Co-development of a Virtual Reality Tool Designed by and for Students for Training in Electrical Hazards: the VirtuElec Project

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Abstract **- The teaching of electrical hazards for future professionals is an important issue. This problem is complex, because to train students in risk, it is necessary to confront them with dangerous situations, but without making them take risks. The VirtuElec project was born in this context: co-producing, with a company specialized in virtual reality, an environment simulating electrical hazards and allowing to train according to different scenarios at different levels of competence. The originality of the project is to involve the students themselves in the construction of this environment. By integrating a project team, they worked in a design office to co-develop this tool and enrich it with video and virtual supports: a training support carried out by students and for students. Students who participated in this project gained knowledge in the areas of electrical hazards, virtual reality, and teamwork, but they felt they gained the most proficiency in the last two skills. Finally, this tool was implemented within the framework of a semi-autonomous training module combining real and virtual experimentation, in order to offer students the most complete experience possible of the professional situations they will face in their future jobs.**

Keywords - Co-design; Electrical hazards Simulation; Immersive Virtual Reality; Interactive Devices; Multi-disciplinary; Problem-Based Learning; Computer Supported Collaborative Learning; Professional gestures

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I. INTRODUCTION

It is essential for students in the field of competence of electrical engineering to have a good knowledge of electrical hazards, in order to be able to identify them and prevent accidents, which are usually very serious. This is indispensable first in the context of their training and for the actions they will have to carry out in the professional world. This more than true since, with the development of apprenticeship training and more generally the professionalization of training, learners are increasingly confronted in their training course with situations of potential danger in an industrial environment.

At present, training exists for the students concerned, but it takes place under conditions quite different from those they will face in their professional activity. Even if some interventions are indeed carried out in conditions close to the industrial context, on a real electrical cabinet, they require the presence of a trainer for a student, due to the presence of very real risks. Moreover, this situation is stressful for the student faced with the risk (even if all precautions are taken) and for the trainer, who assumes a heavy responsibility.

The objective of the project, co-developed with a company specialized in virtual reality, was the design of a virtual environment presenting different scenarios of electrical risks. Depending on the level of expertise of the learner, a mission is given to him or her and he or she must take the right decisions in terms of choice of intervention and protection equipment, of behavior in the face of a risk, and of control of professional gestures.

The objective is to have a unique, innovative, modern and efficient tool developed specifically for our training needs. This allows learners to be able to train at their own pace, on a realistic and secure tool, but also to be able to address all aspects of electrical risk, in autonomy and to benefit from an individualized experience, with an individualized teacher feedback, focusing on the key elements related to each situation. The originality of the project is that it is a real partnership with a company, really involving students who have worked in a design office context, co-developing the tool in terms of ergonomics and functionality. Because of the health context related to the Covid19 pandemic, this collaborative work was necessarily more difficult, and it required the use of collaborative work tools implementing an Agile method in order to make the exchanges more efficient: an educational tool developed by students for students [1]. Obviously, the purely virtual experience can appear to be a bit reductive compared to a real situation. This is why the created tool has been implemented in the framework of a new teaching module based on experiential learning and aiming at developing students' autonomy. The virtual experimentation was thus completed by an experimentation on real systems, but involving lower electricity power for safety reasons.

After a presentation of the context of the use of virtual reality for the prevention of occupational risks and the modalities of development of the project in Section 2, Section 3 describes the methodology followed by the project team, the functionalities of the developed tool, and the methodology and tools used. Finally, Section 4 presents first results of the evaluation of the perception of the project by the students who participated in its conception, as well as the choice of implementation of the virtual tool in relation to real-life experiences, in order to provide the students with the most complete experience possible.

II. CONTEXT

The use of virtual reality for education has been the subject of many articles in recent years, addressing both the interest of this new tool, but also its limitations [2]-[5]. If we refer more specifically to the field of occupational safety and health, realistic virtual environments have many advantages [6][7]. The first and most obvious is the possibility of exploring an environment of potential danger, without taking risks, but also without putting colleagues at risk or causing damage to equipment. The learner also has the opportunity to perform actions and make mistakes without risk to him or her, and without feeling the pressure of other colleagues or the assessor, as would be the case in a real-life scenario [8]. He or she also has the possibility of being wrong, without consequence, and as many times as necessary. All these conditions lead the learner to be a real actor of his or her formation: the solution cannot come from elsewhere; the learner is obliged to act, to interact with what surrounds him or her, to progress in the mission.

