Teaching safety precautions in a laboratory DVE: the effects of information location and interactivity

Enseñando Precauciones de Seguridad en un AVE: el efecto de la ubicación de la Información e Interactividad

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Abstract

Information location and interactivity are two attributes of desktop virtual environment (DVE) design that can be exploited to enhance the ability of learners to acquire information and skills that transfer to real world. The term "information location" refers to the spatial relationship between linguistic information (text and sound) and virtual reality scenes. "Interactivity" refers to the actions by the learner that are afforded by the DVE (i.e. object manipulation, navigation, and user-system interaction). The effects of these attributes were assessed via pre, post, and retention measures of knowledge of laboratory precautions. Although no statistically significant difference was found, results indicate that co-located information produces a positive effect upon the learning and retention of declarative knowledge. However, "interactivity" appears to cause a detrimental effect on learning that depends on user-system activities and performance issues. An interesting finding is that co-located information encourages more extensive exploration of the DVE which, in turn, facilitates retention of spatial knowledge.

Keywords: Desktop Virtual Environments; Spatial Contiguity of Information; Interactivity; Declarative Knowledge.

Resumen

La ubicación de la información y la interactividad son dos atributos del diseño de ambientes virtuales de escritorio (AVE) que pueden ser explotados para mejorar la capacidad del aprendiz para adquirir información y habilidades que se transfieren al mundo real. La "ubicación de la información" se refiere a la relación espacial entre información lingüística (texto y sonido) y escenas virtuales. "Interactividad" se refiere a las acciones del aprendiz que son proporcionadas por el AVE (i. e., manipulación de objetos, navegación e interacción usuario-sistema). Los efectos de estos atributos fueron evaluados midiendo el conocimiento de precauciones de laboratorio antes y después de la capacitación, así como retención del conocimiento. Aunque no se encontraron diferencias estadísticas significativas, los resultados indican que la ubicación de la información produce un efecto positivo en el aprendizaje y retención del conocimiento declarativo. Sin embargo, "interactividad" causa un efecto negativo en el aprendizaje atribuible a las actividades usuario-sistema y ejecución de tareas. Un interesante hallazgo es que la información colocada fomenta una exploración exhaustiva del AVE, lo cual facilitó retención del conocimiento espacial.

Palabras clave: Ambientes virtuales de escritorio; contigüidad espacial de información; interactividad; conocimiento declarativo.

1 Introduction

Unlike other computer-based applications, desktop virtual environments (DVEs) created through the use of virtual reality technology provide unique opportunities for offering learning and training experiences which, hitherto, have only been afforded by real-life environments. Unlike real-life settings, virtual environments permit new types of interaction and offer great scope for experimenting with the location of information in the learning environment.

Learners can 'fly' around a scenario for example if they wish and contextual information can be displayed around the learner within the VE.

The benefits of DVEs for acquiring knowledge and skills that transfer to the real world environment have been studied in a number of different domains and various factors have been studied including level of presence [Romano, Brna and Self, 1998; Slater, et al., 1996; Witmer and Singer, 1994; Held and Durlach, 1992], fidelity of the virtual reality (VR) representation [Romano and Brna, 2000;Witmer, et al., 1996; Scaife and Rogers, 1996; Kenyon and Afenya, 1995; Kozak, et al., 1993], interactivity [Bowman and Wingrave, 2001; Smith, Stürzlinger, and Salzman, 2001; Lindeman, Sibert and Hahn, 1999; Byrne, 1996; Salzman, Dede and Loftin, 1996]. However, there has been little research to date on the relationship between the spatial location of embedded information (text and sound) in VEs and learning.

The concept of information location refers to linguistic information spatially co-located next to objects or scenes in a three-dimensional space to provide instructional messages. In physical environments for learning such as museums and art galleries, textual annotations are presented next to works of art on exhibition. A more modern version allows a narrative of the history of specific places or objects to be played in a hand-held audio device when visitors reach particular vantage points as they roam around museums or open places. Hence the visitor can establish a link between the information read or listened to and the object or scene visited. In contrast, when information is presented out of context, for example with a traditional hand-held printed catalogue, it is necessary to look for the information through the pages and it is less easy to establish that relationship. The virtual environment presented in this paper was designed to offer the elements that facilitate the association between linguistic information and the experience of gathering safety information in a virtual scene.

The study reported in this paper investigated the extent to which information location in a three-dimensional space facilitated the acquisition of declarative knowledge in DVE for learning. Two forms of interactivity allow the learner to negotiate with virtual reality environments which are inherent activities for learning in a three-dimensional space. The first is navigation, moving around the environment as 'driver' or 'passenger' for active participation in exploring the virtual representation of the physical setting. The second form consists of interacting with virtual objects for acting events, manipulation or obtaining information. This research also investigated the relative contributions of interactivity in a three-dimensional space for performing learning activities. Despite the importance of retention of knowledge beyond the end of the training session, few empirical studies have measured this factor [Hall, Stiles and Carol, 1998]. However, in safety contexts there are very important reasons for studying long-term retention of knowledge. The nature of interaction between information location and degree of interactivity for learning in a DVE and how these factors facilitated skill retention after training was also investigated in this research. Before the empirical study is presented, a review of some related works and a description of an experimental virtual environment called VEST-Lab are described. The paper concludes with a discussion of the results and future work.

Information location

The relationship between the physical environment and learning has been well-researched in cognitive psychology. Research has shown that the environmental characteristics in which learning occurs significantly influence learning, transfer, and retention, suggesting that the place and location of their components are not just space and objects but elements that may serve as instructional aids and retrieval cues.

