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Evaluation of a Prototype Desktop Virtual Reality Model Developed to Enhance Electrical Safety and Design in the Built Environment

Martin Barrett
Technological University Dublin, martin.barrett@tudublin.ie

Jonathan Blackledge
Technological University Dublin, jonathan.blackledge@tudublin.ie

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Evaluation of a Prototype Desktop Virtual Reality Model developed to Enhance Electrical Safety and Design in the Built Environment

Martin Barrett and Jonathan Blackledge

***Abstract* — The use of Desktop Virtual Reality (VR) systems for enhancing electrical safety and engineering design is a novel prospect for both practicing and student electrical services engineers. This innovative approach, which can be readily accessed via the World Wide Web, constitutes a marked shift in conventional learning and design techniques to a more immersive, interactive and intuitive working and learning environment. This paper initially identifies the unique characteristics of desktop web based VR technologies and highlights the educational affordances offered by working in such an environment. Subsequently, using a prototype model titled 'Virtual Electrical Services', a case study is carried out to evaluate the users' attitudes toward VR learning environments and also the usability of the prototype model developed. From the completed case study, it appears that the users perceive the prototype to be a useful tool and are receptive to using VR as a learning and design tool. The paper includes a discussion on the limitations of the system developed and the implications for future enhancement.**

***Keywords* — desktop virtual reality, electrical safety, training and education**

I. Introduction

Over the last decade advances in technology have brought about significant development across a broad spectrum of our social, cultural, physical and educational systems. These developments are clearly emphasised by the notable growth and advancements of computer technology applied to a diverse range of applications such as smart phones, cameras, medical devices and communication systems [1]. One facet of this metamorphosis is Desktop VR which is steadily establishing itself as a popular medium to transfer knowledge in modern education and training facilities due to its capacity to afford real time visualisation and interaction within a virtual world that closely mirrors a real world [2].

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M.Barrett is with Dublin Institute of Technology, he is a lecturer in the Department of Electrical Services Engineering (e-mail: martin.barrett@dit.ie)
J. M. Blackledge is Stokes Professor at Dublin Institute of Technology (e-mail: jonathan.blackledge@dit.ie

Previous research [3] has demonstrated that computer based instruction and training can be an effective learning and design tool. Virtual reality can further enhance the effectiveness and realism of these systems via the additional interactivity and immersion offered. Successful working examples have been developed across diverse fields, from medical [4] to engineering [5] to aiding children with development disabilities [6]. Historically however, these systems were generally limited to the minority and not widely accessible. In recent times this trend has diminished, mainly due to the culmination of significant price reductions, rapid advancements in computer processing power along with the proliferation of broadband connections. Consequently the use of desktop VR for research and development has escalated and become widely accessible as VR systems can now operate on relatively cheap systems such as the ubiquitous PC. Furthermore, with the development and maturity of commercial VR packages such as Quest3D [7] and Virtools [8], it is now possible to create professional VR applications in a relative short time span that have the flexibility to support the development of an online training and design environment.

This paper presents an evaluation of a prototype desktop virtual reality model titled 'VES' (Virtual Electrical Services) developed to demonstrate how VR technology can be applied to the electrical services industry and used to enhance electrical safety and design in the built environment. In the considered context, users can navigate through a domestic home using a mouse and keyboard, interact with electrical appliances, carry a touch voltage study and sensitivity analysis, determine the most dangerous location of electrical accidents within the home and receive safety and maintenance advice for various electrical appliances. 'VES' was developed based on the findings of [9] [10] [11] and a complete description of the design process and the scenes developed is given in [12].

The use of Desktop VR can provide an appealing training and design environment, allow users operate in a safe environment and may potentially reduce training costs and enhance electrical safety. In addition, current educational thinking suggests that the form of activity supported by this technology will enhance student's ability to retain and acquire a heightened appreciation of new knowledge when they are actively involved in constructing that knowledge [13]. A note of caution is warranted however as an underlying assumption can often exist among researchers and developers that their

VR application is intrinsically useful and usable just because it is developed using a novel and exciting technology [14]. Admittedly significant progress has been made in this area and nowadays usability engineering and evaluations are more routinely implemented. This affords users with virtual environments that are more effective and productive and not merely contemporary and different. An objective of this paper is to assess the prototype model developed using a cohort of final year undergraduate students from Dublin Institute of Technology. Users' attitudes toward VR learning environments will be evaluated along with the usability of the prototype model developed. This will serve as useful feedback to determine the characteristics of the prototype model which can be enhanced in future developments.

This paper presents an overview of the unique characteristics of desktop web based VR technologies. It reviews the educational affordances offered by working in such an environment and outlines a case study carried out to evaluate 'VES'. A discussion is then presented of the case study findings and the potential for future development and concludes by formulating some guidelines for the effective use of desktop VR.

