layer of the system is built on top of the game modality, inserting into the scene agents with bad behaviour, which will try to induce the trainee to make mistakes. In this modality, errors are used to enhance the learning experience.

4.2 Game Modelling

As far as the effectiveness of using interaction equipment is concerned, with the intrinsic movement restrictions, the magic circle concept was explored and tested with potential users, showing that the concept indeed works. The users easily transferred their minds to the parallel world, with its new rules, namely, the standard controllers and interface devices of off-the-shelf game consoles, which were capable of performing six degrees of freedom hand presence, which contributed to the feeling of immersion by the trainees.

The concept of Flow has also been explored and tested with potential users, showing that the sensation of passage of time had been altered. This means that the users can train more without getting tired, enhancing the level of learning. The tests also showed that immersion significantly enhances the sensation of a captivating experience and thus the learning process.

As stated by Tom et al. (2007), adequate feedback must be given to users, so that they can dynamically predict their performance, their chances of reaching the desired goal and, especially in the case of critical activities, their chances of failing. Since the environment resembles a game, users with prior game experience tend to grasp the dynamic of the environment almost instantaneously.

4.3 Multi-agents and NPCs

Since the environment was modelled as "single-player", it must count on NPCs representing the other participants in the maintenance activity being trained. The use of NPCs here is also based on what the scientific literature claims, that it leads to a higher level of engagement and learning.

In the current version, NPCs are used in order to provide a means for the use of errors in the learning process. In this scenario, one of the NPCs, whose normal role is to assist the learner in the activity and to perform the actions of other electricians involved in the activity, can attempt to lead the player to make a mistake. The mechanism is part of the "unexpected situations modality" of the virtual environment, and makes up its most advanced learning module.

The behaviour of NPCs was modelled based on a solver best known as STRIPS, short for "the Stanford Research Institute Problem Solver". As stated by the authors in their seminal paper (Fikes and Nilsson, 1971), the solver "attempts to find a sequence of operators in a space of world models to transform a given initial world model into a model in which a given goal formula can be proven to be true". However, STRIPS lack two characteristics necessary in the virtual environment: a) it does not account for human (player) interference; and b) it does not account for dynamic priorities.

An extension of STRIPS was then developed in order to allow NPCs to update their tree of plans on each iteration, and then to alter their priorities according to their updated needs. This way, an NPC is able to prioritize harmful actions and thus attempt to lead the player to an error. The model also accounts for an "internal distraction" degree, that is, an NPC has less or more susceptibility of getting distracted in activities such as trying to talk with the player.

In order to control the behaviour of NPCs, the so-called BDI (short for "Belief, Desire, Intention") model was adopted, which provides NPCs with the ability to make decisions on their next actions based on all available information.

4.4 Evaluation Model

The evaluation model of the virtual learning environment is based on the acquisition, processing, analysis and visualization of data collected during and after training. The first issue to address in the evaluation process is to provide the learner with feedback on preliminary performance results, since this is a fundamental principle in the learning process. This is one of the nine events of Gagné's model. The performance assessment (learning results) comes next, and then the enhancement of retention and transfer (internalization of knowledge).

It is important to note that, in the work by Gagné et al. (1992), the concept of instructional planning was based on a cognitive model grounded on information processing. Learning depends on directing efforts and attention to learning outcomes.

A similar cognitive model is fundamental in studies of human error, as in the model of human failure proposed by Rasmussen (1982). This model relates internal mechanisms of human errors with their manifestation by means of observable behaviour. This model is the basis for a learning evaluation method which encompasses elements of human reliability analysis within instructional design.

Analysing the interactions of learners in the virtual environment allows for the mapping of their performance during the execution of a task, which then reveals patterns of behaviour. The key challenge now is to identify and visualize these patterns by means of data mining techniques which should allow for the classification of patterns and the inference on the knowledge states of the learners.

5 RESULTS

The evaluation of knowledge acquisition is a challenge, encompassing many subjective aspects. Four different types of tests were carried out independently to validate the virtual environment. Aspects in one test may be overlapped to some degree with aspects in the other tests.

5.1 Usability and User Perceptions

The first test had a somewhat subjective nature, addressing two aspects: usability and perception of benefits to the learning process by potential users. The second test was carried out with three different groups and addressed four aspects: enjoyment, usefulness, ease of use and immersion. It is worth noting that it is not so easy to carry out tests due to the low number of electricians qualified to perform this kind of activity.

