SPATIAL VISUALIZATION OF BUILDING COMPONENTS

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The new age of computer graphics and the Internet, and the advancement of new technologies, forces the design environment of construction to undergo rapid changes. Such changes require good IT skills and a high level of Spatial Visualization Skills (SVS) for those who are training to use CAD environments. These skills deal with the ability to visualize 2D-3D information, and are considered to be more essential than ever to ensure success in any engineering studies. According to literature, SVS can be gained over time through experience and visualization of construction processes. However, individuals who are undertaking CAD courses, with no or little knowledge of 3D concepts, often face difficulties in translating 2D concepts to 3D concepts. Therefore, it is important to promote educational tools that enhance the spatial visualization skills of CAD users. This paper describes a virtual learning environment, which provides an online interactive Virtual Reality (VR) training system, for enhancing the SVS of CAD users. Meanwhile, this system also provides a database of virtual building components for construction and built environment students when facing difficulties in learning building concepts of two-dimension drawings and three-dimension objects, using Web3D technology.

Keywords: building components, visualization.

INTRODUCTION

The true impact of information revolution has lead the major alternation of engineering design environment, from the use of personal computers to Computer Aided Design (CAD), followed by the widespread use of the Internet. All these changes impel people to possess higher skills than ever before to deal with increasingly diversified multiple information. This information includes audio, visual (images, video and animations) in addition to the conventional textual documents. In engineering design environment, the major information of the traditional visual graphic design has been shifted from two-dimension drawings to three-dimension digital models. To cope with the enormous visual information, high graphic processing skills are required, particularly for 3D information, which require spatial information processing skills, know as ‘spatial abilities’. Spatial abilities, as the essential component of success in many disciplines, have become increasingly important within the IT revolution, particularly within the engineering design domain (Ursyn, 1997; Coleman and Gotch, 1998; Mohler, 2001; Strong and Smith, 2001). Traditionally, spatial visualization has been an established element of engineering graphics and design (Miller, 1996) and is integral for success in graphics and engineering as a whole (Sorby and Baartmans, 1996; McGee, 1979). Visualization skills have been found even more important than verbal or intelligence test scores in these areas (Strong and Smith, 2001). Bertoline and his co-workers (1995), for

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example, suggest that visualization ability is central to design, and that imagery provides a bridge between design ideas and their representation in sketching and drawing. Therefore, how to improve students' spatial abilities used to be a major issue coming across most of the engineering design courses. The typical example is the emergence of Descriptive Geometry (DG) course. However, with the advent of new IT and CAD tools, individuals' mental works are replaced by, computer automatic generator. People become gradually devoted little or no time in the advancement of spatial ability. Bertoline (1987) notes that students are frequently given little or no formal instruction in the use and development of spatial abilities. More recently, Mathewson (1999) also comments that educators commonly neglect teaching visual-spatial thinking. An examination of most paper-based materials reveals that they do little to foster developmental growth of spatial abilities. Will the spatial ability never be so important? In the past, the engineering graphic course emphasized on how to produce complex drawing, even now on general CAD course, the student are taught how to draw a parallel line to another, how to draw a tangent line to an arc, and so on. With the advent of full three-dimensional modelling system in emerging CAD packages, the students now are asked to be able to create 3D models and switch mentally between two-dimension and three-dimension design. The ability to visualize in three-dimensions is now of increased importance in new design environment. In addition, in order for the students to effectively interact with computer models, they will require well-developed spatial visualization skills. It is also widely acknowledged that there are individual differences between differentiate students, especially the gender differences. Many researchers indicate that there are certain amounts of freshman engineering students who have demonstrated weakness in their ability to visualize (Sorby and Baartmans, 1998; Sorby and Gorska, 1998). Also, Sorby and Gorska (1998) found that the students experienced a great deal of difficulty in mentally switching gears between the engineering graphics and the computer modelling components of the CAD course. Therefore, how to develop the comprehensive spatial visualization skills and release the frustrations experienced students with poor visualization skills, becomes the major issue placed in front of us. The rest of this paper describes ways of developing these skills proposed by literature, and describes the approach adopted to aid CAD individuals with the development of these skills.

