MAINTAINING A HUMAN TOUCH IN THE DESIGN OF VIRTUAL PART-TASK TRAINERS (VPPT): LESSONS FROM COGNITIVE PSYCHOLOGY AND LEARNING DESIGN

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Abstract

Virtual part-task trainers (VPTTs) are employed in the acquisition and retention of a range of procedural and psychomotor skills. Taking the position that all tasks involve a level of cognitive engagement, this paper discusses cognitive theories of skill acquisition, learning, and multimodal learning and their application to the design of VPTTs and similar learning technologies. The inclusion of human audio and visual presence may be used to stimulate learning and recall of specific skills.

Introduction

When deciding on the training priorities for a task or job role, it is beneficial to have an understanding of the type of Knowledge, Skills and Attitudes (KSA) that are required to competently and successfully perform a task to the standard required. In this paper we first present a modified view of KSA for Defence training, which can be applied to inform the design of more effective learning interventions. There then follows a discussion of learning theory with respect to skills acquisition and the use of learning technology prior to a description of research conducted by the authors. The paper emphasises the importance of the "human" component in certain types of virtual training. Lessons for learning design are identified.

Psychological Knowledge and Skill Domains

Following the job analysis stage of the Defence Systems Approach to Training (DSAT) used in UK military training design and delivery, the KSA analysis is performed. Here a military task is decomposed into the KSA that must be acquired in order to effectively perform the task or demonstrate the relevant task-related competences. DSAT recognises that in addition to knowledge, different types of skills exist and it presents a definition of these skills that are used when conducting a KSA analysis. However, the classification of KSA currently used in DSAT documentation is inconsistent with advances in the psychological literature. As a consequence the accurate consideration of competence and the underlying knowledge and skills that need to be acquired and retained, and the factors that determine how this competence can be best trained and maintained, is constrained. Cahillane, Launchbury, MacLean, and Webb (2013) developed a re-classification of KSA, in terms of the psychological components (categories) of competence retention, referred to as psychological knowledge and skill domains. This re-classification defined KSA in a manner that is consistent with the psychological literature on knowledge and skills retention. Any job-related knowledge and skills can be aligned to this generic taxonomy of psychological domains.

Outline of Domains

Outlining the psychological domains that underpin the knowledge and skills or sub tasks (knowledge and different skills) enables the consideration of generic principles and guidance for the optimisation of their acquisition and retention.

Knowledge. Knowledge precedes all other skills, whether technical or non-technical in nature. However, the retainability of knowledge depends on the type of knowledge. Also, knowledge can be examined outside of its relationship with any other type of skill as a distinct category to be addressed in providing training interventions aimed at the acquisition and maintenance of competence.

Declarative knowledge. The first stage of learning addresses the development of declarative knowledge, e.g., what things are and why things work. Declarative knowledge includes facts, rules or information about a task and as such represents explicit knowledge. Performance of a task is thought to be based on the declarative knowledge that must be held in working memory during the execution tasks (Beilock & Carr, 2004; Rhem, 2005). Declarative knowledge is developed through the presentation of new information being translated by the individual into propositions (ideas), associations and connections, which generates new connections and inferences (Rhem, 2005). Declarative knowledge can change with the acquisition of new information. Declarative knowledge is not conscious until it is retrieved using cues in the environment such as questions (Berge & Hezewijk, 1999).

Procedural (skill-based) knowledge. The declarative knowledge gained at initial acquisition is further refined and converted into procedural knowledge to produce skill-based behaviour. Procedural knowledge refers to knowing the required actions and how to carry them out; hence the behaviour or task execution becomes more automatic (Ritter, Baxter, Kim, & Srinivasmurthy, 2011). Knowledge or information about a task is available in both declarative and procedural forms. At this stage, the procedural knowledge predominantly drives performance; this knowledge is made up of *productions* that represent knowledge about how we do things. Unlike declarative knowledge, procedural knowledge does not require the active maintenance of each step of task execution in working memory.

Procedural skills. Many military activities are underpinned by the application of procedural skills, such as Standard Operating Procedures (SOP), drills and digital procedures to be followed in order to execute commands on complex software based systems (Cahillane & Morin, 2012). Numerous research studies in cognitive psychology have demonstrated that tasks requiring the application of procedural skills are highly susceptible to skills decay. Tasks requiring the application of procedural skill have a number of coherent steps, which include the application of both cognitive and motor skills, although the motor element is minimal. Where the motor element is more prevalent a task would be representative of a discrete psychomotor skill.