II. Unique characteristics of virtual reality

Virtual reality is generally defined as the use of computer graphic systems with various display and interface devices to provide the effect of immersion in an interactive three dimensional environment [15]. From the above, it is apparent that the commonly perceived characteristics or VR namely interactivity and immersion are recognised. Burdea and Coiffet [16] go further however, and define the three I's of VR, namely 'Immersion, Interaction and Imagination' and suggest that VR has applications that involve solutions to real world engineering, medical and military problems. In doing so they theorise that the extent of an application to perform well depends equally on the human imagination. 'Imagination' referring to the minds capacity to perceive nonexistent things, which may reflect the user's perception of engagement.

From a pedagogical perspective virtual reality offers a unique set of characteristics in contrast to other learning environments which have the potential to offer an enhanced learning experience. In this context Hedberg and Alexander [17] cite increased 'immersion', increased 'fidelity' and a higher level of 'active learner participation' while Whitelock et al [18] cite 'representational fidelity', 'immediacy of control' and 'presence' as the distinguishing characteristics. Each set of characteristics having identifiable similarities as identified by Dalgarno [19]. Previous research has shown that technological features could influence learning outcomes [20]. Most notably, as identified by [2] the degree of realism of the scenes along with the level of control the user has on activities, which dictate to some degree the interaction experience (usability) and learning experience. Hence the desktop VR features evaluated in this study will spotlight these characteristics.

Representational fidelity is the level of realism afforded by the 3-D image content of a desktop VR model. Two important visual aspects of this characteristic are realistic display of the environment and smooth display of object motion and view changes [19]. A further aspect to this characteristic is the consistency of the behaviour of objects and their response to user interaction. Consequently, frame rate is significant. Quest3D which was used to develop 'VES' operates in real time meaning it continually executes an entire application and revises the preview. One complete loop through an entire project channel structure is called a frame. Even though Quest3D does not have a preset limit on how many polygons and objects a scene should contain or how large a 3D scene should be, it is advisable to simplify the scene as much as possible when modeling. A reduction in the number of objects and polygons improves the rendering performance and reduces the file size. However, as a result the visual quality may suffer and in turn decrease the representational fidelity. Hence a compromise needs to be struck so that the user experience is not reduced by either the performance or poor visual quality.

Real-time interactivity is another feature of virtual reality. This can be defined as a virtual reality systems ability to detect a users input and respond instantaneously. Designed correctly, a well refined interface used to capture and respond to users commands can afford a heightened sense of immersion. An example of real time interactivity provided in VES is shown in Figure 1.

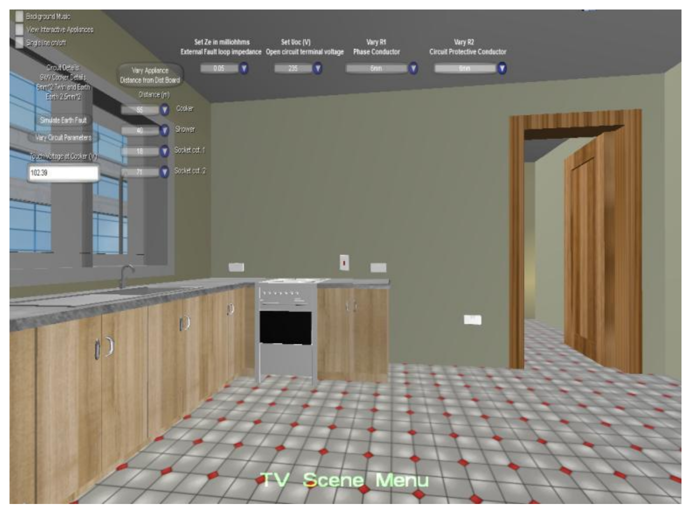

Figure 1 Screenshot of real-time interactivity provided in VES

Depending on the VR system, various forms of user interface can be used. For 'VES', a mouse and keyboard is utilised. A further aspect of VR systems which can also affect a users experience is immediacy of control which refers to a user's ability to alter their viewing position or change direction while giving the impression of smooth movement through a VR scene. In order to afford the expected cohesion and flow, user's action should be suitably overt. In terms of 'VES' it is acknowledged that using the keyboard arrow keys and mouse for navigation can at times be cumbersome and will require a brief adjustment period from the user. However, early in the development stage, accessibility was deemed one of the most important design characteristics. Therefore it was decided on balance that this method was the most appropriate for user navigation as it meant no additional hardware requirements and hence the user audience via the World Wide Web would not be limited by such a design decision.

Immersion and presence are often stressed in distinguishing VR systems from other various forms of computer applications. According to Dalgarno et al [19] presence relates to the subjective sense of being in a place and immersion as the objective and quantifiable properties of a system that conspire to give a sense of presence. [19] argues that a strong sense of presence in a VR system occurs as a result of the high degree of immersion offered by the fidelity of the representation in conjunction with the type of interactivity available. Hence it could be assumed that presence is determined by human response to immersion on an individual basis and as such it would appear the level of presence experienced for the same system may vary for a range of people. In contrast to more immersive systems, Desktop VR systems have received criticism for not utilising the full potential of the 3-D and 'presence' qualities of VEs [21]. Nunez however [22] argues that desktop VR can provide a high presence experience. In any case, the ability of developers to exploit and harness the immersive properties VR offer can only be advantageous in securing and retaining user attention and consequently inducing learning and understanding.