According to Smith (1979), people make associations between information and the place in which it is learned. In a verbal learning study, Smith (1979) examined the incidental association between learning list words and the environmental context where the learning occurs in terms of environmental reinstatement effect. His finding showed that subjects tested in the same context recalled 26.25% more words than subjects tested in a different context. A second study by Smith revealed that when subjects in the different-context condition were instructed to recall the learning environment they were able to recall nearly the same number of words (M = 17.2) as same-context condition subjects (M = 18). Smith (1979) claimed that such contextual relationships can be activated by physically replacing the learner in the appropriate environment, or mnemonically by asking the learner to remember the learning context, suggesting that some aspect of the environmental context other than objects in the environment becomes associated with information and provides a source of retrieval cues useful for recalling information learned in that context.

In order to investigate the effect of providing cues at the time of learning to facilitate recalling information, [Tan, et al., 2001] developed a system called Infocockpit, which aimed to provide environmental cues by immersing the user with panoramic images and distributed information with multiple monitors located around the learner. During the learning phase of the study, people learned lists of word pairs presented on monitors while contextual images were displayed along with ambient sounds. The same lists of word pairs were presented to a second group in a conventional desktop computer. Participants were tested for retention away from the learning environment one day later by giving them a cue word and asking them to recall the corresponding target word. The study showed that people were able to remember 56% more information under the Infocockpit condition than using a conventional desktop in recalling three lists of ten word pairs. Although there was no difference between conditions in the time and effectiveness for learning the material, results showed a high correlation between the remembered word-pair and location of information. Results suggest that memory cues provided by the environment and information location facilitates encoding and retrieving of information.

The experimental environments of the research cited above have provided perceptual cues for learning and retention of knowledge in actual settings. This approach has been also explored in mixed physical and digital environments. Augmented reality has used information location by overlaying graphical and textual information on the user's view of the physical world. Neumann and Majoros (1998) argue that incorporating virtual information into the user's view of the real context creates a framework of association that aids recall and learning. This can be exploited in order to provide concurrent instructions for manufacturing and maintenance task training (e.g. Neumann and Majoros, 1998). The Ambient Wood project is another example of location information where children explore a wood through a periscope. The periscope adds digital information to see the effect of the introduction of other organisms on the habitats [Wild e, et al., 2003]. In this approach, learners are allowed to access information that would not be visible or available by watching the physical environment with the naked eye. Furthermore, supplementary information to the physical environment can be presented during the problem-solving. This is useful in application domains such as equipment maintenance and also to support exploratory activity (e.g. Ambient Wood).

In both real-life and mixed-reality (hybrid) environments, the spatial location of information in computer-based environments has major implications for learning. Mayer (2003) found that when corresponding words and pictures are presented near to rather than far from each other on the screen in a multimedia instruction, learners are more likely to be able to hold corresponding words and pictures at the same time and learn more deeply. In his study a multimedia animation with textual explanation next to a picture was given to a group of students. The same explanation was given to another group of students with the difference that the statement was printed at the bottom of the screen far from the centre of the picture. Mayer (2003) reported that students in the group with co-located information generated 43% more creative solutions on a problem-solving transfer test than the group of students with separated information. Mayer (2003) calls this the 'spatial contiguity effect'.

As in the spatial contiguity effect, it is expected that acquiring information relevant to objects, scenes, or situations in a context-dependent and co-located form would be more meaningful and effective for learning and retention than unlinked decoupled information in a DVE. Previous research by Bolter et al. (1995), Bowman et al. (1998) and Bowman et al. (1999) has explored the possibility to create information-rich virtual environments aiming not only to reproduce the perceptual experience of 'being there', but also to provide additional information about the environment. Bowman et al. (1998) found that embedded information that was tightly coupled to the virtual environment enhanced the relevance of both the virtual environment and the information. A usability study showed that the most effective types of information were those that were pertinent to or otherwise associated with the object or location in the environment. In a more recent study, Bowman et al. (1999) compared traditional classroom teaching lectures and the use of a virtual environment to support the lecture. They investigated the value of providing contextual information of an abstract or symbolic nature related to the environment in an educational domain. In this study three groups of students were compared: a control group, in which students attended normal class presentations; an information group, in which students attended classes and explored the VE in order to recognize the spatial layout of the virtual zoo and to gather zoo exhibit design information; and a habitat group, in which students explored the VE with no access to embedded information in order to discriminate the value of embedded information for learning outcomes. Groups were tested on the material covered five days later. The evaluation revealed a higher

average score for the information group compared to the other two groups. Bowman et al. (1999) interpreted the results to mean that VE instruction paired with a lecture on the same material provides greater learning and understanding than a lecture alone. Although the differences were not statistically significant, there was a trend for the VE to facilitate the association of spatial and abstract information. However, it was not clear which elements of the perceptual experience facilitated students' creation of mental associations between spatial and symbolic information that produced increased learning.

Zayas and Cox (2005) reported the effect of presenting co-located and non co-located information on learning and retention of knowledge in a virtual environment. Their findings indicate a tendency for co-located information to produce improved retention of declarative knowledge. The study described in this paper addresses the issue of co-located embedded information along with an interactivity condition for supporting learning and retention of knowledge.

