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An Investigation of Acceptance and E-Readiness for the Application of Virtual Reality and Augmented Reality Technologies to Maintenance Training in the Manufacturing Industry

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Abstract: Virtual Reality (VR) and Augmented Reality (AR) technologies offer new ways of providing training in manufacturing maintenance. The adoption of modern maintenance training practices has the potential to create efficiencies in terms of cost and time to train, while enhancing the quality of learning and maintenance outputs. However, in order to utilise the potential improvements that VR and AR offer in a manufacturing maintenance context, it is first important to understand the specific factors associated with VR and AR readiness and user requirement. The paper will firstly describe the results from a number of interviews conducted within a range of manufacturing companies in the North East of England to establish the state of e-technology readiness and acceptance, with specific emphasis on VR and AR applications. The results will identify how VR and AR might be utilised, relative to the company's needs. Secondly, a new 'model' for maintenance training utilising VR/AR technologies will be described, based upon the initial findings and analyses combining cognitive behavioural models, real world data, and learning theory.

Keywords: Virtual Reality (VR), Augmented Reality (AR), Manufacturing Maintenance, Maintenance Training, Technology Readiness, Technology Acceptance, Cognitive Behavioural Models.

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1 Introduction

Virtual Reality (VR) and Augmented Reality (AR) technologies are now widely available across a broad range of applications and platforms, utilising various user interfaces and enabling real-time collaborative interactions (Helie, Raja and Calvo, 2017). Positioned at opposite ends of the Reality- Virtuality Continuum (Milgram and Kashino, 1994), VR represents pure Virtuality, whereas AR technology augments the sense of reality by overlaying virtual objects and cues upon the real world in real time (Mekni and Lemieux, 2014).

VR applications typically utilise a head-mounted display (HMD), blocking out the real world to deliver an immersive, interactive and collaborative user experience in a computer mediated synthetic world (Shah, Mehta and Katre, 2017). VR based projection displays (CAVE Automatic Virtual Environment) can also be used to immerse single or multiple users in a shared physical and virtual environment (Halarnkar et al, 2012; Manjrekar et al. 2014).

AR applications overlay the real world with computer generated graphics including 3 D models, objects, text, and video, in real time, enhancing the user perception of reality, thus transforming learning and the user experience (Mekni and Lemieux, 2014). AR technologies also utilise HMDs, for example the Microsoft HoloLens can run on multiple interfaces, and less specialised handheld devices such as a tablet or Smart-Phone. Applications of VR and AR are however, rarely mutually exclusive.

The term Mixed Reality (MR) or Hybrid Reality is widely used as an umbrella term to describe applications utilising a combination of both VR and AR. Further subcategories are also used to differentiate Augmented Reality from Augmented Virtuality (AV), with AV referred to, as the merging of real world objects into virtual worlds (van Krevelen and Poelman, 2010; Milgram and Kashino, 1994). Mekni and Lemieux (2014) reviewed AR applications and identified twelve distinct application domains; Medical, Military, Visualisation, Entertainment and Games, Robotics, Education, Marketing, Navigation and Path Planning, Tourism, Geospatial, Urban Planning and Civil Engineering, and Manufacturing. While these do not exhaustively cover every application domain of AR, the authors state that they covered the areas explored at the time of writing.

The potential to utilise AR, VR in manufacturing companies has largely remained unknown, often due to the perceived high cost of the equipment or the perceived lack of programming skills required in order to use the equipment (Simon et.al, 2014). However, when maintaining assets for manufacturing, an expert has to apply background knowledge acquired over many years. According to Crescenzio et al (2011), this accumulated expertise, extracted from performing repetitive tasks should be stored and analysed for future maintenance engineers, and VR and AR technologies can play a crucial role in retaining and utilising explicit knowledge.

Furthermore, this technology allows the users to improve their knowledge instantaneously during the maintenance actions. Such features can help to reduce errors due to procedure violations, misinterpretation of facts, or insufficient training (Simon et al, 2014). Therefore, the adoption of modern maintenance training practices has the potential to create efficiencies in terms of cost and time to train, while enhancing the quality of learning and maintenance outputs (Lawson, Salanitri, and Waterfield, 2016; Marzano, 2017; Rao et al, 2017).