III. Virtual Reality in Training and Education

The flexibility and portability offered by Web based Desktop VR systems allows developers design applications for a broad range of disciplines. As outlined by Chittaro et al [23] the context for development within these disciplines can be quite diverse with successful working examples spanning across many areas such as formal education in universities, informal education in cultural sites along with distance learning, vocational training and special needs education. In contrast to more traditional learning practices educational use of Desktop VR offers learning affordances to users with certain advantages that perhaps could never be achieved using standard methods. As an example VR systems can facilitate enhanced spatial knowledge in disabled children [24] and diversely aid in the visualization of the physical evolution of work in civil engineering projects [25]. In addition well designed VR systems with specified learning tasks may more effectively engage learners and increase motivation. Desktop VR can also provide a broad range of experiences that may perhaps prove impossible to replicate in the real world due to danger, inconvenience, cost, distance or impracticability.

A growing body of research alludes to constructivism as the main pedagogical driver that underpins the educational use of VR [23]. This is a philosophy of learning that suggests knowledge is constructed by learners through experience and activity [2]. In this regard Desktop VR is ideally suited to affording constructivist learning as it provides an interactive environment in which learners may actively participate. Predicated on this belief that knowledge can be closely related to experience researchers have argued that freshly obtained knowledge will be realized more effectively in the real world if the context of the modeled learning environment is equivalent to where the knowledge shall be applied. This is based on VR systems ability to provide visual realism and interactivity that closely replicates the real world and hence knowledge obtained within the virtual system should be more readily recalled and applied in practice [19]. In contrast to more conventional educational methods which is often dependent on learners acquiring knowledge from books and teachers and subsequently applying this knowledge to real situations [23], Desktop VR is student-centered and focuses on meeting the learners' needs by allowing users control their learning pace and become responsible for their learning in a contextualised simulated environment. Bell and Fogler [26] also assert that VR offers an environment where students can exercise the higher levels of Bloom's Taxonomy which is unique from any other educational methods. This is argued due to the freedom users have to explore an environment and the ability to analyse problems and assess alternatives in ways that were previously not possible. Hence the activities supported by Desktop VR promote current educational thinking that students are more adept at mastering, retaining, and generalising new knowledge when they are actively involved in constructing that knowledge in a hands on learning environment [13]. Evidently the learning affordance offered by VR are abundant and the potential to develop enhanced systems for widespread use will become even more accessible as desktop VR technology continues to advance and become even more economical to develop. However it is important that developed applications are user centered and focus is brought to bear on how the technology can foster learning and not just on what can be achieved using the technology.

In academic areas such as engineering very often the ability of a student to visualize and interpret abstract information determines how successful they will be in fully comprehending the material under study. Developing ways to enhance this learning process through multi sensory 3D visualisation environments with the ability to control dynamic models at the user own pace can only be positive. The practical application of 'VES' which is the desktop VR model under scrutiny in this paper is to provide support in Electrical Services Engineering design and training and is specifically focused on disciplines relating to enhancing electrical safety. The model is not developed to replace traditional methods of training but rather to provide an additional tool that may enhance understanding and learning and as a result increase safety. The virtual model can be manipulated interactively to allow users assess the impact of their electrical design decisions, interact with the electrical components and visualise many of the current rules for electrical installations along with providing electrical safety accident and maintenance advice. By providing an environment where users can interact with a simulated environment in an intuitive manner, repeat tasks until the required proficiency is attained and work safely constitutes a marked shift in conventional learning and design techniques in the area of Electrical Services Engineering. The role VR can possibly play in this field of engineering can be summarized as follows.

- Enhance the learning effect by demonstrating through an immersive medium in a contextualized environment the design features, processes and electrical components involved in an electrical installation.
- Reduce capital investment by solving the issues surrounding space and time for training institutes.

- Provides a safe training environment for users to work in.
- May enhance user motivation and subject interest
- It offers an alternative to site visits and allows users become familiar with inaccessible locations that may pose a health and safety risk
- VR offers a training system that is reusable which may allow users master a task.
- It may be convenient to update.
- Allow users to experience a sense of immersiveness in electrical installation design and concepts
- Allows users attain a better understanding of complex ideas, systems or environments

IV. CASE STUDY

A. Software

Virtual Electrical Services (VES) is a Web-based Desktop VR interactive learning and design system that is designed for engineering students to obtain knowledge regarding electrical safety and design in the built environment. It may also have practical applications for electrical design engineers. The Web-based VR system is designed in three parts: Touch Voltage Design, Electrical Safety and Electrical Rules and Standards. The system was developed using Quest3D to create the VR content and utilises Autodesk 3DS Max to create the virtual environment. 3DS Max is a commercial software package used to create 3D models while Quest3D is software for creating interactive 3D scenes developed by the Leiden company Act3D since 1998. It uses a unique style of visual programming called channeling and in contrast to writing code developers can logically combine large set of powerful building blocks to build complex scenes. This method of programming reduces debugging time and avoids time consuming syntax errors. In addition to this, scene development in Quest3D occurs in real time meaning the developer is constantly working on and viewing the end result. In the virtual environment created, users can navigate through a domestic home, examine many of the electrical components, receive electrical safety advice and interactively carry out electrical designs and view the impact of their decisions [12]. Two screenshots from VES are shown in Figure 2 and 3 for demonstration purposes.