The specific case of electrical hazards, which currently remains one of the main causes of fatal accidents in industrial environments, has been the subject of numerous studies and developments in the field of virtual reality. In particular, we can mention the application of virtual reality for the training of electricians working on substations [9][10], in the field of construction [11] or power distribution networks [12], and more generally in all fields where electrical risks are present [13]. These generally concern tools for experienced professionals, the aim of which is to enable them to train on devices on which it is usually difficult, if not impossible, to train, either because of their difficult access or because it is impossible to manoeuvre on these elements without causing a customer blackout. Other types of educational tools exist in the context of electrical risk training, the most common being based on videos illustrating risk situations and including quizzes that allow students to position themselves in terms of what to do when an electrical risk appears. Even if these tools illustrate realistic situations, the students are always in the position of an outside observer, and are never really confronted with the potential danger. These learning conditions are therefore far from reality.

The VirtuElec project's approach is complementary to these developments: it aims to enable the training of students with no professional experience related to interventions on electrical installations. In this context, the virtual environment is of course intended to reproduce as closely as possible the real environment, but not in order to remind the learners of their daily life, but on the contrary to make them discover what their real future environment will be. In these circumstances, it is important to simplify the environment by not including too many non-essential elements, so that the learner can quickly focus on his or her mission.

In addition, the target audience is wide, and skill levels in electrical hazard situations are very different. It was therefore necessary to provide a virtual environment compatible with several intervention scenarios.

This project also fits into the restructuring process of university and technological formation in France, now based on a competency-based approach. Within this framework, teaching methods are expected to evolve significantly, and the use of video, virtual reality and augmented reality media to help students gain autonomy is logically expected to grow and generalize.

III. MATERIALS AND METHODS

The first step in this work to create a virtual environment from realistic situations and equipment present at the university was to constitute a 'project team'. The work carried out is highly multidisciplinary and has been the subject of a close partnership between (1) the "Electrical engeneering team" including two teachers in the field of electrical hazards, two technicians specialized in this field, and 9 undergraduate students; (2) the "partner company", a specialist in virtual reality and recipient of several awards in this field, (3) the "audio-visual team", composed of two technicians, for the production of audio and video media and (4) the "pedagogical engineering team", made up of two pedagogical engineers whose mission is to ensure the accompaniment of all the actors in this innovative approach (Figure 1).

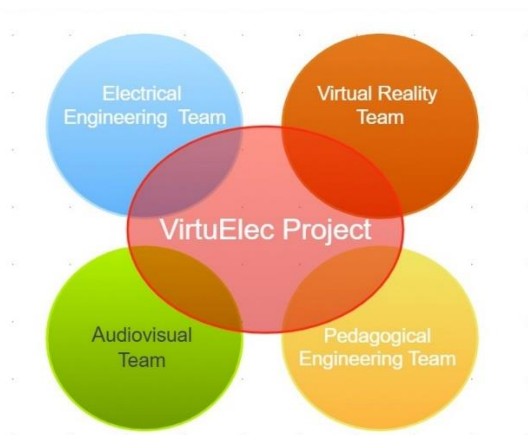

Figure 1. Synoptic of the VirtuElec project

The highly multidisciplinary nature of the project required the implementation of collaborative tools. This is all the more true that the specific context linked to the Covid19 pandemic has strongly complicated this process of joint work. In addition to the difficulties linked to the highly multidisciplinary aspect of the project, there were also difficulties in exchanging ideas during meetings, as well as the complexity of carrying out tests and trials, demonstrations of equipment and simulations of the modelled equipment as well as the envisaged scenarios. In order to be able to work remotely during the containment phases, different tools were therefore set up to share information, documents and experience.

The first one consisted in the implementation of the Microsoft Teams tool, at the initiative of the project manager and the teaching team. Microsoft Teams is the tool chosen by our university to ensure pedagogical continuity during the containment phases [14]. Within the framework of this project, it allowed a collaboration between the various teams involved and located on different geographical sites in France. The functionalities available to them were exploited at several levels: first of all, a collaborative space was created, in the form of a "VirtuElec" team, in order to allow information exchanges. The framework documents of the project (specifications, planning, framing document) were thus shared. This space was also intended to be a place of exchange, and it was the support of our bimonthly progress meetings, involving all the participants. Beyond these imposed deadlines, the exchange space was also used freely by the students, to exchange on the progress of the project, without intervention of the technical and pedagogical team. A document sharing system was also set up in order to allow the co-construction of the different stages of the project, with a progress follow-up managed in the form of different versions of documents, thus allowing the students to go back if necessary. Finally, during this very delicate period, the schedules of all parties were regularly disrupted, and the large number of people involved made it difficult for everyone to participate in the scheduled meetings. It was therefore decided to record videos of the most important meetings, with the prior agreement of all participants, in order to allow everyone to follow the project. It should therefore be noted that, while the Covid19 crisis obviously complicated the realization of this work, it also accelerated the deployment of tools that were not previously in use and that proved to be of real added value for the monitoring of the project.