However, the literature has identified a number of possible concerns, which predominantly relate to the complexity of the technology and the time and cost to develop specific applications. As stated earlier, these concerns are often perceived as barriers to the adoption of the technology. Halarukar et al (2012) conducted a comprehensive review of VR across multiple application contexts and identified five main challenges to implementation and use of VR. These were cost, usability, limitations of the modelling software, limited dynamic programming capability, interface and design limitations.

VR and AR technologies have nevertheless been hailed as extremely important in meeting the diverse challenges of modern maintenance tasks and maintenance problems (Roa et al, 2017), and research studies comparing virtual training methods to face-to-face conventional training methods largely report positive learning outcomes and efficiencies (Lin et al. 2002; Webel et al, 2013). In order to utilise the potential improvements that VR and AR offer in a maintenance engineering context, within small to medium enterprises, which are often overlooked when developing and implementing new manufacturing techniques, it is firstly important to understand the specific factors associated with VR and AR readiness and user requirement. This paper will therefore adopt the following structure:

The first section will provide a brief overview of the potential for VR and AR application and opportunities in a manufacturing context, and a model of technology acceptance will be used in the design of interview questions to identify and characterise the contextual and organizational factors that help or hinder SMEs' ability to exploit visualization technologies. The method adopted will be described and results reported.

The second section will combine existing cognitive models of processing and real-world findings to propose a new model for maintenance training utilising VR and AR technologies, taking into account appropriate models of learning. The proposed model will provide a platform for multimodal VR and AR based training which could allow small to medium sized companies to develop and implement appropriate maintenance tasks, based upon cost effective and efficient training systems. The results of the interviews will be considered to identify how VR and AR might be utilised, relative to the identified needs and concerns of the companies.

2. Acceptance and E-Readiness for Virtual and Augmented Reality Applications

In fields such as preventive or corrective maintenance, medium and small companies can achieve profitable improvements utilizing VR and AR-based training (Baglee et al, 2016). Theability to visualize and project three-dimensional data or textual information in a virtual or real environment, provides the user an intuitive means to interact with information, explore structures, parts, or data, in a way that has not been previously available (Roa et al, 2017). The technologies allow for speech recognition, interaction using voice commands, gesture recognition, motion system, images, video and audio recording. This allows the user to communicate with different types of platforms, which can store, analyse and treat this data to feedback augmented information (Mekni and Lemieux, 2014). This is beneficial for product design and development, maintenance task development, factory, line or cell layout. This will allow companies to evaluate, demonstrate and integrate early stage technologies, de-risk development projects, reduce manufacturing costs and improve processes.

VR and AR technologies also provide advanced modelling, systems modelling and simulation, product and system design integration and virtual life cycle analysis using visualization and system modeling environments. Maintenance can be highly enhanced in terms of efficiency if using VR and AR technologies, to identify the necessary maintenance tasks and to present the information in such a way that the instructions are programmed where the user is trained, and guided through the task (Marzano, Friel, Erkoyuncu and Court, 2015). These technologies can be used in a number of industries including automotive, aerospace, nuclear and subsea. However, questions remain to be answered in respect of the readiness of companies to adopt this type of training mechanism. The factors associated with VR and AR Readiness includes: technical infrastructure, budget, matching technology to tasks, and knowledge acquisition processes. There are also issues in respect of technology acceptance and human factors (Lai, 2017; Sheikhalishahi, Pintelon and Azadeh, 2016).

According to Bottecchia et al (2010) multiple models are reported in the literature to explain factors influencing acceptance and e- readiness for technology adoption. The NASA Technology Readiness Model has been widely accepted as a systems engineering and technology management matric tool and has been used to measure the risk of introducing a new technology into a company's current practice (Wang, 2016). With nine levels described, the model runs from the first level where only basic principles of the technology have been observed and reported through to a ninth level at which the actual system has been adopted and proven through successful operation. Arguably, one of the most widely used and validated technology acceptance models is the Technology Acceptance Model (TAM) developed by Davis (1985) to explain intention to use and acceptance of new technology in an organization.

The purpose of TAM is to explain the determinant of computer acceptance across a wide range of fields and user populations. TAM proposes that external variables affect users' perception of the perceived usefulness and perceived ease of use of the technology, which in turn leads to attitude towards the technology, intention to use and whether or not the technology is actually used. In practice, various researchers have merged the basic TAM model with other constructs identified as appropriate for the specific technology being investigated (Lai, 2017). Vankatesh et al (2003) compared and integrated elements across eight core models of user acceptance, which were then empirically validated to form the Unified Model of User Acceptance, which consists of four key constructs; Performance Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions, which influence Voluntariness of Use, and Behavioural Intention. Individual factors such as Gender, Age and Experience, combined with the other constructs determine technology use.