Discrete and continuous psychomotor skills. Psychomotor skills can be classed as continuous or discrete. Continuous (open loop) skills are characterised by repeated actions or steps with no discrete initial or final steps, such as flying an aircraft or driving a vehicle (Arthur, 1998; Stothard & Nicholson, 2001; Wisher, Sabol, & Ellis, 1999; Wisher, Sabol, Sukenik, & Kern, 1991). Discrete psychomotor (closed loop) skills on the other hand are physical movements applied to tasks with discrete beginning and endings, which include sequences of steps. Stripping and assembling a rifle is a good example of a task requiring the application of discrete psychomotor skill. In this example, an individual is required to remember a sequence of component steps within a "Skill at Arms" drill, whilst performing the physical/motor component, of manipulating the respective parts and characteristics of the rifle.

Decision making skills. Decision-making skills involve the application of cognitive processes such as judgement, problem solving and analysis in order for an individual to arrive at a decision. Two tasks representative of these skills are troubleshooting faulty equipment (which involves the use of reasoning skills in order to identify the problem) and the interpretation of topographical maps to identify symbols with terrain features on the ground (Wisher et al., 1999).

Attitude. The attitude category is covered in terms of the behavioural attitudes and attributes which are representative of the role of the affective domain in learning. The taxonomy learning objectives in the cognitive domain developed by Bloom and others (Bloom, Engelhart, Furst, Hill, & Krathwohl, (1956) is still widely used by trainers and educators in Defence and other sectors. However, we draw upon Anderson et al.'s revision (2001) of the original 1956 "Bloom's Taxonomy " that identified the cognitive and metacognitive knowledge dimensions and processes and recognised that most cognitive training objectives will have an attitudinal component. Not withstanding this point, if addressing the *attitude* component of KSA, specification of attitudes into training objectives should be limited to those observable attitudinal behaviours that are essential to the task or desired performance. This is because it is difficult to specify training objectives for attitudes that are not directly observable. Behavioural anchors reflecting attitudes towards safety, quality of performance, cultural awareness, etc., can be described and observed.

In contexts where no observable attitudes can be described, at least meaningfully, the KSA analysis and specification of training objectives should be concentrated upon the knowledge and skills domains. Attitudes should be considered in terms of attributes which moderate learning and competence retention. These should be inculcated at both the organisational and individual level. Therefore, the affective domain (Krathwohl, Bloom, & Masia, 1964) is considered in terms of a framework of psychological attributes that drive self-regulation of learning. Many of these attributes can be trained and observed for example, the skills of planning, self-monitoring, evaluation and motivation.

Learning Theory and Skills Acquisition

Deliberate practice and rehearsal is required in order for psychomotor procedural skills to be successfully acquired. When physical practice is not possible, for whatever reason, simulation-based practice and instruction can provide a learner with the opportunity for structured mental rehearsal of a skill providing effective feedback on performance outcomes. Moreover, detailed immediate information feedback stemming from a learner's performance, combined with a chance to improve performance, is important to skills acquisition (Issenburg, McGaghie, Petrusa, Lee, & Scalese, 2005; Wang et al., 2008).

Context-Dependent Memory

Context-dependent memory refers to the observation that people are better at remembering information if they either return to the environment in which it was encoded (learned) or imagine the environment in which they acquired the information (Anderson, 1983; Godden & Baddeley, 1975; Raaijmakers & Shriffrin, 1981). Smith and Vela (2001) demonstrated that when people who are associated with the learning context are the same at encoding and retrieval, more information is correctly retrieved. Smith and Vela argue distinctive faces and voices associated with the environment at encoding serve as cues for the later successful retrieval of information and thus maintenance of knowledge and skills.

Mental Practice

Several studies in the scientific literature have reported that mental practice, also known as rehearsal, enhances performance (Driskell, Copper, & Willis, 1994; Lee, 1990; Rogers, 2006) and can benefit the acquisition and maintenance of tasks with a cognitive element. There are different types of cognitive tasks. For example, cognitive tasks are higher order cognitive tasks that require the application of decision-making type skills such as reasoning, evaluation, judgement and problem solving. However, here we are referring to those with a procedural component, that is, where a sequence of steps has to be retained. Mental practice can be defined as the cognitive rehearsal of a physical procedural activity in the absence of overt physical movements being conducted (Richardson, 1967; Driskell et al., 1994). Physical-procedural tasks relate to discrete psychomotor tasks that have discrete beginnings and endings and require the memorization of sequenced steps. Research has indicated that new learning technologies can support the acquisition and retention of skills, in particular those that have a procedural component (Cahillane, Morin, Maclean, & Stone, 2012).