Interactivity -spatial navigation and object interaction

It has also been argued that interactivity has implications for the learning process, not only in the way the information is presented to the learner, but also in how this is gathered from the learning environment. Educational theory and cognitive science advocate that there is merit in active participation in terms of self-constructed knowledge via direct experience of interpreting objects and scenes [Jonassen, 1991]. Youngblut (1998) states that people are better able to master, retain, and generalise new knowledge when they are actively involved in constructing that knowledge in a 'learning-by-doing' situation. Youngblut (1998) believes that the constructivist learning approach in VEs offer an alternative approach for some activities over other more instructivist learning environments. This type of interactivity has been demonstrated to be useful for understanding complex and abstract scientific concepts through experimenting situations [Dede, Salzman and Loftin, 1996; Salzman, et al., 1999]. However, for learning factual information such as safety regulations the type of interactivity that has been explored is related to the enactment of 'doing' activities in a VE that are similar to the real world, such as exploring a virtual representation of a physical environment for gathering information, interacting with objects and reacting to events in the virtual scene. In so doing, the learner is able to acquiring information in a contextual environment where knowledge will subsequently used in real world circumstances. Through a virtual experience, the learner develop configuration knowledge of the represented physical setting and associates that information to spatial location where was learnt.

Peruch, Vercher, and Gauthier (1995) found that being involved in active exploration of a virtual environment provided better resources for spatial acquisition for route-finding than passively watching the exploration of the same VE. Brooks, et al. (1999) investigated the advantage of active exploration over passive exploration in a DVE in terms of spatial memory, object memory, and object location memory. They found that active participants recalled the spatial layout of the VE better than passive participants. However, no significant differences were found for recalling objects and their position in the VE. As there was no interaction with objects to be recalled during VE exploration, Brooks et al. claimed that memory enhancement happened only when the learner is directly involved with navigation and object manipulation. Cheesman and Perkins (2002) suggest that the enactment effect of 'doing' a task in a VE also allows the learner to encode spatial information related to task performance. Furthermore, research indicates that learners recall actions they themselves perform better than those they observe (e.g. Foley and Johnson, 1985; Foley, Johnson and Raye, 1983; Baker-Ward, Hess and Flannagan, 1990). As active participation represents an advantage over passive observation for knowledge acquisition, it is expected that VE interactivity would facilitate the acquisition and retention of factual information.

2 VEST-Lab

Virtual Environment for Safety Training Laboratory (VEST-Lab) is a DVE which depicts a highly realistic representation of an actual chemistry laboratory. VEST-Lab affords distinctly new and innovative safety training experiences which have not hitherto been possible with conventional methods such as videos, printed information, and lectures. It offers: a contextual environment to learn about laboratory precautions; the opportunity to practice

responses to emergency situations; and a useful tool for researching the teaching and learning of laboratory safety knowledge.

On the basis of reading safety literature, safety rules sheets, and talking to safety personnel, a number of training scenarios were identified, designed, and evaluated for usability and instructional information. The criteria for selecting scenarios were based on the degree of user activity required for getting information. Although Wilson (1993) reported that gaining spatial knowledge in VEs is similar to physical environments, there are usability problems associated with navigation and interaction with VEs. Navigation is an essential activity for any VE to explore and interact with information. According to Hix et al. (1999), usability problems associated with navigation in complex virtual worlds affect not only the performance of the user, but also other interactive tasks, for example, object manipulation, object selection, and query response. In order to prevent usability problems from impeding learning, VEST-Lab interactivity was reduced to two simple user actions: the freedom-to-roaming inside a single room to prevent disorientation and a single click on objects for obtaining information.

Training scenarios in VEST-Lab were divided into three instructional sessions: (1) knowing the laboratory, which aimed to show the position of safety points; (2) laboratory precautions, which showed risks involved with a laboratory including laboratory housekeeping, safety gear, handling chemicals, and storing chemicals; (3) emergency procedures, which offered guidance for responding appropriately to incidents and accidents in a chemistry laboratory. In the first and second session the learner freely explored the laboratory to identify safety points and to spot safety violations, respectively. Then, the learner clicked on objects associated with safety points or safety violations to reveal textual and audio annotations on a virtual panel. For example, clicking on a virtual cylinder lying on the floor displays housekeeping annotations for storing cylinders in a chemistry laboratory. In order to learn emergency procedures in VEST-Lab, the learner read through a list of actions to be performed and then she/he practices the procedures in virtual emergency scenarios. The system provides feedback when a wrong action is executed.

3 Method

A fully-crossed between-groups factorial design was used. It consisted of two between-group independent variables and three repeated measure variables. The first independent variable, interactivity, had two levels (interactive, non interactive). The second factor, information location, had also two levels (co-located, non co-located). The repeated measure variables were: laboratory safety knowledge score (SK), spatial knowledge acquisition score (SKA), and object location memory score (OLM).

Two versions of VEST-Lab were designed that differed only in the way that information is presented, co-located and non co-located. The co-located condition displays panels with information near the location of entities, which aims to foster a framework of association between information and entities. These displays 'recede' as the user navigates away from them. The non co-located condition displays panels in the form of pop-up windows overlaying the scene, which remain visible until the user closes the panel (see Figures 1).

The interactivity condition was achieved by having two groups of participants, interactive and non-interactive. The former group actively interact with the VE while a video of on-screen activity was recorded. The latter group passively watched a playback of the screen-display recordings of former 'active' participant. These subjects formed the 'passive' (i.e. non-interactive) group. Each active participant's interaction with VEST-Lab formed a stimulus for one 'passive' participant. Hence the design was a 'yoked pair' design.