Table 1 Company profile

Company	Sector	Size	Total Employees
C1	Manufacture of Audio Equipment	SME	138
C2	Brush Manufacture	SME	28
C3	Medical Injection Moulding	SME	163
C4	Tank Manufacture	SME	115
C5	Aircraft Recycling and logistics of spares	SME	12
C6	Engineered Products	SME	38
C7	Pump Maintenance	SME	24
C8	Kitchen Manufacture	SME	8
C9	Manufacture of Pump and plant equipment	Global	172
C10	Injection Moulding	Global	550
C11	Maintenance Engineering	Global	Confidential

2.1.2 Interview Design

The purpose of the interview was to determine the readiness of companies to adopt VR/AR technology and to discuss what they believed were the barriers to adoption. The design of the questions was informed from the literature and concepts from e-readiness research and from theories of technology acceptance (Venkatesh, et al, 2003). Questions were designed therefore to probe the current levels of technology use and skill, perceived barriers and perceived usefulness.

2.1.3 Data Collection

All interviews were conducted on the client premises and all interviews were performed in two phases.

The Unified Model of User Acceptance described by Vankatesh et al. (2003) was used as a framework for the design of interview questions to capture information on acceptance and e-readiness for the application of VR and AR technologies to maintenance training in the present study.

2.1 Method

Interviews were conducted with 11 manufacturing companies in the North East of England to establish the state of e-technology readiness and acceptance for VR and AR applications. This section describes the recruitment of participants, the design and analysis of the interview protocols, and the data collection process.

2.1.1 Participant Recruitment

Participating companies were recruited through two mechanisms: i) personal contacts of the second author ii) selection from a list of companies in the manufacturing and maintenance sector. As the aim of the study was to gather an understanding of the readiness of companies to adopt VR and AR all company premises were based within a 50-mile radius of the University of Sunderland. The participants were all senior managers with responsibility for training or manufacturing management decisions. The research used purposive sampling and in inviting organisations to participate the research team sought to identify companies that:

1. Represented a range of sectors
2. Represented a range of current IT infrastructure

Table 1 provides a summary of the sectors and size of participating organisations. Participants were told that the purpose of the interview was to understand their readiness to use VR and AR technologies within their usual business practices. Participation was based upon a confidentiality agreement that specified that company names would remain anonymous.

2.1.2 Phase One:

The aim of phase one questions was to gather an understanding of the company current situation in terms of quantifying their readiness for VR and AR adoption and to gain insights into barriers to adoption. A set of structured questions was used as a guiding framework for each interview. The interviewer used probing questions as follow-ups to either gain a deeper insight into their response or to clarify understanding of the answers given. Interviews were recorded and transcribed by the researcher after each session.

2.1.3 Phase Two:

The aim of phase two was to examine how each company believed specific VR/AR technologies might support their own specific context. Again, the focus was to determine readiness and to isolate barriers to adoption. In order to ground this part of the interview to experience rather than hypothetical use of VR and AR the interviewer showed each participant a range of VR and AR technologies.

2.1.4 Data Analysis

After each interview, the researcher transcribed the session question by question. Open thematic coding was used to identify emergent themes. This was accomplished in the following stages recommended by Braun and Clarke (2006): Taking one question at a time and across all participants, the researchers read and re- read each transcript to become familiar with the data and to identify any initial patterns. These patterns became the initial codes or themes.

From this point the researchers then re-visited the transcripts again began to process the responses using the coding scheme. Specifically, the transcript was read and important themes were highlighted and a coding label was attached. The researchers started with question one and completed that question for each company interview before progressing to the next question. Individual codes were then combined into overarching themes within each question and across all transcripts and then across all questions and transcripts. The overarching themes are presented in the next section.

2.2 Results

Three overarching themes emerged from the interview data,

1. Technology Readiness
2. Perceived Benefits & Barriers
3. Return on Investment.

These are discussed below.

2.2.1 Technology Readiness

To understand the baseline technologies used in each company, participants were asked to indicate which of the technologies identified in Figure 1 they currently used. The majority were making extensive use of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) software. None of the companies, even the two global organisations were using VR and AR in either design or as a tool to aid training.