In order for mental practice to be effective, it must take place when the learner is already familiar with the task and has thus received hands-on practice during training (Rogers, 2006). An example of mental practice applied to a discrete psychomotor task is a soldier thinking a drill through and visualising the steps in the sequence required to perform the drill successfully. In this instance, mental practice of physical drills and handling procedures can be supported by technology in the form of multi-modal PC-based learning (Cahillane et al., 2012). According to Cahillane et al., research has indicated that new learning technologies can support the acquisition and retention of skills, in particular those that have a procedural component. The impact of mental practice on performance is lower than that which is observed with physical hands-on practice but has been found to have a moderate and significant effect on performance (Driskell et al. (1994). Driskell et al. observed that mental rehearsal was effective for both cognitive and physical tasks. Furthermore, the more a task is comprised of cognitive elements, the more of an influence mental practice has on performance for that task. Moreover, those less experienced at a task benefit more from mental practice when that task is cognitive than they do when the task is mostly physical.

Physical vs. Psychological Fidelity

In a comprehensive and practical set of guidelines, Stone (2008, 2012) makes several evidence-based recommendations for the design of immersive 3-dimensional and Virtual Environments (VE) for training either as game-based simulations or part-task trainers. Foremost among these is the need to address fidelity issues, that is, the extent to which the simulated environment represents the real world. For example, physical fidelity is concerned with how well the virtual environment mimics the appearance of the real-world counterpart. This is contrasted with psychological fidelity, which is “the degree to which simulated tasks reproduce behaviours that are required for the actual, real-world target application” (Stone, 2012, p.6) and which Stone associated more closely than physical fidelity with transfer of training. The physical and psychological attributes of military VPTTS or games-based training environments require attention to four key classes of fidelity: task fidelity, context fidelity, hypo- and hyper-fidelity, and interactive technology fidelity.

The Modality Effect and Learning with Media

Moreno & Mayer’s (2007) model of cognitive-affective learning with media depicts how visual and auditory instructional materials are processed from presentation, into working memory and finally to integration with long-term memory. Addressing modality (e.g., presenting learning materials in dual format with explanations as an auditory narration rather than visually as onscreen text) is one of the principles of good multimedia (MM) design recommended by Clark and Mayer (2002). The key feature of the modality effect is that the audio/visual instructional sources of information presented to the learner have to refer to and support each other and must be processed together in order to be intelligible. Materials that are designed to take advantage of the modality effect by presenting onscreen audio and visual information together are superior to those in a visual only format and reduce cognitive load (Leahy & Sweller, 2011).

The principles referred to above tend to be used only for what has so far been referred to as multimedia or multimodal design of instructional materials.

However, the term *bimodal* should probably be used when addressing dual sensory channels (auditory and visual) just as *unimodal* may refer to text only materials. True multimodal learning, then, would address other sensory channels. One such modality is the pressure modality, which receives information through passive exploration known as *tactile* perception. *Haptic* perception refers to the process of actively exploring stimuli in the learning environment. Technologies delivering haptic in addition to audio and visual information and feedback would better represent multimodal learning. Inclusion of olfactory information in simulated or virtual environments is currently of limited interest to defence training but odour may have a role. Stone (2012) suggested three possible scenarios for military training: odour could create an ambience effect in urban patrol training or be used to simulate the smell of burning in safety critical maritime simulations as well as detection of fluid or vapour leakages.

Virtual Part-Task Trainers (VPPTs)

In light of the above discussion of knowledge, learning theory, and skills acquisition it is argued that when physical practice is not possible, owing to factors such as reduced availability of equipment for “hands on” training, simulation-based practice and instruction can provide an opportunity for maintaining key skills, in particular those with a procedural component. Moreover, simulation-based practice and instruction can support structured mental practice through encouraging and coaching learners in visualising the tasks to be retained. Part-Task Trainers (PTTs) may be used to develop critical sub-skills prior to more comprehensive training either in a simulator or on live equipment (Wightman & Lintern, 1983). PTTs are used to train limited aspects of a task rather than providing an integrated learning experience (Gaba, 2004). Part-task training is intended to provide more efficient training often with the aim of reducing cost. VPPTs provide 3D interactive equipment simulations to assist in the acquisition of new skills and knowledge through familiarisation and practice. They can function on various platforms such as personal computers (PCs), interactive whiteboards, tablet PCs, and mobile devices. Interaction with a PC-based VPTT is achieved through use of a computer mouse, keyboard, and/or touchscreen. VPTTs can be designed with a high degree of detail depending on the learning objectives and required levels of physical and psychological fidelity.