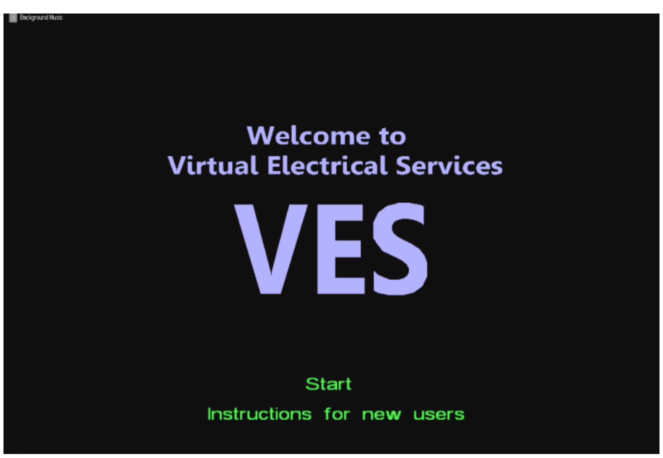

Figure 2 Screenshot of welcoming menu in VES

Figure 3 Screenshot of a virtual scene in VES

B. 'VES' Model Evaluation

Through the ongoing advancements of virtual environments, usability has increasingly become a major focus of system development. Usability can be broadly defined as the ability to carry out tasks: effectively, efficiently and with satisfaction [27]. Hence the more successfully users can complete their task in a manner which satisfies them, the more usable this system will be considered to be. Terms such as "usefulness" or "ease of use" are often cited [28] when VR systems are considered. Such terms resonate strongly with the widely accepted Technology Acceptance Model (TAM) which was developed with the primary aim of identifying the determinants involved in computer acceptance [29] and has been used extensively by various researchers to explain or predict the use of different technologies. This model suggests that the perceived ease of use (expectation that a technology requires minimum effort) and perceived usefulness (perception that the technology can enhance his/her performance of a task) can determine the intention to use a technology. In addition, both Salzman et al [20] and Lee et al [2] outlined that the unique features VR offer such as immediacy of control, representational fidelity and presence which collectively can influence the interaction experience are significant in determining the usability of a system.

Various methods of evaluations are often used to ascertain the usability of a computer-based system. In this paper a questionnaire following a usability evaluation period is the primary technique utilized to acquire the user's findings. Bowman et al [28] in their survey of usability evaluations consider questionnaires to be good for collecting subjective data that can often be more convenient and consistent than personal interviews. Within the survey users were afforded the opportunity to express their thoughts on the model and to highlight any perceived areas of strength or weakness. Post evaluation discussion groups were also held with class groups to provide additional feedback. Furthermore in order to assess the users understanding of the learning content, a set of problems which are coded into the VR system are taken by all participants prior to entering the virtual environment receiving only basic tutor instruction on the material. Subsequently using the interactive environment of the 'VES' model where learners can actively participate, the user's are posed the same problems in what is effectively a problem based learning exercise. This task is in line with the thoughts of Dalgarno et al [19] where it is suggested that a virtual learning environment with a good representational fidelity and immediacy control, developed around a real world system will not automatically lead to conceptual understanding and therefore appropriate learning tasks are required so that the user will be encouraged to undertake learning activities that will lead to a greater understanding of the learning content. Additionally, by engaging the user in the 'VES' model and encouraging active participation should result in a situation where the users will be in a more effective position to perform a usability evaluation.

The questionnaire was developed in order to primarily answer two research questions (1) evaluate the usability of the prototype model and (2) to assess the users' attitudes toward Desktop VR as a learning environment. Users are assessed over 11 measurement items as shown in Table 1. Items 1-5 set out to primarily evaluate the usability of the system, closely monitoring the unique VR characteristics as they are often cited as being intrinsic in establishing the usability of the system while items 6-8 will provide feedback on the psychological factors that affect the learning experience which in conjunction with items 9-11 should provide a platform to establish user attitudes towards VR as a learning environment. The questionnaire was drafted by referencing survey questions used in published literature. The individual questions corresponding to each measurement item are set out in the appendix.

Measurement Items	References
1. Immersion	Huang et al (2010)
2. Representational Fidelity	Dalgarno et al(2002), Lee et al (2010)
3. Immediacy of Control	Dalgarno et al(2002), Lee et al (2010)
4. Perceived Usefulness	Davis (1989), Lee et al (2010)
5. Perceived Ease of Use	Davis (1989),
6. Presence	Lee et al (2010)
7. Motivation	McAuley et al. (1989)
8. Cognitive benefits	Antonietti et al. (2000)
9. Intention to use system	Huang et al (2010)
10. Perceived Learning Effectiveness	Lee et al (2010)
11. Satisfaction	Chou and Liu (2005)