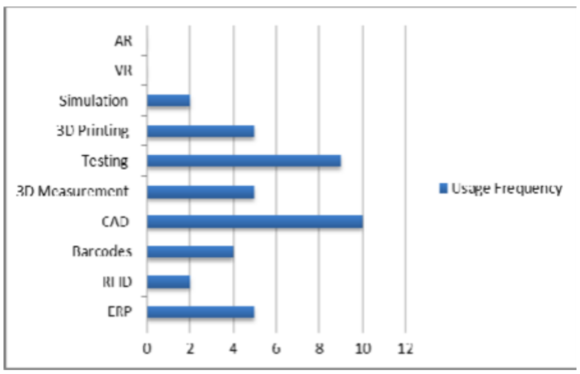

Figure 1 Current Tools Use

In terms of the qualitative analysis the overarching theme of Technology Readiness encompassed the following themes.

2.2.2 Current Technology Skill Set

Three respondents indicated that adoption of VR and AR would go beyond the skill set of their current workforce. The remaining 8 respondents indicated that they had employees with the necessary skills to accommodate the adoption of VR and AR technology. Within this group of 8 the majority indicated that some additional training would be needed. All emphasized that their preference would be to adopt technology through the training of existing staff and one company C1 expressed a concern about the age of their existing staff

> *"Our design department is ageing and we may need to review our strategy as they may find it more difficult to adapt than the younger members but we would expect at least half of our IT staff would be very interested and willing, and would be sold on the ideas and we could definitely like to develop them as a first call rather than bringing in outside skills".*

However, without talking to individual staff members themselves it is difficult to know if this is simply the activation of an age- related stereotype or if the comment is representative.

2.2.3 Perceived Benefits

Figure 2 depicts the themes that emerged from the analysis. Three out of the 11 companies we interviewed expressed that they could see no initial benefits that VR and AR could offer to their business operations. These were the smallest of the organisations sampled.

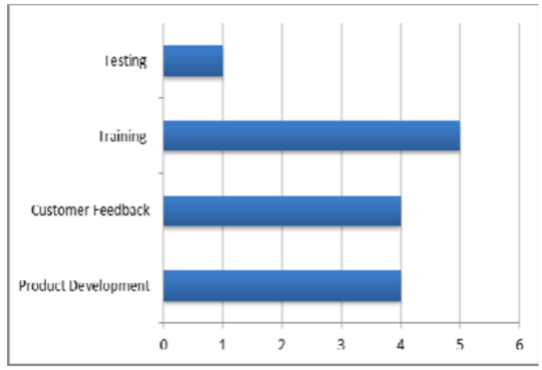

Figure 2 Perceived Benefits

Training was seen to be the most tangible benefit in terms of both training in-house staff , but also in respect of communication between employees operating at a distance. C6 commented

> *"last week we had a machine break down and instead of having an engineer travel to site if he had been able to access remotely, we could have completed the repair with his guidance"*

The respondents could also see benefits the technology might offer to both customer feedback and product development. The ideas expressed in these areas related to the ability to generate lower cost prototype that could be used to gather customer feedback thereby ensuring customer satisfaction and continued innovation. For example, C3 indicated

> *"We feel that the ability to look at the products in 3d and to pull apart the objects in VR will allow us to get valuable feedback at the design review process for the products but also for production assembly process".*

However, 2 companies commented that while the technology would support customer exploration of design ideas the VR and AR would not support the assessment of the more tangible qualities of the product, such as look and feel. C6 commented

> *"but we would be wary of disconnecting from some traditional methods, for example to get look, feel, texture, weight and customer feedback may need an actual component and our concern would be that over dependence on the technology would miss some product characteristics".*

2.2.4 Barriers

A number of barriers to adoption were identified within the transcripts. The most populous theme (9 out of 11 respondents) was the cost of adoption in terms of the acquisition of the hardware, maintaining the necessary infrastructure and staff training. 5 companies indicated that these factors would be of particular concern to them. Two of the larger global companies were more positive about adoption in terms of the readiness of their IT infrastructure and suggested that the primary barrier for them would be concerns over the accuracy and reliability of the technology. C10 indicated.