It was hypothesised that co-located information would facilitate the association between entities in the VE (objects and scenes) and pertinent information about such entities. Conversely, non co-located information would not afford this perceptual cue as information is displayed in a way that is less closely coupled to the target object location. A second assumption is that active participation combined with object interaction would provide the learner with additional resources for learning. Consequently, the interaction of these two factors would provide the optimal facilitation of learning and retention of knowledge. It was predicted, therefore, that learners with co-located information combined with interactivity would have the highest scores in a safety knowledge test and as well as the

highest scores in a spatial knowledge test. A corollary of this prediction would be that the lowest scores in this evaluation would be achieved by the combination of non co-located and passive participation.

An alternative 'cognitive load' based hypothesis was that active participants might be penalised by having to interact with the VE (i.e. to navigate and 'drive' as well as learn), which might decrease cognitive resources available to focus on learning; and, in contrast passive participants might benefit from undivided attention.
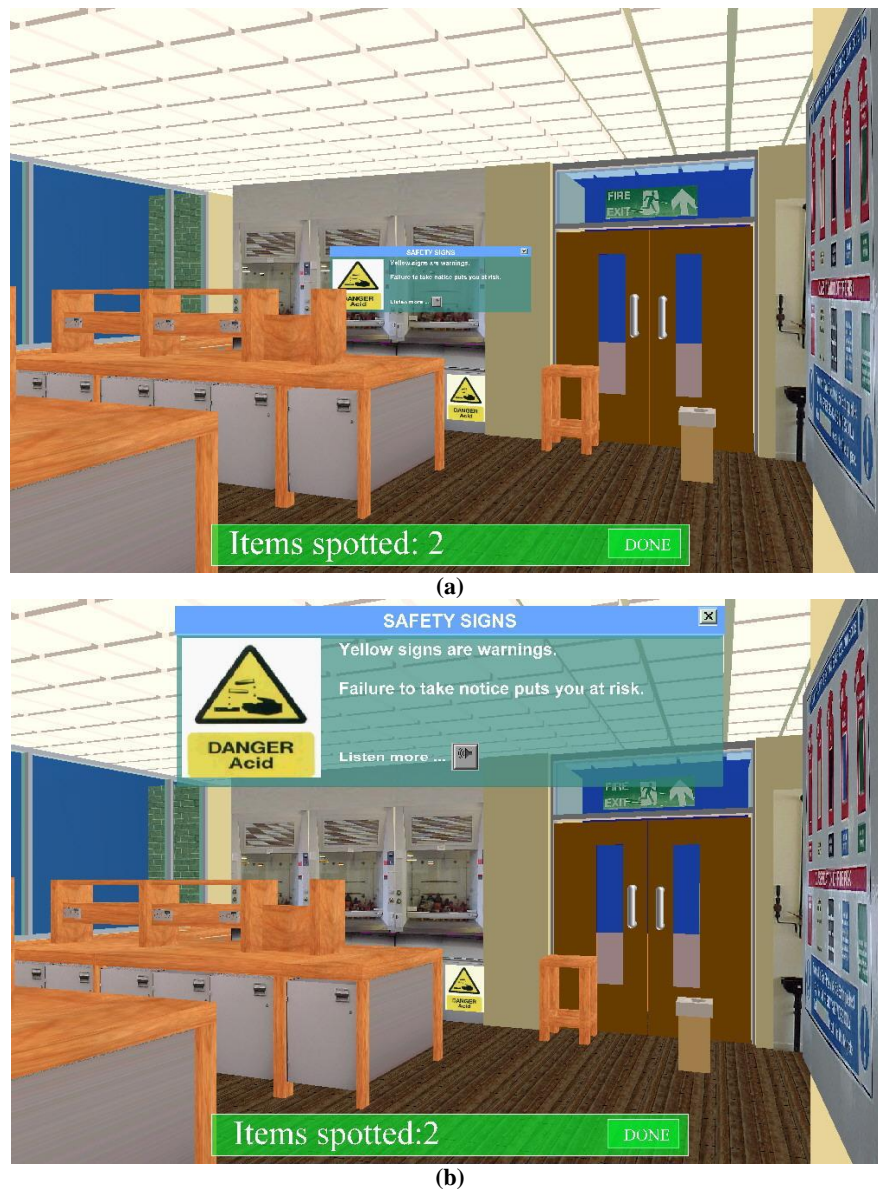

(a)

(b)

Fig 1. Safety information is displayed on virtual panels with textual and audio annotations in VEST-Lab. A frame from the same vantage view point shows co-located information and non co-located information regarding yellow safety signs. (a) The co-located condition displays panels near to objects or scenes, which aims to foster a framework of association between information and entities. These panels 'recede' as the user navigates away from them. (b) In the non co-located condition panels are displayed as a form of pop-up windows overlaying the scene and which move along with the learner field of view

Participants

A total of 48 science students, mean age 24.25 years (SD 6.13), participated in the experiment. There were 24 females and 24 males. Participants were paid for their participation and randomly allocated to one of the four experimental conditions. The only constraint was that the active participant was allocated first to create the screen recording used by a subsequent passive participant.

Material

A DELL Pentium 1.8 GHz desktop PC with a 15" LCD flat colour screen, mouse, keyboard and speakers was used. The desktop PC was fitted with a graphics processor 64MB NVIDIA GeForce2 MX/MX 4000. Camtasia Studio was used to record the screen during active training and to play back the video for passive training. The virtual chemistry laboratory was modelled with VRML and embedded in an HTML page. MS Internet Explorer and Cortona VRML browser were used to visualise VEST-Lab. A questionnaire with 12 questions was used to assess the learning of safety knowledge. 21 laboratory regulations including information concerned with safety points were addressed in this assessment.