In the first test, each of the two aspects was evaluated with a single question, as described below:

- Usability: Can you compare this virtual environment, in terms of effectiveness, with other computer programs used for learning purposes?
- Learning benefits: Do you think this virtual environment will be useful to complement the training process, bringing benefits in terms of interest and motivation?

Table 2 shows results of the tests carried out with 19 electricians, in three different virtual environment experiments, attempting to assess "usability" and "learning benefits".

Table 2: Results of usability tests.

Criteria	Likert Scale				
	Much worse / strongly disagree	Worse / disagree	Similar / neutral	Better / agree	Much better / strongly agree
Usability	0	0	7	6	6
Learning benefits	1	2	0	8	8

After careful analysis of the answers, it was clear that the negative observations on learning benefits were, in fact, related to usability. This is confirmed by other arguments they presented in their speeches. This kind of confusion is fairly normal in experiments like the ones made here.

The difficulties reported are presented below along with how the system attempts to address them:

a) Lack of safety distances: the version he tested did not include safety distances;
b) Lack of force feedback: the system should address aspects of the learning process which do not rely on force feedback;
c) Difficulties with the interface: users with no experience in games or virtual applications tend to perform significantly better on the second experiment, improving their ability in such a way as to match the skills of experienced users.

The second test had a more general approach in terms of public, and attempted to assess the virtual environment as a game. Three different groups were interviewed: a) game design professionals; b) non-critical maintenance professionals; and c) critical activity maintenance professionals. This means that only the third group corresponded to the public to which the virtual environment was designed.

The method employed in these tests were by free speech interview, where interviewees are allowed to express themselves as they wish. The interviews were later analysed to produce the results shown here.

Results presented in Figure 3 show satisfactory perceptions on enjoyment and usefulness, relatively satisfactory perceptions on immersion and reasonable perceptions on ease of use. This will be discussed in more details in the next section.

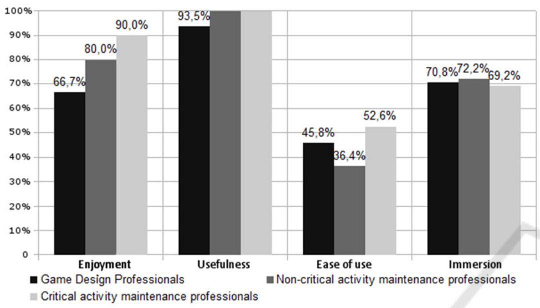

Figure 3: Responses of interviews with different groups on four aspects of the virtual learning environment.

5.2 Analysis and Visualization of Performance Patterns

The modelling of human error and the tracking of the behaviour of the trainee, by means of the interaction process in virtual systems, comprises a first stage of the learning evaluation, which generates data about their performance. Determining patterns from these data requires the concomitant use of classification and visualization techniques.

An important gap in the development of interactive data visualization techniques, applied to user interaction data from virtual training and educational systems, according to Vieira et al. (2018), is the lack of connection between data visualization techniques and learning theories. This lack of integration has produced a situation where the sophistication and interactivity of visualization methods are unrelated to a learning theory and thus fail to communicate information regarding user performance.

Based on the analysis of the activity called "pedestal isolator exchange", analysis of the system database, expert interactions and literature review on human error in the electrical sector, a knowledge model and an elementary data structure are proposed aimed at composing a "model of the trainee". The available data were extracted from a database of 23 training sessions of a simulated activity composed of 13 tasks represented in the unweighted and directed graph in Figure 4. The complete execution of the activity corresponds to a minimum spanning tree of the graph subject to constraints imposed by edge directions. The identification of violations which occurred in the training sessions was based on violations of the constraints derived from the mapping of tasks relationships in the system database.

The classification of the mistakes made in training sessions, as well as information about the time and number of executions of each task, support the modular structure for the trainee model. Thus, the probability of error in a given task is subject to the knowledge of the chance of occurrence of three error categories (Table 1), illustrated in Figure 5a, namely, (P) procedure choice, (E) execution and (R) recovery from error, as well as the expectation of (T) the time spent and (No) the number of times the task will be performed. This model is applied to each task performed, as illustrated in Figure 5b. A state of the knowledge of the trainee throughout the 13 proposed tasks is therefore given by a vector of 65 components.