Table 1 Questionnaire Measurement Items and Sources

C. Participants and Procedures

Participants consisted of final year undergraduate students studying Electrical Services Engineering and Energy Management from the School of Electrical Engineering Systems in Dublin Institute of Technology. A total of 101 students were given a brief demonstration on how to use the VR system. Students were then allowed to access the system via the web or as a downloadable executable file. Subsequently an on line questionnaire was distributed to the participants. All subjects were asked to respond to the questionnaire and their responses were guaranteed to be confidential. The questionnaires contained the users' background, age and qualification. Furthermore the questionnaires also provided the opportunity to highlight the strengths and weaknesses of the system along with suggestions for improvement. There were 14 uncompleted responses leaving 87 completed responses for analysis. Males made up 100% of the subjects surveyed. The questionnaire had 41 questions that were evaluated using a 7-point Likert scale ranging from 1 which means ''strongly disagree'' to 7 which means ''strongly agree''. After completing the experiment, group discussions were used to provide additional qualitative feedback during debriefing sessions.

V. Data analysis and Results

The internal consistency reliability for the measurement items was assessed by computing Cronbach's αs. The alpha reliability was considered acceptable with values ranging between 0.7 and 0.86. The mean coefficient associated with each measurement item and the standard deviation is outlined in Table 3. The individual coefficients of each questionnaire item are presented in Appendix A. Additionally a Spearman correlation was carried out between each measurement item and the results are presented in Table 4. PASW Statistics 18 software package was used for the analysis of the results.

Prior to further analysis of the results obtained it will be useful to examine the participants to highlight the context and background in which the results were obtained. The academic programme from which the participants were taken from is an advanced level entry programme which contains a significant number of mature students with many years of industry experience alongside a number of standard entry students that have continued their formal education through since second level. This is reflected in the age profile of the participant's where the user's ages range from 21-57. The average age of the participants is 29. Of the 87 participants, 82% of them have already obtained a BEng Tech in Electrical Services Engineering or an equivalent electrical degree. The remainder also have an equivalent engineering degree; however the focus on electrical engineering is to a lesser extent. Considering that 'VES' is developed to potentially aid electrical design and safety for both industry and university students and in light of the knowledge and experience of the user group, the participants should provide a very good representative sample of the target audience and therefore the feedback received should provide much more useful information in contrast to obtaining feedback from a less mature/knowledgeable audience. Table 2 gives a picture of the VR knowledge of the users.

Virtual Reality knowledge of the users	%
No knowledge	25%
Some Knowledge	47%
Medium knowledge	26%
A lot of knowledge	2%

Table 2 Virtual Reality knowledge of the users

A. Interaction Experience

Analysing the usability of the model, measurement items 1-5 are primarily analysed. Items 4 and 5 which measure the perceived usefulness and perceived ease of use provide feedback on the interaction experience while items 1-3 will provide feedback on the VR characteristics of 'VES' and their influence on the usability of the system. Perceived usefulness which can be used to indicate whether the technology can enhance his/her performance of a task attained a slightly higher mean score (5.84) than perceived ease of use (5.5). There was a strong, positive correlation between perceived usefulness and all three VR features which was statistically significant as shown in Table 4. Perceived ease of use which

Measurement Items		α	Mean	S.D
1. Immersion	VR Features	0.7	5.3	0.9
2. Representational Fidelity		0.78	5.2	0.99
3. Immediacy of Control		0.76	5.96	0.82
4. Perceived Usefulness	Usability	0.71	5.84	0.81
5. Perceived Ease of Use		0.85	5.5	1.1
6. Presence	Learning Experience	n/a	5.05	1.37
7. Motivation		0.86	5.5	0.97
8. Cognitive Benefits		0.81	5.61	0.8
9. Intention to use system	VR model Measurement outcomes	0.77	5.51	1.04
10. Perceived learning effectiveness		0.85	5.42	0.84
11. Satisfaction		0.82	5.41	0.77

Table 3 Questionnaire Measurement Items

can be used to indicate the accessibility of the system and the expectation that a technology requires minimum effort showed a small to medium correlation effect with the VR features. Examining the correlation effect between the perceived usefulness and the user's intention to use the system and satisfaction with the system shows a strong correlation, which is statistically significant. A medium to strong correlation also exists between perceived ease of use and satisfaction.

In agreement with Lee [2] and Salzman [20] findings, the VR features in this study can be considered to play a significant role and indicate a positive influence in terms of the usability of the system. VR features that were measured by immersion, representational fidelity and immediacy of control which refers to the user's ability to interact and control the virtual objects collectively impact on the interaction experience of the participants. One could indicate from these findings that with enhanced control components and realism, users will be offered an enhanced interaction experience.

Analysing the influence the usability measurements items have in relation to the psychological factors associated with the learning experience shows a strong correlation that is statistically significant. This indicates that the usability of 'VES' model has an appreciable effect on the learning experience, which in turn will influence the learning effectiveness of the system. These finding are consistent with the findings of Lee et al [2] and Sun et al [30] where it is suggested that Desktop VR models that consider closely the perceived usefulness and ease of use will positively influence the learning experience and learning effectiveness.