Procedure

Knowledge about laboratory safety and emergency procedures was measured before training, immediately after training, and a week later (retention). Participants were given written and verbal instructions. They were told that the objective of the study was to assess the effectiveness of a VE in providing safety training in a chemistry laboratory and it was explained to them that the whole study would have two sessions separated by one week. Active participants were told that they would be able to interact with the VE, while passive participants were told they would watch an animated screen recording depicting a virtual chemistry laboratory. All subjects were instructed to read and listen carefully to the information provided in the VE.

Active participants were allowed five minutes to become familiar with the VE before the experimental tasks. After familiarisation with the VE, instructions about the tasks to be performed were given to subjects in the interactive condition. The tasks and order of the sessions were as follows: (1) in the knowing the lab session, five minutes were allowed to locate the position of 6 safety points; (2) the laboratory precautions task was to spot 10 laboratory precautions within a limited time of 10 minutes; (3) in the emergency procedures session participants were asked to find 4 pictures in the laboratory that illustrated emergency procedures and instructed to perform 2 emergency procedures. A total time of 8 minutes was allowed for the whole session.

After completing the three training sessions participants were administered a knowledge acquisition assessment without VEST-Lab present:

1. Safety knowledge test. Participants were allowed ten minutes to complete a laboratory safety questionnaire. Items included, for example, multiple-choice questions about the colour code of fire extinguishers.
2. Spatial knowledge test. Subjects were asked to sketch a plan of the layout of the laboratory on a blank A4 size paper. A limited time of three minutes was allowed for this task.

A sheet of A4 paper with a plan of the laboratory and a list of six safety points was given. Participants were asked to indicate the location of these six safety points by writing down on the plan the corresponding number from the given list. Three minutes were allowed for this task. Participants were asked to return a week later for the retention-test and to be paid for their participation. The retention-test was to repeat the safety knowledge and spatial knowledge test.

4 Results and Discussion

The results of the empirical study are discussed in the following sections. None of the differences in the test scores were statistically significant mainly due to the small samples size for each experimental group. However, trends found in the results partially support the hypotheses.

Declarative Knowledge

A safety knowledge score was computed by totalling correct answers out of 21 multiple-choice questions. One point was given to each correct answer. The results indicate an across-test consistent small advantage for subjects in the passive condition in terms of learning on paper-and-pencil test of safety knowledge. However, a repeated measure ANOVA revealed that there was a no significant main effect of interactivity nor information location for acquiring declarative knowledge.

Although the differences in test scores for the four groups were not statistically significant for interactivity and location of information, trends show that the four groups of learners improved their knowledge after training (see Figure 2). Non interactive learners with co-located information (NI+CL) were the experimental subjects that improved more in learning declarative knowledge about laboratory safety. Except for the interactive learners with non co-located information (I+NCL) group, all groups showed positive retention of knowledge or an 'incubation' effect in which performance continues to improve beyond the post-test. Interactive learners with co-located information (I+CL) showed the greatest improvement in retention of knowledge from post-test to retention-test.
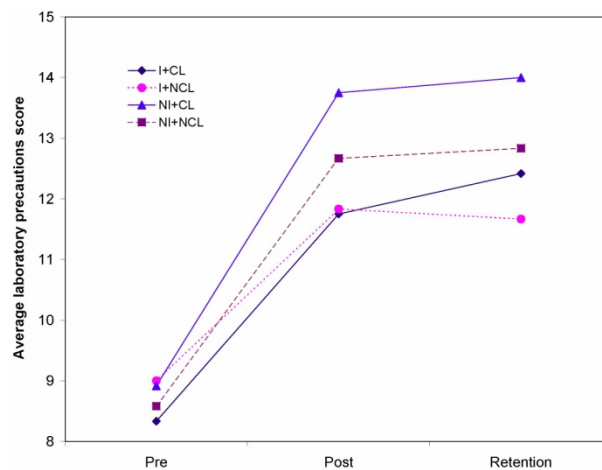

Fig. 2. Summary of average test score results of safety knowledge
(I: Interactive; CL: Co-located; NI: Non interactive; NCL: Non co-located)

The results partially contradict the hypothesis which predicted that the combination of interactivity and co-located information would provide the best resources for acquiring declarative knowledge. The results showed that passive learners performed better than active learners in both information location conditions for acquiring declarative knowledge. However, except for the I+CL versus I+NCL conditions at post-test, students who learned with co-located information tended to score higher than students in the non co-located condition. The results suggest, therefore, that the additional tasks that active learners performed during learning along with decoupled information interfered to some degree with the cognitive processes or resources required to learn factual information.

The findings that passive learners enhanced knowledge relative to active learners confirms the 'cognitive load' hypothesis, which predicted that cognitive resources available to focus on learning would be decreased. User-system interaction and performance issues seemed to consume attentional resources at the expense of focusing on learning at different levels or subtypes of interactivity. At the level of active versus passive learning (i.e., I versus NI conditions), the results revealed that being involved in 'driving' and 'doing' activities in the VE imposes cognitive loads that might impede learning. In contrast, passive learners were benefited from undivided attention as they were guided through the VE exploration and were more able to concentrate on learning.