> "*We use a lot of technology but we are not technologists, we work in the real world. It needs to be simple to use and hard to get wrong. We need it to be repeatable and consistent and it needs to give us all the exact same view, and not open to interpretations".*

In a similar vein C11 commented:

> *"The VR technology would need to be both reliable and accurate, we would be worried about the tolerances, and we would need confidence in the technical accuracy of the technology".*

2.2.5 Return on Investment

In terms of technology adoption 10 out of 11 companies indicated that they would consider making future investments in the use of AR/VR but a Return on Investment would be needed in the short- term (2-5 years) for the smaller organisations. Interestingly, some respondents indicated that the ROI need not be financial figure initially but would be judgment on a more strategic level in terms of business agility. For example, C5 commented "We consider ROI as a broader perspective than just a financial return. We look at benefits to the organisation such as competitive advantage. C7 commented

> *"Sometimes we need to make an investment and innovation leap - Sometimes you don't have to know the exact return, so sometimes do we buy machine tools and win the work or win the work and buy machine tools? Sometimes investments are a leap of faith".*

2.3 Summary

The idea of employing VR and AR for training of maintenance personnel in a manufacturing context has been briefly considered. The findings presented so far were obtained through interviews encompassing a variety of manufacturing companies in the North East of England. The results of the pilot survey that mapped key concepts from well-established models of technology acceptance and e-readiness to VR and AR training have been presented.

Real world information from the interviews highlight perceived barriers to acceptance and e-technology readiness for VR and AR technologies in maintenance training. Factors related to three main categories, namely the perceived impact on the organisation, performance of the technology, and performance of the user. These findings are consistent with those of Halarukar et al (2012); Lai (2017); Sheikhalishahi, Pintelon and Azadeh (2016).

In terms of technology readiness, it can be concluded that all 11 companies interviewed were at a very basic level of technology acceptance as proposed by NASSA (1995), in having observed the basic principles only. Skill for using the technology was a concern with 3 companies stating that VR and AR would go beyond the skill set of their current workforce. The other 8 companies indicated that some additional training would be needed. However, the results in terms of attitudes towards the technologies suggest general positive attitudes to the technologies and although ROI within the first 2-5 years was deemed important, there was also some flexibility acknowledging strategic benefits to adoption.

The work is an important stepping stone on the way to future research in using VR and AR for training. The next section of the paper will consider the main processes necessary for carrying out maintenance tasks and operations from a psychology perspective. The relevance of interview results will be included in proposing a new model for the design of maintenance training courses and programmes.

3. A New Model for Maintenance Training

Both corrective and preventive maintenance tasks are carried out according to pre-defined procedures for that maintenance task requiring skilled maintenance personnel. Consequently, these skilled workers perform a vital role in many companies by ensuring that production facilities operate permanently which, in turn, contributes to time and cost savings. In order to be able to perform these maintenance tasks the maintenance operator (technician) has to collect and collate information about the system itself such as maintenance plans as well as information related to fault diagnosis or real-time inspection for example (Oliveira, et al, 2013). In addition, the knowledge required to complete such tasks is acquired through many years of experience. However, some of this knowledge may not be documented.

Maintenance and assembly tasks are largely procedural in nature and therefore maintenance operators (technicians) need to develop, or have, good procedural skill, that is, implicit knowledge of how to do things. Possessing good procedural skill indicates that the operator (technician) has developed a good mental model of the task, each step of the task and how to perform it, and the correct order to perform each step (Gavish, et al, 2011). Each of these aspects is based on a good mental model of the machine, its components and the tools required, and procedural memory (Gavish, et al, 2011). The use of VR and AR in the maintenance process can not only facilitate but also enhance the work of the maintenance operator (technician) as it allows the maintenance operator (technician) to become aware of his/her surroundings and tasks in real-time. Potentially, VR and AR could improve safety as the maintenance operator (technician) can be warned of possible dangers or errors when executing a particular operation in the maintenance sequence (Oliveira, et al, 2013), for example, the power is on, the wrong wire, high temperature, radioactivity, etc.

3.1 VR and AR for training in assembly and maintenance

Training is one area where VR and AR have good potential but a key feature to improving efficiency in training is instruction or guidance that is well designed, linked to appropriate scenarios. However, training is often highly theoretical and potentially therefore inefficient, and can be expensive both in terms of the time required and the cost. Training may also take place on-the-job but due to increasing complexity in manufacturing equipment and systems and consequently in maintenance tasks, traditional approaches to training may not be able to meet future demands or trends in maintenance procedures.