Using the VR measurement outcomes as outlined in Table 3 as a benchmark to evaluate the impact usability has on the system clearly demonstrates that the satisfaction of the user group with the 'VES' model is strongly correlated to the usability of the VR system, while more specifically the perceived usefulness of the system can be seen as very influential in determining one's motivation and intention to use the VR system. Consequently, based on the findings of this research, VR designers and developers should be cognisant that the tasks and activities encountered within a VR model should be considered 'easy to use' and particularly 'useful' to fully exploit desktop VR's learning potential.

B. *Learning Experience*

In determining the user groups attitude towards VR as a learning environment, items 6-8 were used to assess the psychological factors that affect the learning experience while items 9-11 were used to benchmark the user groups perceived effectiveness and satisfaction with the 'VES' prototype model as a learning environment.

Sense of presence received the lowest mean score (5.05) of all the measurement items. However, the score is not so low as to indicate that low immersion systems are not capable of providing a sense of presence. As highlighted by [19] and noted earlier, presence is a subjective feeling that is induced by the level of immersion, interactivity and fidelity offered by the model. This suggestion is consistent with the findings of this research by virtue of the medium to strong positive correlation that exists between presence and the VR features as outlined in Table 4 indicating that with increased fidelity and interactivity a heightened sense of presence will be realised by the user. Furthermore by correlating the sense of presence to perceived learning effectiveness a positive medium size effect exists suggesting that a heightened sense of presence can offer an enhanced learning effect. To emphasise the subjective nature of presence in a VR system one participant interestingly noted the following;*"After a prolonged time using the VR model I felt a sense of nausea from the constant movements and tracking using the VR model"*, the same participant also commented *"The good features which I found from my use of the VR model, was the feeling of been physically present in the application"*.

Motivation as defined by [31], is an internal state or condition that activates, guides, and maintains or directs behaviour. Sutcliffe [32] suggests that motivation is a major factor that influences learning and thus better-motivated users can learn more effectively. In this study motivation was found to be an influential psychological factor that is positively related to the VR measurement outcomes. This is consistent with previous related studies [2] [33] thereby demonstrating the plausible effect motivation can have on learning effectiveness. VR features were also found to be significant in influencing user motivation, this is in keeping with the findings of Huang [33]. Additionally, usability and in particular perceived usefulness was found to be significant in terms of user motivation indicating that a useful, easy to use system will enhance user motivation. This serves to highlight the negative impact a poor interaction experience could have which may lead to user frustration and ultimately negatively impact on a user's intention to use the system.

Cognitive benefits were found to have a strong positive correlation with the perceived learning effectiveness of the VR model, satisfaction and also the intention of the participant to use the system. This is consistent with the findings of lee [2]

Measurement Items	1	2	3	4	5	6	7	8	9	10	11
1. Immersion	1										
2. Representational Fidelity	.568	1									
3. Immediacy of Control	.412	.292	1								
4. Perceived Usefulness	.571	.543	.519	1							
5. Perceived Ease of Use	.264	.243	.187*	.174*	1						
6. Presence	.495	.471	.173*	.431	.370	1					
7. Motivation	.461	.493	.329	.611	.229	.437	1				
8. Cognitive Benefits	.423	.379	.401	.665	.199*	.374	.576	1			
9. Intention to use system	.54	.498	.434	.628	.059*	.242	.649	.686	1		
10.Perceived Learning Effectiveness	.51	.501	.485	.649	.304	.342	.606	.724	.671	1	
11.Satisfaction	.506	.363	.416	.571	.413	.348	.511	.648	.598	.636	1

Table 4. Spearman correlation between the measurement items *Denotes where (*P* > 0.05)

and Antonetti [34] suggesting that users see VR as advantageous in terms of understanding and memorisation. The significant influence perceived usefulness has on the cognitive benefits in contrast to the VR features may also indicate that it is the usefulness of the task set within the model more so than representational fidelity which perhaps will heighten user conceptual understanding. This emphasises the critical nature of the role instructional content plays in fully capturing the cognitive benefits VR can offer.

Analysing the VR model measurement outcomes in Table 3 highlights that perceived learning effectiveness attained a relatively high mean score (5.42). This finding can be substantiated by the results of the problem based learning exercise developed for the participants, where it was found that by using the VR model users scores increased on average by 31%. This emphasises further and provides evidence for the assertion made by Dalgarno that in order to facilitate conceptual understanding a well designed set of learning tasks is crucial. From the evidence of this research it would appear that the learning activities contained in a VR model have a significant influence on the cognitive benefits which in turn strongly influence the perceived learning effectiveness.