Another modality has been put in place in order to gain efficiency in the monitoring of the project: the Agile method [15][16]. This can be defined as a project management method that consists of breaking down a project into a succession of small, quickly attainable objectives. Each step corresponded to a very short period of time, from one to two weeks, and was complementary to the overall project planning, which spanned three years and included design, deployment and feedback. In terms of concept, the Agile method emphasizes people and their interactions over processes and tools, close collaboration between different stakeholders, and adaptation to change rather than following a plan. This approach has many advantages. It allowed us to adapt to unforeseen circumstances that arose, such as the underestimation of the time needed to model the virtual environment or the complexity of describing exhaustively the different tasks to be performed in each scenario. But the most important was the notion of feedback, which is at the heart of the Agile methodology. Thus, at each step, a quick assessment was made, allowing to orientate the next steps of the project.

From a practical point of view, the virtual environment was developed to be implemented on Oculus Quest 2 virtual reality headsets, which are autonomous headsets allowing greater freedom of movement and better portability of the device [17]. The possibility of connecting the helmet to a large screen for demonstrations was also provided. Finally, the tool made also allows recording the journey of each learner in the virtual environment in video format, to be able to debrief a posteriori.

The actions carried out by the students in relation to the project teams can be divided into 3 main steps:
The first consisted of the design of the 3D environment, including the virtual electrical cabinet on which the learners will have to intervene, but also the operative part, consisting of a robotic arm, as well as a intervention preparation room where the necessary equipment is available. For more realism, a real device present on the training center inspired this virtual set. In this context, the students had to imagine the virtual electrical installation, draw up the electrical diagram, define and then model all the components, and finally to design the implementation in the complete virtual environment (Figure 2).

The second step was to design the intervention scenarios for electrician apprentices, simulating 3 levels of competence in a professional environment. The simplest is the beginner level, (including two options: step-by-step guidance or free learning) during which the operator must replace a defective element that was previously indicated to him. The most complex is the autonomous level (autonomy in actions, alerts are displayed in case of error and aids are available) during which the operator must look for the cause of a failure and perform troubleshooting. Finally, the expert level (anticipation of risks before the intervention) during which the operator must manage the safety of a teamworking on an installation. For each of these levels, the learner is expected to be able to choose the protective equipment and tools required for their mission, follow the correct procedure, and perform the correct technical actions.

In order to have a common language between the “electrical engineering team” and the “virtual reality team”, the scenarios description was developed in Grafcet (graphic programming, easily interpretable by all) [18] (Figure 3).

Figure 2. Actual electrical cabinet (a) and associated VR modelling (b)

For the virtual experience to be realistic, it was essential to give the learner the opportunity to make mistakes up to virtual electrification, simulated by a vibration. On the initiative of the students in charge of the project, these possible errors were translated into different colours in the graphic. The green colour logically corresponds to the case where the operations are performed correctly. The red one corresponds to errors that require to stop the current action and to start it again (the troubleshooter does not intervene on the right element for example). Finally, the orange one corresponds to errors that do not have an immediate consequence, but will cause an accident in the long term (the operator has incorrectly assessed the risk, or poorly chooses its protective equipment). In case of false manipulation, a vibration of the joysticks and a flash light simulates the electric shock (Figure 4).