As a result of the increasing complexity of maintenance tasks it is likely that technicians will need to be trained not only in the execution of the task but also in the underlying sensorimotor and cognitive skills required to efficiently acquire and perform new maintenance operations. Assembly and maintenance tasks can be very complex and while maintenance workers can be trained for these tasks using traditional 2D printed materials and VR-based simulation systems, which have the benefit of allowing the user to train in a safe virtual environment, however they cannot be applied where interaction with real machines is required. AR technology, therefore, has the potential to be of great benefit in this area as the technology enables the direct linking of instructions about how to perform the task to the machine parts that require attention. User interfaces can be rendered frequently requiring less effort on the part of the worker to see the instructions, and interactions in the AR environment help with maintenance data management and more intuitive remote collaboration (Nee, et al, 2012).

Training for industrial maintenance and assembly essentially consists of two elements. The maintenance operator (technician) has to understand the basic working principles of the machine to be maintained, and has to learn the sequence of steps required to either assemble or replace some part of the machine. Therefore it is likely that what will be required in the future is training aimed at the underlying sensorimotor and cognitive skills. The training of these skills will provide the technicians with the ability to transfer skills from one situation to another enabling them to efficiently acquire and perform new tasks.

Existing applications of VR and AR in manufacturing maintenance training generally adapt traditional training methods from real world application for use in a virtual or augmented environment, not fully utilising the potential of these new technologies. It is proposed that a new approach to maintenance training is required to enhance rather than replicate current real world approaches. Two well established areas of research in the field of psychology with direct relevance to issues in maintenance training utilising VR and AR technologies are; models of human processing and decision making in dynamic environments, and behavioural change techniques.

3.2 Cognitive Behavioural Models

Rassmusen (1983) described information processing requirements in industrial tasks according to three levels of classification; skill, rules and knowledge. The classification provides a useful framework for explaining the information processing demands of tasks, human performance, and potential errors (Reason, 1990). Classification levels relate to the different levels of awareness in the decision making process and behaviour for complex tasks, such as those involved in maintenance assembly and at different stages in the learning process. For example, knowledge based processing relates to tasks carried out with a high level of awareness. A trainee technician carrying out a task for the first time or an experienced technician learning a new way of performing a previously overlearned task would be described as operating at the knowledge based level.

The rule-based level of the model relates to rule-based operation and processing in which the level of awareness of their performance in-puts and out-puts is intermediate. Decision making at the rule-based level relates to learned rules (if the symptom is X then the problem is Y, and if the problem is Y then do Z). A technician performing a newly learned task might operate at the rule based level, while a highly skilled, experienced operator might perform the same task at the skill based level, with little awareness of individual task elements and processing requirements. Performance at the skill based level equates to proceduralised skill, consistent with a good or well-learned mental model of the machine and the associated maintenance task requirements. There is also movement between the levels of the model. So for example an experienced technician carrying out a routine task may switch from skill based, proceduralised to rule based performance if a non-routine technical problem is encountered. Similarly, a trainee technician may move from performance at the knowledge based level, through rule-based then eventually to skill based as they gain more knowledge and experience.

Three of the companies interviewed were concerned that the adoption of VR and AR technologies would go beyond the work forces current skill set. When considered in the context of Rassmusens model, it can be assumed that for many of the skilled technicians already working in the companies, any updating of skills and training in maintenance tasks might result in a change from skill based processing to processing at the knowledge or rule- based levels of the model, requiring increased use of cognitive resources and chance of error. Processing at the upper levels of the model influence processing at the lower levels of the model, for example a strategic decision at the knowledge based level will have implications for tasks performed at the lower levels of the model.

Introducing a new training regime or methodology into an organisations operations, and more specifically maintenance, introduces new challenges, to a company's strategic objectives and operations, and for the technician, thus disrupting familiar behaviours and processing requirements. Indeed 3 of the smallest out of the 11 companies interviewed expressed that they could see no initial benefits the VR or AR could offer to their business operations.

Attitudes and organisational or individual factors have the potential to inhibit or enhance the adoption of new training regimes, and the learning process. It is therefore proposed that an additional level should be added to Rassmusens model representing individual characteristics of the technician such as preconceptions, self-evaluation skills and perceived control.