However, considering subtypes of interactivity, it was found that a greater degree of exploratory activity in terms of displacements and changes of view direction facilitate recalling of information. The analysis of navigation path logs of active subjects revealed two patters of exploratory activity: proactive explores and active explores. The differences between these exploration patterns were in terms of the pace of navigating. The former explores moved

around the VE with a higher pace and they had a larger number of changes of viewpoint positions and visited a wider area of the laboratory than the latter explores. Conversely, active explorers preferred to systematically view their surroundings from several vantage points rather than wander around more aimlessly (see Figure 3).
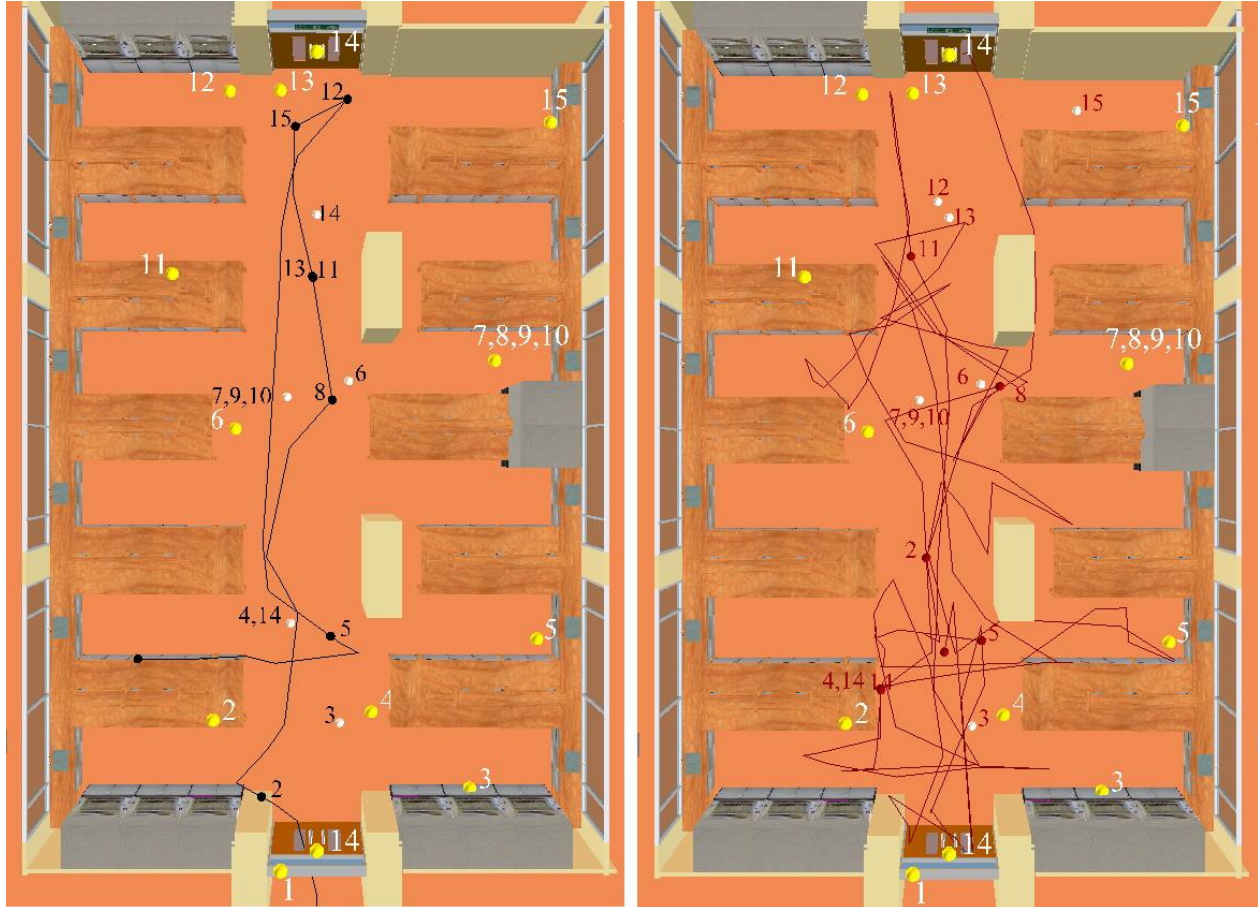

Fig. 3. A birds-eye view of navigation trace of active explorers (left) and proactive explorers (right) captured during a learning session

It was found that the explorative strategy adopted by the learner was closely related to performance. For example, being vigilant, spotting objects and spending time to complete the task. For instance it was observed that proactive explores tended to try to complete the task as rapidly as they could manage with fast visual scanning and dynamic, constantly-moving patterns of exploration.

In order to analyse the effect of explorative pattern on learning, a repeated measures ANOVA analysis was performed with the exploratory activity measure as a between-groups factor in learning laboratory safety precautions. The results showed no significant differences across-tests, but a small advantage for active explores ($\overline{x}$ =12.18; standard error -SE = 1.04) over proactive explorers ($\overline{x}$ =11.46; SE = 0.95) at post-test. However, active explorers' knowledge decayed one week later ($\overline{x}$= 11.55; SE = 0.98). In contrast, explorers with a high degree of exploratory activity increased their knowledge during this period of time ($\overline{x}$ = 12.46; SE = 0.90). The result shows that although proactive explorers were penalized at immediate learning of factual information, this degree of activity provided better resources for recalling of information. It seems that an intense exploration of the virtual environment allows learners to assimilate the spatial relationship between information and the scene where it was displayed.