Figure 3. Programming of intervention scenarios

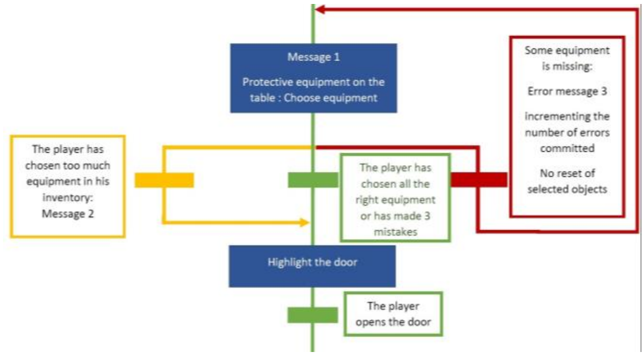

Figure 4. Example of programming scenarios in grafcet language

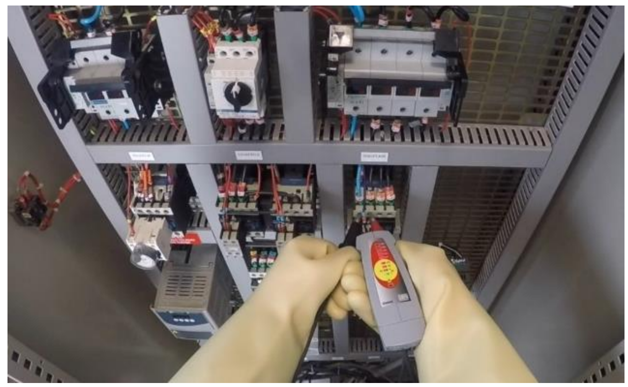

Figure 5. Image extracted from a video explaining the voltage measurement process

Finally, to illustrate the complex technical gestures, difficult to represent in the virtual environment, because demanding in terms of calculation capabilities, videos are accessible in the form of help in the virtual environment. These videos were shot with immersive cameras to illustrate as accurately as possible the technical actions to be performed, as shown in Figure 5 in a troubleshooting procedure

The final step, which is still under optimisation process, is the encoding of the scenarios algorithm by the partner company and their testing in the virtual environment for validation.

During the entire development phase of the project, a double follow-up was carried out: first, a technical follow-up, with regular meetings (each week) including the different teams involved in the progress made, and a pedagogical follow-up in the form of questionnaires offered to students in order to collect their feelings on different aspects of the project. The areas questioned were the evaluation of the accompaniment in the project, the links between the project and the teaching, the material and technical environment and the contributions for them of the project, in particular its multidisciplinary aspect.

IV. Preliminary Results

The pedagogical interest of this project lies at two different levels; the creation of a custom VR tool for the training of students on the one hand, and the pedagogical approach of co-design of this tool, including future users in the design of the training tool on the other hand. Now, the tool is still under development, and it is therefore too early to assess its impact on the electrical risk training of students. This analysis will of course be carried out as soon as the tool is in place, scheduled for december 2021. Following this initial implementation and feedback from the student evaluations, we plan to continue to evolve the scenarios and to a lesser degree the virtual environment, in order to make it even more efficient. This evolution will be based on the results of surveys submitted to students in order to analyze their appropriation of the virtual reality tool. These tests will be carried out at two levels: firstly with beginners, for whom the virtual environment will be the only experience of electrical risks, but also with final year students, who will have had the opportunity to work on real electrical installations. The idea behind this double evaluation is to assess the tool's ability to address both the problem of discovering electrical risks for non-electricians and the realism of simulated situations for more experienced users.

The analysis that we have already been able to do relates to the approach of co-designing the teaching support by involving the students themselves. The results of the evaluations, relating to the items described in the description of the method, made it possible to highlight several interesting elements.

First, the students expressed an overall satisfaction level of 9.5/10 for this project. They particularly appreciated the autonomy they were given (100% satisfaction) as well as the support and follow-up (89% very satisfied, 11% satisfied).

In terms of support, the students did not have any difficulty managing the high number of interlocutors around them. On the contrary, they appreciated the cohesion and the diversity of this team and the associated skills were really experienced as an asset. Collaborative work with specialists in other technical fields was evaluated as an asset by 78% of students, both an asset and a constraint by 11% and neither an asset nor a constraint by 11% of students

In terms of the links between the project and teaching, the students' perception is clearly that they have developed competence in fields not directly related to their core training, electricity: 56% strongly agree and 44% agree with this perception. They are also aware that they have made progress on aspects related to electrical safety, but less noticeably: 0% strongly agree, 78% somewhat agree, and 22% somewhat disagree with this perception. It is clear that in this respect, students are underestimating their rise in competence in their field of specialization. To be able to write the intervention scenarios in the virtual environment, students had to reach a high level of mastery of the intervention rules in a context of electrical risk, but this essential aspect appeared secondary to the students compared to the new skills in virtual reality and video production. The reason may be that these two areas are completely absent from their initial competency panel, so the discovery was total. However, from the teacher point of view, it is in the field of electrical risks that the students in charge of the project have made the most technical progress. In terms of the contribution of the project, the multidisciplinary and collaborative dimensions of the project were the most appreciated by the students, more than the technical contribution on the heart of the subject, that is to say the management of electrical risks. The collaborative work demonstrated the need to communicate with people with other skills, and it was these values of openness and communication that were considered the most beneficial elements of the project. Thus, to the question of the main skill developed in the framework of this project, 56% of the students answered the ability to communicate with interlocutors from various fields of competence, 33% the ability to formalize expectations and only 11% the ability to master the technical elements.