An adaptation of Rasmussens model, with an additional level representing attitude and preconceptions has been used in the field of driver training with widespread success (Hatakka et al, 2002). It is proposed that the principle of a fourth level in the model, and the inclusion of Reasons error classifications and mechanisms, apply to any tasks requiring complex processing, and are therefore applicable to the cognitive processes involved in learning maintenance tasks. The proposed framework adapted from Rasmussen (1983), Hatakka et al. (2002), combining a mapping of error causations according to Reason (1990), to the various levels, is shown in Table 2. Reason described human failure according to two categories; errors and violations. Errors were further categorised as slips due to misapplied competence at the skill- based level, and mistakes due to failure of expertise at the rule -based level and lack of expertise at the knowledge-based level. Violations were described according to routine failure to follow procedure that is no longer relevant, or deviation from rules in exceptional circumstances. Both types of violations are considered as purposeful and under the conscious control of the user whereas errors are not.

If VR and AR applications are to be successfully implemented into maintenance training, organisations, trainers and trainees will need to embrace change and the uptake of the new technologies and skills necessary to achieve successful outcomes. Michie et al (2011) introduced a new method for characterising and designing behaviour change interventions. Behaviour change interventions can be defined as coordinated sets of activities designed to change specified behaviour patterns (Michie et al, 2011). Core elements of change in Michies 2011 model relate to social/psychological, reflective, automatic and physical processes consistent with positive learning outcomes. Factors on the extremities if Michies model represent higher level factors such as organisational objectives, strategy, legislation, standards and legal criteria which influence behaviour in all other elements of the model and are consistent with higher level factors described by Hattaka et al (2011) as shown in the adapted model in figure 3. Michies work has been successfully applied in various contexts such as driver training and safety (Fylan and Stradling, 2014), and in a health- care context (Abraham and Michie, 2008). Abraham and Michie (2008) described 26 evidence based behavioural change techniques (BCTs).

All 26 interventions map directly to the proposed, adapted model shown in Figure 3., and are distributed across levels as follows: Attitude and self-awareness 11 BCTs, Knowledge based 6 BCTs, Rule based 4 BCTs, Skill based 5 BCTs. It is further proposed that the adapted model combining models by Rasmussen (1983), Hatakka et al. (2002) and Reason (1990), should include an overlay of BCTs identified by Abraham and Michie (2008) and Michie (2011) to form the basis of a framework for the design and evaluation of training programmes for optimising learning outcomes in maintenance training utilising VR and AR technologies.

3.3 User Requirement Specification

VR and AR technologies require the user to interact with various interface formats. The adapted model shown in Figure 3, described above, considers error mechanism, and includes error identification and recovery mechanisms as part of the applied framework. It is however, also important that usability criteria are considered. Neilson (1993) and Norman (1988) developed a suite of heuristics and rules for user design, based on the principle that an item or task should be designed in such a way that its' operational requirements and purpose are obvious and intuitive to the user. Iterations of their guidelines are still widely used today.

Results of the interview show that in order for companies C 10 and C11 to adopt VR and AR the technology must be 'simple to use and hard to get wrong.'

The results of the interviews highlighted concerns from C1 over staff skill and an aging workforce in integrating VR and AR technologies into working practice. Differences between the learning styles of, for example, millennial learners and older learners (Toohey et al, 2016) will require careful consideration if VR and AR based maintenance training applications are to be successful. A learning style approach (Cassidy, 2004) advocates that there are four different learning types; visual, auditory, text reading and writing, and kinaesthetic. One approach to optimise learning in virtual and mixed reality environments for all learners might be the provision of multiple selection options relating to information presentation, where the technician can select their preferred option, for example tradition text based instruction, symbolic representation, audio or tactile.

Finally, the adapted model acknowledges the important role of the wider social and organisational context within which the technician operates. It is therefore proposed that educational content of training courses should be guided by principles of social learning theory based on the underpinning work of Bandura (1978) which advocates that learning occurs through exposure to social contexts in which the learner is able to observe, imitate and model behaviour.

Table 2. Levels of Processing and Error Mechanisms Adapted from (Rasmussen (1983), Hatakka et al. (2002), Reason (1990.)