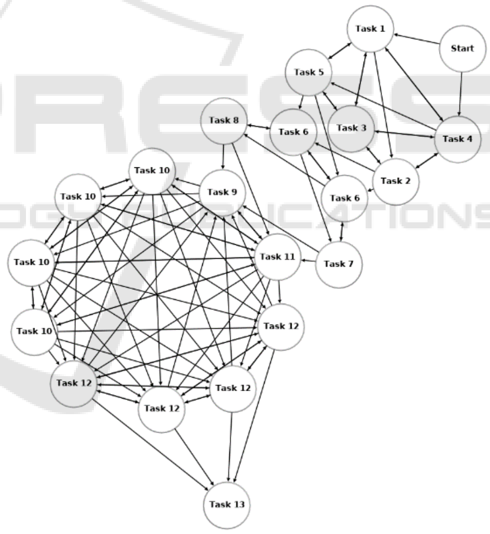

Figure 4: Graph of possible paths for performing the tasks within the simulated activity.

The error patterns created from the analysis and treatment of the interaction data of the 23 training sessions are represented in the heatmap of Figure 6. Each line corresponds to the monitoring of trainee interactions with the system. The columns, taken from 13 to 13, correspond, respectively, to the values of the variables T, No., P, R and E.

The mapping of interactions through heatmaps has been explored in the study of social network users. Cao et al. (2015) propose a system for user model visualization, called TargetVue, which allows for the comparison of patterns of user behaviour over time and supports the detection of anomalies from different data sources.

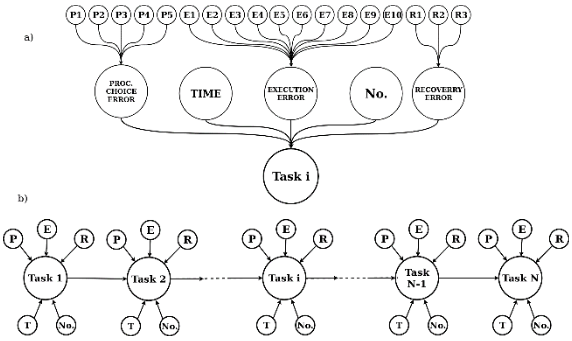

Figure 5: Graphs of the model: a) Subgraph that models probability of error occurrence in Task i; b) Graph of simulated activity with concatenated tasks.

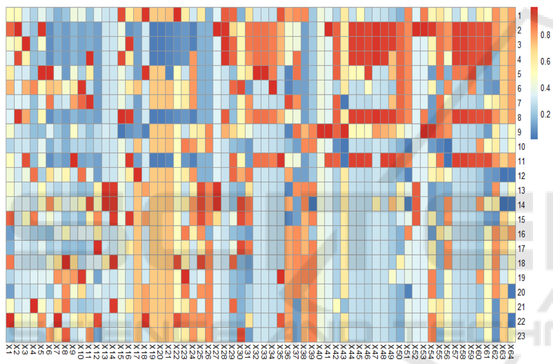

Figure 6: Heatmap of interactions of 23 training sessions sorted according to the system entry.

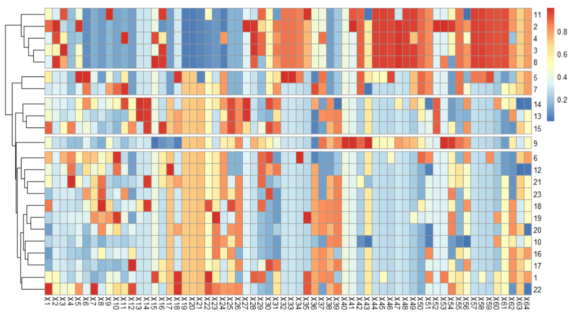

Figure 7: Heatmap ordered and stratified according to five performance classes.

In the heatmap shown in Figure 7, the matrix lines were ordered according to similarity between the patterns. The dendrogram to the left of the figure allows for the visualization of possible hierarchical clusters (highlighted line), according to the depth levels of the groups.