Research

Cahillane, Morin, MacLean, and Stone (2012) carried out an empirical comparative evaluation of an innovative training delivery method intended to support the acquisition of weapon handling drills. Cahillane and MacLean (in preparation) describe research involving a prototype PC-based MM tool developed to gather evidence for optimising a blend of training delivery methods and media that could be used for the acquisition of psychomotor procedural skills. The prototype was designed as an aid to the evaluation of the underlying concepts and principles of learning design and was not intended to enter service. HTML and JavaScript were used to present text, video and images within the MM tool. Interactive formative assessments and feedback were included to stimulate the cognitive processes involved in learning. The use of multimodal cues designed into the materials was intended to enhance learning and performance. Audio, images, and video were used and the voice of a trained instructor included helping the learners associate the drills to be learned with the familiar auditory commands originally heard in the classroom and thus the required movements. The psychological nature of many of the drills being trained using the tool are representative of the discrete psychomotor skills typically required in many tasks trained using VPTTs, i.e., they have a procedural and perceptual-motor element.

Learning Design

The theory and research discussed in this paper are intended to promote deeper consideration for the evidence of effects in using a range of technologies to target cognitive learning processes and support categories of psychological skill referred to above while taking into account how the human cognitive system encodes, stores and retrieves information. An understanding of the cognitive mechanisms that underpin learning is important when designing technology to support skill acquisition and maintenance, which must be congruent with the cognitive capabilities of the user. Dror (2008) specifically noted how it is often perceived that technology drives learning when the focus should be on using technology to support the acquisition and maintenance of knowledge and skills. When writing specifications for new learning technologies, developers should not only understand the task to be trained but be provided with a clear breakdown of the training objectives. Developers and instructional designers should clearly indicate to the learner what the Key Learning Points (KLPs) and Intended Learning Objectives (ILOs) are and how these will be covered by the technology in question (Clark & Mayer, 2011). It is important to focus on the learner and not solely the technology and materials or animations.

The principles for learning design that harness mental processes involved when learning from a two-dimensional, dual-channel environment are still highly relevant to the design of e-learning materials. When a principle-based approach that addresses human cognition and technology is applied, the intended learning is more likely to occur. During the research an evaluation of two technological packages intended for revision and reinforcement of weapon handling drills (see Cahillane, Morin, Maclean, & Stone, 2012) highlighted the importance of applying the principles in the revision and retention of psychomotor procedural skills in the design of VPTTs. In this case, the use of multimodal information, including the presence of the operator hands manipulating the equipment, enhanced performance by enabling learners to associate auditory commands with the required movements. The need to base multimodal design on the psychology of human learning and behaviour is extended in the guidance for design of immersive three-dimensional and games-based training systems (see Stone, 2008, 2012).

A significant output of the authors' studies into the use of MM and VPTTs was recognizing the importance of a *handling human*, or at least representations of human hands carrying out more difficult manipulation tasks. Qualitative data gathered from participant feedback suggest that such a human presence improves engagement with the materials and understanding of the tasks to be learned. The results from the trial suggest that incorporation of additional MM materials such as interactive video should be considered in the design of future VPTTs seeking to train similar skills. Thus, it would include the best features of both types of approach and support not only the acquisition of knowledge about the VPTT subject matter, but also that for how to carry out a greater diversity of discrete psychomotor tasks.

Concluding Remarks

A modified approach to the conventional analysis of knowledge, skills, and attitudes in defence systems approach to training was discussed that more accurately may reflect advances in cognitive psychology. It was argued that this approach could be used to more precisely understand what psychological categories of skills should be targeted when designing training interventions and to reflect those aspects of learning and retention of skills and competence that should be addressed. Learning theory and skill acquisition were discussed with an orientation towards learning mediated by technology illustrated by the description of a prototype multi-media (MM) tool the authors developed and used in their research. The research investigated the acquisition of discrete psychomotor (closed loop) skills (physical movements applied to tasks with discrete beginning and endings), which include sequences of steps found in skill at arms training in the military. It was argued that by more effectively addressing the importance of associative and context dependent memory, individual learning could be improved.

Finally, it is worth noting that although crude in format, the tool developed for the research proved popular among students and instructors alike and continued to be used to supplement regular training which, as discussed in the accompanying paper (Cahillane & MacLean, manuscript in preparation), clearly demonstrated it to be effective and fit for its purpose.

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