In general, the overall attitude toward VR as a learning environment was found to be positive. The evidence to support this claim can be ascertained by reviewing the mean scores received for the measurement items 'Satisfaction' and 'Intention to use the system' which can justifiably be argued as indicative benchmarks. The qualitative feedback received from the questionnaire and also the debriefing sessions also support this claim where the majority of users observed the usefulness of the model in addition to the perceived positive influence that VR could have on their learning. Examples of positive feedback from the users include; (1) "*The good features are that the model makes it more interesting to learn the topic. I found it a lot easier to understand than having to look at schematics of the same scenario.*" (2) "*The VR model provides a realistic environment that allows the user to make learning more interesting and practical.*" (3)*"The model showed a different approach to a common technical proposition and it does drive home the message. The immediacy of the response to a change in design made the learning process easy and encouraged further manipulation.*

The potential for enhancing electrical safety and design through the use of VR is evident from the above analysis. There appears to be general agreement from previous studies and the findings of this research that VR can have a strong motivational impact on users. This research suggests that this leads to a greater learning effect that evolves into a potentially greater understanding of the concept or task in hand. One could conclude from this that through the use of a well designed VR model, users will be more competent in the area under study and the net effect in this instance will be to enhance electrical safety in the built environment. However it must be noted that if the usability of the system is poor and the instructional content and tasks are flawed the ability of the system to achieve its objective will be significantly diminished.

VI. Limitations and Implications

Evaluation of the prototype 'VES' model, especially in terms of its usability and learning experience is very important to the successful uptake of the system. To enhance the prototype to a point where it could be successfully commercialised or integrated seamlessly into an educational module in a third level programme will require further development taking account of the feedback received via the questionnaire and debriefing sessions. To this end a number of the issues highlighted will be addressed and some guidelines for the effective of use of VR will be put forward.

A number of the user's encountered problems navigating through the system. There were a couple of explanations to account for this. Firstly, difficulties were noted in terms of adjusting to using the arrow keys and mouse for navigation. In general this appeared to be a short lived effect and that after using the system for a period of time users overcame this control issue. However it is noted that this could add to user frustration and weaken the interaction experience. Using a control pad is a viable alternative. Secondly, some users encountered an unsmooth jumpy display navigating the scene. When this issue was discussed with the relevant users, it became apparent that they were using older machines with a reduced processing power in contrast to more modern PC's. In future versions it may be worth highlighting a minimum requirement specification, above which this problem would not be encountered as an issue.

Although many users noted their satisfaction with the representational fidelity of the system, some users did comment on how the graphics of the system should be enhanced. In making this comment, most users reflected on the contrast between this system and current video games that are on the market. It is evident from these comments that users who are familiar with these video games consider this level of detail as the perceived benchmark and the level of expected quality. To bring 'VES' to this standard would require a dedicated development team. However it does highlight the level of detail that would be expected from the current generation and improvements in this area would undoubtedly increase the fidelity, usability and satisfaction with the system.

Other areas the user group highlighted was the contrast of text with the 3D display which made it difficult to view in places. This can be easily overcome in future versions by using dialog boxes. Finally, users commented on the wish for more interactive appliances and additional scenes and scenarios such as commercial and industrial electrical installations. Based on the findings of this research where it appears the use of VR improves users' ability to analyze problems and explore new concepts, further development as suggested by the group can be justified.

In order to widely deploy VR for electrical safety and design, developers need to appreciate the challenges of utilising VR technology for instruction rather than relying on the novelty of the technology. Based on the findings of this research some suggested guidelines for the effective use of VR in this field are listed below.

- A well designed set of applicable tasks or activities that are considered to be useful and easy to use is vital in enhancing the perceived learning effectiveness.
- VR features play a significant role in user satisfaction and perceived learning effectiveness
- Usability of the interface design. Rather than ensuring basic functionality, developers should attempt to ensure the interface design is understandable and the user interactions easy to understand.
- The perceived usefulness of the application appears from this research to be significant in establishing user satisfaction and their intention to use the system
- Affording the user the ability to interact with the environment while providing real time feedback significantly enhances engagement and increases motivation leading to increased learning outcomes.

VII. Conclusion

Engineering education and design can be greatly enhanced and facilitated by the use of virtual reality. Evaluation of the model by a representative sample of potential users indicated that a) the developed prototype has the potential to increase understanding of issues related to electrical safety and hence could potentially help to cut down on accidents and fatalities related to electrical shock and electrocution, b) it was found that users were receptive to using VR as a learning and design tool and c) 'VES' the prototype model offered an acceptable interaction experience. The findings of this research should also make a significant contribution to understanding the role desktop VR can play in supporting learning and design in engineering while also highlighting some of the important aspects in determining the user's 'satisfaction', 'intention to use the system' and the 'perceived learning effectiveness'. Generally, Desktop VR has reached the level of development where it should be seriously considered by the electrical services industry to support designers, contractors and training personnel in increasing understanding, improving safety and potentially improving productivity.