In order to investigate whether information location influences the exploratory strategy adopted by learners, the number of displacements performed (Moves) and the number of viewpoints altered (Views) were analysed. It was predicted that co-located information would promote a higher level of exploratory activity since panels, once displayed, stay in a fixed position as the user navigates away from them; hence, explorers need to approach the panels in order to be able to read and listen to annotations. An independent-samples t-test indicated that information location had a significant effect on exploration patterns. Significant differences were revealed for group I+CL ($\bar{x}$= 170.92, SE = 14.20) versus group I+NCL ($\bar{x}$= 124.92, SE = 9.62) with respect to Moves measure, t(22) = 2.68, p = 0.007. Similarly, there was a significant difference for group I+CL ($\bar{x}$= 197.33, SE = 16.81) versus group I+NCL ($\bar{x}$= 151.83, SE = 8.89) in terms of Views measure, t(22) = 2.39, p = 0.01. The results can be interpreted to mean that co-located information promotes greater exploratory activity and more dynamic navigation around the virtual environment than non co-located information. This activity benefits active learners for acquiring spatial knowledge as will be discussed in next section.

Another issue related to task performance was the time that active learners spent attending annotations. Once the annotation was displayed, the learner was commanded to read and listening carefully to safety information. Time spent on attending annotations was calculated by counting the period in seconds between clicking on an object to display a panel with annotations and closing the panel. The total time was obtained by adding the time spent at each annotation. It was assumed that learners would be more able to read and listen carefully to information if they spent an average of 17 seconds per panel. A correlation test between moves and views measures, and time spent in attending annotations was performed. There was a significant negative correlation between moves score and time spent on panels for Group I+CL (r = -0.48, p = 0.05) and a relatively strong positive significant correlation between moves score and time spent on panels for Group I+NCL (r = 0.72, p < 0.01). The results showed that the greater the amount of changing viewpoint positions, the shorter the time spent on reading and listening to information on co-located panels. Conversely, active explorers with non co-located information tended to spend more time in reading and listening to information. Similarly, there was a significant negative correlation between views score and time spent on panels for Group I+CL (r = -0.58, p < 0.05) and a positive correlation between views score and time spent on panels for Group I+NCL (r = 0.66, p < 0.05). The results showed that the greater the amount of altering viewpoint angles of the 'camera', the shorter the time spent on reading and listening to information on co-located panels. The results can be interpreted to mean that explorers with co-located information tended to read and listen to declarative information superficially. This result was confirmed with an independent-samples t-test, which indicates that information location had a significant effect on reading and listening to declarative information. A significant difference was revealed for Group I+CL ($\bar{x}$= 165 seconds, SE = 13.64) versus Group I+NCL ($\bar{x}$= 212 seconds, SE = 13.08) in time spent on panels (t(22) = -2.49, p < 0.05). The results suggest again that co-located information promotes exploratory activity in a DVE consistent with proactive explorer behaviour, in which activity is focused more on roaming around the VE than spending time on reading or listening to information. Apparently this patter of exploration encourages superficial attention to annotation, therefore less learning. However, learners with co-located information were more resistant to forget knowledge.

The influence of co-located information on exploratory behaviour can be explained in terms of visual attention in video-game contexts. Since co-located panels remain in the same position, the distance between the explorer and the annotation panel was variable. This modality to present information forced learners to approach to, or move away from them in order to attend annotation. In contrast, the distance between the explorer and non co-located panels was constant and readable from any vantage viewpoint. Therefore, non co-located panels occluded part of the virtual environment window as they moved along with the learner's field of view. The co-located panels allowed participants to see a wider area of the virtual environment scene than the non co-located panels. Green and Bavelier (2003) have reported that computer video-game players are attentive to peripheral details that impair their ability to focus on one object a time. Therefore, it might be expected that explorers with co-located panels were switching their attention between co-located panels and their surrounding scene. It seems to be that the combination of proactive explores and co-located panels helped learners to establish a spatial relationship between information and objects and scenes. This relationship was also observed on non interactive learners with co-located information, who score higher in the safety knowledge test than non interactive learners with non co-located information. This result

suggests that spatially coupled information in a DVE provide spatial cues that are beneficial for learning and retention of declarative knowledge.

Spatial knowledge acquisition

In order to investigate the relationship between spatial knowledge acquisition and learning from co-located information, learners' spatial knowledge was measured in terms of spatial and object location memory. While the spatial memory task tested recall of the spatial layout of the virtual laboratory, the object location memory task required the recall of the correct position of objects in the virtual laboratory. A spatial memory score was computed for each participant by counting the number of objects drawn and their correct position on the sketch of the laboratory. One point was given per object sketched and one per correct position. The maximum possible score was 31 points. An object location memory score was calculated for each participant by counting the number of objects correctly located on the map of the VE. The maximum possible score was 17 points.

Spatial memory

Interactive learners with co-located information (I+CL) showed the greater acquisition of spatial knowledge and retain more than the other groups of learners (see Figure 4). Although the difference between-groups conditions was not significant for recalling the spatial layout of the virtual laboratory one week later, the results demonstrated an advantage for I+CL group over the other groups for immediately spatial memory. An independent-samples t-test was conducted to evaluate the advantage of I+CL group over the other conditions at post performance. The tests were significant for I+CL versus I+NCL ($t(22) = 2.98$, $p = 0.003$), I+CL versus NI+CL ($t(22) = 1.93$, $p = 0.03$); and I+CL versus NI+NCL ($t(22) = 2.45$, $p=0.01$). This advantage was retained through to retention-test but incubation effects in the other groups made their performance more similar by this time (see Figure 4).