Even if this tool is still in the optimization phase, the first version has already been tested as part of the implementation of a new pedagogical approach based on competency and the increase in student autonomy. This approach was initiated this year for students entering the university. The aim is to confront students with problems similar to those they are likely to encounter in a professional environment, and to guide them in their progress while leaving them free to develop their own experimental methodology, to learn from their mistakes, and thus to increase their competence.

This approach is implemented in particular in the field of electrical energy production, and it is in this context that the VirtuElec tool makes sense. An experimental learning situation has been set up, within the framework of the understanding of the functioning of the photovoltaic energy production and the implementation of the complete chain of production and transformation of the electric energy. The idea here is to couple classical experimentation with virtual reality: the experimentation is carried out on low-power structures, which do not present any electrical risks and allow autonomous testing for the students. If it allows to understand the operating principles of the various devices, it remains however rather far from the conditions of implementation of the real systems. The virtual reality tool offers here this possibility of change of scale, by authorizing the intervention on realistic systems simulating real installations. More than the virtual tool itself, it is therefore the combination of reality and virtuality that allows us to address a wide range of situations and to increase the student's competence (Figure 6).

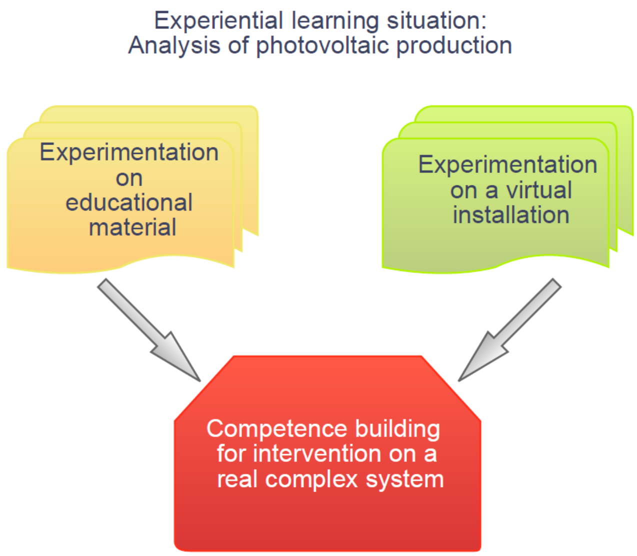

Figure 6. Description of the experiential learning approach mixing virtuality and reality

The first feedback from the students on this approach clearly shows the interest of this coupling of real experimentation and virtual experimentation. The virtual representation only makes sense when it is associated with real problems, and identified experimentally. On the other hand, experimentation on pedagogical models only makes sense when virtual reality allows us to evaluate how to transpose these results to a more realistic scale.

This phase of deployment of the VirtuElec tool has thus opened up new perspectives, by federating a larger teaching team around these aspects mixing real and virtual experimentation. It will also be possible to enrich it with another approach, which is still in its infancy and which consists of creating digital twins of two experimental devices present at the university. The students will thus have access to a complete panel of solutions coupling virtuality and reality.

V. CONCLUSION

The developed system allows the learner to be truly immersed in the virtual context. It allows students to project into their future professional world, and to progress at their own pace, and with a level of autonomy that they can manage, by requesting or not to contextual aids present in the virtual environment.

The realization of this project by the students aroused a great deal of enthusiasm and the organisation of the project team as an engineering office allowed a lot of interaction within the micro-enterprise thus formed. While the initial idea of involving students in the design of teaching tools was primarily intended to enable students to develop technical and pedagogical skills, rather, it was found that they placed greater emphasis on the opening of their field of expertise to virtual reality, video production, and team-based collaborative work experience. This awareness of the perceived gap in the interest of the project between teachers and students was only possible thanks to the support of the project by the pedagogical team and the associated desire to better understand how this type of pedagogical initiative is perceived by the main stakeholders. This better understanding of the expectations and motivations of the various people involved will make it possible to sustain and strengthen these actions and better support future initiatives. Beyond the development phase of the project, the challenge is now to optimise its integration into the existing educational context. The choice that has been made is to mix virtual and real experience, the virtual experience having the aim of allowing the experimentation of dangerous situations impossible to manage in a university context. Finding the right balance between real and virtual experience will require further efforts, so the evaluation of the users' perception of the project will continue

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