Appendix

Measurement Item	Question	Mean	S.D
Immersion	1. The 3D simulation system creates a realistic-looking environment.	5.64	0.96
	2. I feel immersed in the 3D simulation system.	4.75	1.23
	3. I feel that the 3D simulated environment makes me concentrate more while learning.	5.47	1.4
Representational Fidelity	1. The realism of the 3-D images motivates me to learn	4.97	1.27
	2. The smooth changes of images make learning more motivating and interesting	5.17	1.18
	3. The realism of the 3-D images helps to enhance my understanding	5.33	1.12
Immediacy of control	1. The ability to manipulate the objects within the virtual environment makes learning more motivating and interesting	6.11	0.89
	2. The ability to manipulate the objects in real time helps to enhance my understanding.	5.8	0.94
Perceived usefulness	1. Using this type of computer program as a tool for electrical services/will increase my learning and academic performance	5.76	1.02
	2. Using this type of computer program enhances/will enhance the effectiveness of my learning	5.72	1.03
	3. This type of computer program allows/will allow me to progress at my own pace	5.91	1.00
	4. This type of computer program is useful in supporting my learning	5.97	0.92
Perceived ease of use	1. Learning to operate this type of computer program is easy for me	5.66	1.28
	2. It is easy for me to find information with the computer program	5.37	1.20
	3. Overall, I think this type of computer program is easy to use	5.37	1.26
Presence	1. There is a sense of presence (being there) while learning with this type of computer program.	5.05	1.37
Motivation	1. It was enjoyable using the VR system for learning purposes	5.52	1.23
	2. The system can enhance my learning interest	5.61	1.06
	3. The system can enhance my learning motivation	5.32	1.11
Intention to use the system	1. I think this system can strengthen my intentions to learn	5.20	1.30
	2. I am willing to continue using this system in the future	5.22	1.40
	3. Overall, I think this system can to be a good learning tool	6.13	1.05

Cognitive Benefits	1. This type of computer program makes the comprehension easier 2. This type of computer program makes the memorization easier 3. This type of computer program helps me to better apply what was learned 4. This type of computer program helps me to better analyze the problems 5. This type of computer program helps me to have a better overview of the content learned	5.68 5.39 5.76 5.68 5.56	0.96 1.21 1.01 0.98 1.02
Perceived Learning effectiveness	1. I was more interested to learn the topics 2. I learned a lot of factual information in the topics 3. I gained a good understanding of the basic concepts of the materials 4. I learned to identify the main and important issues of the topics 5. I was interested and stimulated to learn more 6. The learning activities were meaningful. 7. What I learned, I can apply in real context	5.26 5.18 5.52 5.56 5.26 5.56 5.59	1.10 1.16 0.89 0.88 1.08 1.01 1.12
Satisfaction	1. I was satisfied with this type of computer-based learning experience 2. A wide variety of learning materials was provided in this type of computer-based learning environment. 3. I don't think this type of computer-based learning environment would benefit my learning achievement **(R)** 4. I was satisfied with the immediate information gained in this type of computer-based learning environment 5. I was satisfied with the teaching methods in this type of computer-based learning environment 6. I was satisfied with this type of computer-based learning environment 7. I was satisfied with the overall learning effectiveness	5.01 5.40 5.49 5.30 5.54 5.63 5.50	1.19 1.41 0.89 1.04 1.00 1.10 1.10

(R) Ranking Reversed **Questionnaire measurement items – source of questions outlined in Table 1**

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Martin BARRETT received a BSc (Eng) degree with first class honours in Electrical/Electronic Engineering from Trinity College Dublin in 2002. He worked as an electrical design engineer with ESB international from 2002-2005. He joined Dublin Institute of Technology in 2005 and is a lecturer in the a Department of Electrical Services Engineering. He is chartered member of Engineers Ireland.

Jonathan Blackledge graduated in physics from Imperial College in 1980. He gained a PhD in theoretical physics from London University in 1984 and was then appointed a Research Fellow of Physics at Kings College, London, from 1984 to 1988, specializing in inverse problems in electromagnetism and acoustics. During this period, he worked on a number of industrial research contracts undertaking theoretical and computational research into the applications of inverse scattering theory for the analysis of signals and images. In 1988, he joined the Applied Mathematics and Computing Group at Cranfield University as Lecturer and later, as Senior Lecturer and Head of Group where he promoted postgraduate teaching and research in applied and engineering mathematics in areas which included computer aided engineering, digital signal processing and computer graphics. While at Cranfield, he co-founded Management and Personnel Services Limited through the Cranfield Business School which was originally established for the promotion of management consultancy working in partnership with the Chamber of Commerce. He managed the growth of the company from 1993 to 2007 to include the delivery of a range of National Vocational Qualifications, primarily through the City and Guilds London Institute, including engineering, ICT, business administration and management. In 1994, Jonathan Blackledge was appointed Professor of Applied Mathematics and Head of the Department of Mathematical Sciences at De Montfort University where he expanded the post-graduate and research portfolio of the Department and established the Institute of Simulation Sciences. From 2002-2008 he was appointed Visiting Professor of Information and Communications Technology in the Advanced Signal Processing Research Group, Department of Electronics and Electrical Engineering at Loughborough University, England (a group which he co-founded in 2003 as part of his appointment). In 2004 he was appointed Professor Extraordinaire of Computer Science in the Department of Computer Science at the University of the Western Cape, South Africa. His principal roles at these institutes include the supervision of MSc and MPhil/PhD students and the delivery of specialist short courses for their Continuous Professional Development programmes.He currently holds the prestigious Stokes Professorship in Digital Signal Processing for ICT under the Science Foundation Ireland Programme based in the School of Electrical Engineering Systems, Faculty of Engineering, Dublin Institute of Technology.