The clusters found in this procedure demonstrate the ability of the model to capture the state of the trainee's knowledge by means of patterns which identify distinct performance classes. The strong correlation between similar patterns provides important parameters for the implementation of tools for automatic performance classification.

5.3 Error-inducing Scheme

The tests carried out to measure perceptions on the error-inducing scheme involved five live line electricians. It is worth noting that there are not so many professionals available for tests, since it is a very restricted public.

The methodology used in these tests were as follows: First, electricians were asked to perform a maintenance activity in the virtual environment, being told that a virtual assistant (NPC) would help them. Then, they were asked to do it for a second time, but they were not advised about the change of behaviour of the virtual assistant, who was supposed to, at some point, mislead them. After the second experience, they were told that the virtual assistant tried to mislead them, and they were asked to perform the activity for the third time, but this time the virtual assistant would behave normally.

After the three performances, they were asked to answer four questions (free speech) and an additional question using the Likert scale, as follows:

1. *Did you notice that the virtual assistant tried to mislead you? Did you notice it immediately? If not, how long did you take to notice?* Only two electricians noticed the error immediately;
2. *What did you think when you were sure that there was a mistake?* Three electricians focused on what to do to correct the actions when they realized there was an error. One thought there was an error in the system;
3. *Did this mistake lead you to change your attitude during the experience?* Four participants said they changed their attitude. One decided not to rely on the virtual assistant. The other three said they decided to pay more attention;
4. *Did you expect another attempt by the virtual assistant to mislead you in the third session?* All participants were expecting an error in the third session;
5. *Do you think the error-inducing mechanism can bring benefits for the training? Does it induce the trainee to think more about how to perform the activity? (Likert scale: 1 -*

strongly disagree; 5 - strongly agree) Four participants strongly agreed about the benefits the error-inducing scheme can bring (score 5) and one agreed to some degree (score 4).

6 DISCUSSION

In terms of usability, most users approved the use of the environment as an important tool to complement traditional training, as the first test showed (Table 2). The minority that was sceptical towards the system based their opinion in arguments which are either out of scope or dealt with either in future versions, with the inclusion of other functionalities, or in further virtual sessions, since other tests have already shown that the cognitive load of the system is very low. Furthermore, in one particular case the trainee even misunderstood the purpose of the system, claiming that it would not replace the traditional training process. In fact, this has never been the purpose of the system.

The second usability test, carried out with three different groups using free speech interviews, showed that all groups perceive the system as useful for its purposes. Furthermore, despite not unanimous, they find the system enjoyable, which is an important aspect of the system since learning is affected by the way learners feel about the process.

However, none of the groups found that the system was easy to use. Live line maintenance professionals had a slightly more positive view on this aspect. This may be related to the unfamiliarity other users had on the activity itself, which is understandable. If one does not know what to do in real practice, one tends to have more difficulties in finding out what to do in the virtual environment.

As Figure 3 shows, ease of use received a significantly lower score in comparison to the other criteria. In order to analyse this, it is important to distinguish the two types of population, as their differences in profile cause significant impact as far as this criterion is concerned. Technical audiences are generally focused on solving problems. Indeed, the literature is right when it says that games are a type of problem-solving method that refrains from unnecessary complications. Although the chart does not segregate the groups, results show that active maintenance personnel have scored significantly better than the other groups, mostly due to the knowledge of what tools should be used at every step of the activity.

Interviews after the experiments also showed that there was a general misunderstanding about the meaning of the term "ease of use". From the thirteen times the term appeared in the interview (that is, the thirteen interviewees referred to the term after being asked about it), twelve of them (all but one) were used in the sense of "lack of familiarity" with the equipment.

This means that the criterion "ease of use" has been compromised, and should be addressed in a different way. Analyses such as this, based on free speech and using specific terms, proved to be more complex than previously imagined. Nevertheless, the whole experiment was presented here in order to ensure its reliability and authenticity.

The proposed evaluation model, based on the analysis of errors occurred during training sessions, aims at providing parameters for the classification of trainee performance. In this sense, a cluster analysis was carried out in order to identify performance classes. Data were normalized and clustering techniques were implemented through the libraries and functions available in the R-CRAN language and the RStudio development environment (Williams, 2011).

As for the error-inducing tests, results show that the use of the virtual environment brings benefits for the learning process.

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