Attitude and Self-Evaluation	Causes of error
Importance placed on organizational and personal priorities and goals Attitudes and preconceptions of the technology Self-awareness and control Risk taking factors	Individual tendencies • Cognitive heuristics and biases • Physical and emotional state
Knowledge- Based	
Improvisation in unfamiliar environments No routines or rules available for handling the situation	Lack of expertise • Overload • Manual variability • Lack of knowledge of modes of use • Lack of awareness of consequences
Rule-Based	
Pre-packaged units of behaviour released when appropriate rule is applied: If the symptoms are X THEN the problem is Y IF the problem is Y THEN do Z	Failure of expertise Misapplied rules
Skill Based	
Automated routines requiring little conscious attention	Misapplied competence • Strong habit intrusions • Frequent invoked rule used inappropriately • Situational changes that do not trigger the need to change habits

Three of the smaller companies interviewed could not see any initial benefit to adopting the technology. This is rather concerning given that research shows that perceived usefulness, and perceived ease of use can affect attitudes towards use, therefore influencing the behavioral intention of whether or not to adopt the technology (Mungo et al. 2017).

The framework proposed in this paper addresses concerns about impact to the organization, by utilizing behavioral change techniques mapped to the top level which encompasses all of the model, referred to as organizational objectives of the model, for example, by providing information, evidence, and practical examples for potential savings and benefits specific to the organisations goals and strategic vision.

Perceived performance of the technology and user issues can be addressed with a selection of behavioral change techniques at the knowledge, rule and skill based levels of the model.

4. Conclusion.

The study used a well-established model of technology acceptance and readiness to design structured interview questions for capturing real-world data, identifying the contextual and organisational factors that help or hinder SMEs' ability to exploit visualization technologies. A new model is proposed combining well-established theoretical models of human processing and human error with Behavioural Change Techniques, and to form a framework for the design and evaluation of training courses utilising VR and AR applications in the context of maintenance engineering. The framework includes an analysis of user needs based on essential Human Computer Interface (HCI) design criteria (See figure 3), and the idea of a learning styles approach to functionality is also proposed (Coffield et al, 2004). It is acknowledged that learning occurs within a social context constrained by organisational boundaries and so a social learning approach (Bandura, 1978) should be adopted in the teaching and learning process. This fits well with the functional nature of VR and AR applications which are well suited to collaborative learning situations.

The proposed model provides a framework through which organisational goals and tasks can be aligned with the needs and characteristics of maintenance technicians and operators, while also providing a tool for the evaluation of training interventions and learning outcomes. Evaluation results will feed back into the course development process to form a cycle of continuous improvement (Figure 3). The proposed model will further provide a platform for multimodal VR and AR based training which could allow small to medium sized companies to develop and implement appropriate maintenance tasks, based upon cost effective and efficient training systems.

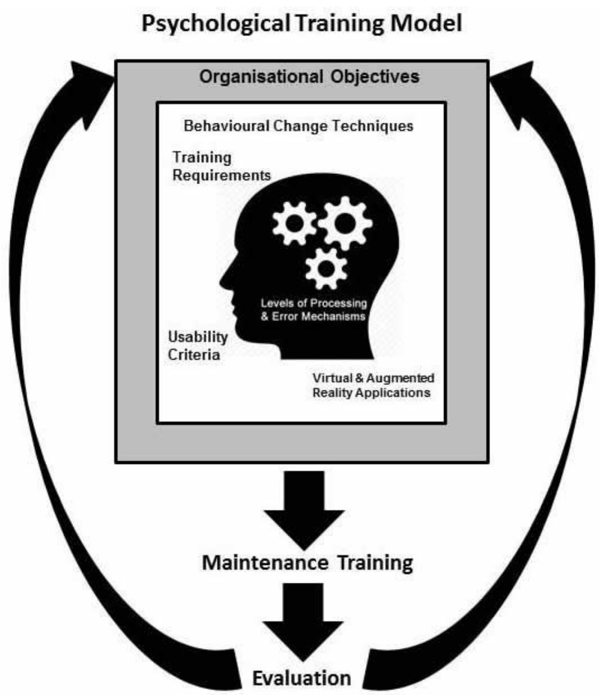

Figure 3. Framework the design of training courses using VR and AR technologies

Figure 3 represents the elements of the framework, which can be applied across multiple contexts in designing and developing learning content for maintenance training programmes utilising VR and AR technologies. The framework is currently under development and will be applied to the design and pilot evaluation of a specific maintenance training course comparing VR and AR, in collaboration with a local manufacturer in order to meet their specific training needs. Any required modifications to the framework identified as a result of feedback from the pilot will be incorporated into the framework and applied to the design of at least three other courses in maintenance training across different manufacturing contexts, and evaluated through a series of real world trials.

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