The results confirm the assumption that active exploration supports better the acquisition of spatial knowledge than passive exploration. The results were consistent with findings by Brooks et al. (1999), whose research suggests that when navigation and object interaction is directly involved in the learner activity, this contribute to a great extent to memory enhancements.
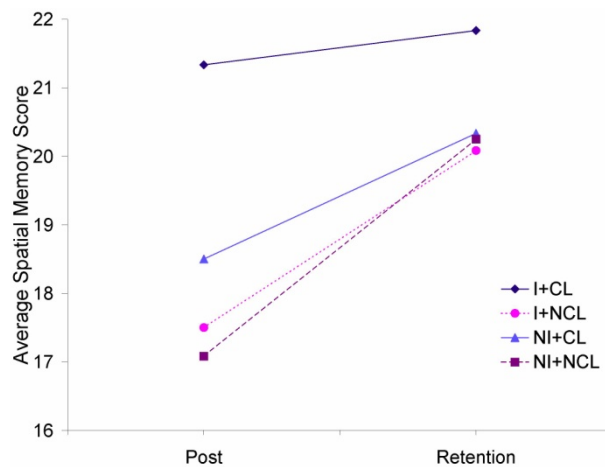

Fig. 4. Summary of average test score results of spatial memory

Object location memory

Interactive learners with co-located information (I+CL) revealed the best performance on recalling objects after training than the other groups of learners (see Figure 5) at the object location test. At post-test, the effects of I+CL were clearly superior to the other conditions. This advantage remained at retention-test a week later with a small degree of further improvement. The interactivity factor showed a significant difference in a repeated measure

ANOVA (F(1,44) = 8.28, p = 0.006) but it was insignificant for the information location factor and the interaction between these two factors. Figure 5 also shows that NI+CL group was the only condition, which showed a slight improvement at retention-test, which can be attributable to co-located information.
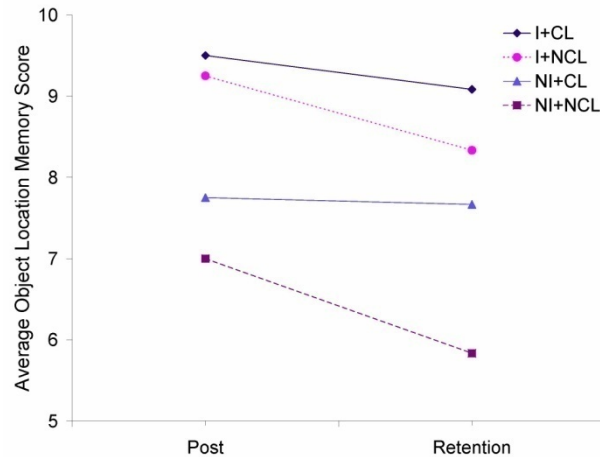

Fig. 5. Summary of average test score results of object location memory

Spatial memory and object location memory were both facilitated by the combination of interactivity and co-location of information. Active exploration and interaction with objects during the experimental tasks helped with recall of object positions in VEST-Lab. It seems that co-located information also contributed, to some extent, by providing additional perceptual cues for object location memory. The results also corroborate, to some extent, the fact that such enhancement occurs in an incidental memory test since participants did not anticipate that they would be tested on spatial knowledge.

5 Conclusions

The present study investigated the effects of information location and interactivity in a desktop virtual environment for teaching declarative knowledge in the domain of laboratory safety training. Two forms of presenting instructional messages (co-located and non co-located) and two levels of interactivity (passive and active) were compared.

The study shows that the spatial relationship between linguistic information (text and sound) and virtual reality scenes has implications for learning. Co-located information better equipped learners for retention of knowledge. However, due to the small sample size further research is needed to produce statistically robust demonstrations of the advantage of co-located information. It seems that co-located information provides perceptual clues that are subconsciously encoded by the learner. This was corroborated by the finding that learners with co-located annotations improved the acquisition of spatial knowledge better than the non co-located group, which was facilitated by a more proactive and exhaustive exploration of the virtual environment.

The study shows that levels and subtypes of interactivity also affect learning in a desktop virtual environment. At the level of active versus passive learning, the study shows that passive observation with co-located information condition allows learners better acquisition of factual declarative knowledge and made knowledge more memorable than learners in other conditions. It was identified that the additional tasks that active participants performed during learning produced cognitive load. Additional tasks included user-system interaction (interface control, navigation and object interaction) and performance issues (degree of explorative activity, vigilance for spotting safety violations, time exposed to information and time to complete the task). Cognitive load was responsible for an advantage of passive observers over active learners for acquiring declarative knowledge as passive observers had more cognitive resources available to focus on learning. Considering subtypes of interactivity, it was found that a

greater degree of exploratory activity in terms of displacements and changes of view direction facilitate recalling of information. Apparently, this subtype of interactivity encouraged learners to superficially attends instructional annotations. However, it was showed that learners with co-located information that developed a proactive exploration were benefited for learning and retention of knowledge. It can be therefore concluded that at the first level of interactivity for 'driving' in virtual environment affect learning, but sublevels of interactivity support recalling of information because the enactment of 'driving' and 'doing'. This is more beneficial when information is co-located or when the spatial nature of the virtual environment is exploited to provide linked information to scenes.

For desktop virtual environment design, the results suggest the value of presenting embedded co-located instructional messages in a contextual scenario rather apart from the virtual environment. Therefore, affording linked information to objects and scenes not only may make more explicit the learning scenario, but also could foster cognitive aids for learning and retention of knowledge.

Future research in the area could investigate the role that plays individual differences in spatial ability and other peripheral data not related to performance on learning declarative knowledge in a desktop virtual environment.

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