THE DEVELOPMENT SPATIAL VISUALIZATION SKILLS

Developing a particular skill, can be summarized as a learning process in which people gain knowledge or skills by studying, either from experience, or from being taught. According to the Information Process Theory (IPT) of learning (Hilgard and Bower, 1975), in the learning process, the student are actively processing, storing, and retrieving the information, while the teaching involves helping learners to develop information processing skills and applying them systematically to master the curriculum. The highly recommendation from IPT is providing multiple meaningful information for learning while learners possess different skills for dealing with such information. Meanwhile, the IPT provides an explanation for how visual information, especially the spatial information is processed in general learning. The dual-coding model (Paivio, 1986) suggests that spatial information is mentally processed by the nonverbal system, which is responsible for handling the concrete information. The nonverbal representations are activated based on a combination of environmental variables and individual difference variables. The target stimuli of environmental variables in particular task are those that are presented for processing, such as items to be remembered, compared, comprehended, or mentally manipulated in some way (Paivio, 1986). Paivio (1986) describes that the development of nonverbal representations and skills involves the formation of an indefinitely large (and expanding) set of representational variants, or tokens, all of which are complex, integrated structures that incorporate information from different modalities in varying degrees. The dual-coding model also emphasizes the effect of experience with exemplars on the formation of representations to perceptual concepts. Guay and Mcdaniel (1979); Pearson and Ferguson (1989) also discovered that environment factors influence the development of representational systems. For this reason, the linking of the visual stimuli to the formation of representations, and to perceptual concepts, which can be achieved by developing spatial cognition and gaining spatial experience, is considered as an effective manner for improving the learning process in developing spatial visualization skills. Historically, regarding the importance of three-dimensional geometry and projection methods in teaching, the International Commission on Mathematical Instruction (ICMI) called for an international study concerning "Perspectives on the Teaching of Geometry for the 21st Century" (1994). In this paper, relevant aspects of geometry instruction for the future are based on the premise that geometry is the science of space and as such is a method for visual representation of concepts and processes. In this context, the Descriptive Geometry course is designed to enhance spatial visualization skills and to serve as the foundation for a visual education. It mainly focuses on the representation of spatial objects, the projection methods used to produce images of these spatial objects, and the interpretation of the resulting images (cited in Strong and Smith, 2001). It has been proved that DG instruction is effective in developing spatial visualization skills (Gittler, 1994; cited by Leopold and Muller, 1998). With the advent of new technology in IT, numerous methods in an attempt to teach and further spatial abilities of engineering students emerged, each with varying level of success. These methods endeavour to alter the traditional way of spatial visualization training, such as paper and pencil (Dejong, 1977; Newlin, 1979) and real models (Wiley, 1989; Wiley, 1990; Miller, 1992a), to 2D CAD (Mack,1995; Mack, 1994), 3D CAD (Devon *et al.*, 1994; Braukmann and Pedras, 1993; Miller, 1992b; Leach, 1992; Vanderwall, 1981), 3D animation (McCuistion, 1990; Weibe, 1993), computer games (Dorval and Pepin, 1986) and VRML (Leopold and Muller, 1998). However, the advent of up-to-date computer technologies, such as simulation, animation and virtual reality, continuously change the way of these efforts. Meanwhile, the integration of virtual reality technology into existing CAD/CAM environments has just begun (Steffan, 2000). So does one need a certain level of spatial visualization ability to effectively use these technologies? By using the previously mentioned technologies, can spatial visualization be significantly improved? If in fact improvements are significant, are they significantly different from traditional methods for improving spatial visualization? This paper adds a new effort on improving spatial visualization skills by using online virtual reality technology to present a virtual learning environment for construction CAD training.

SYSTEM ARCHITECTURE

With the development of new IT tools, the traditional GD course for improving spatial visualization skills does not ever fulfil the requirement of up-to-date learning environment. People now are expecting a rich media, interactions, flexibilities, and distance learning environment, base on that the necessary motivation is stimulated for students to build up their own knowledge on learning engineering design course.

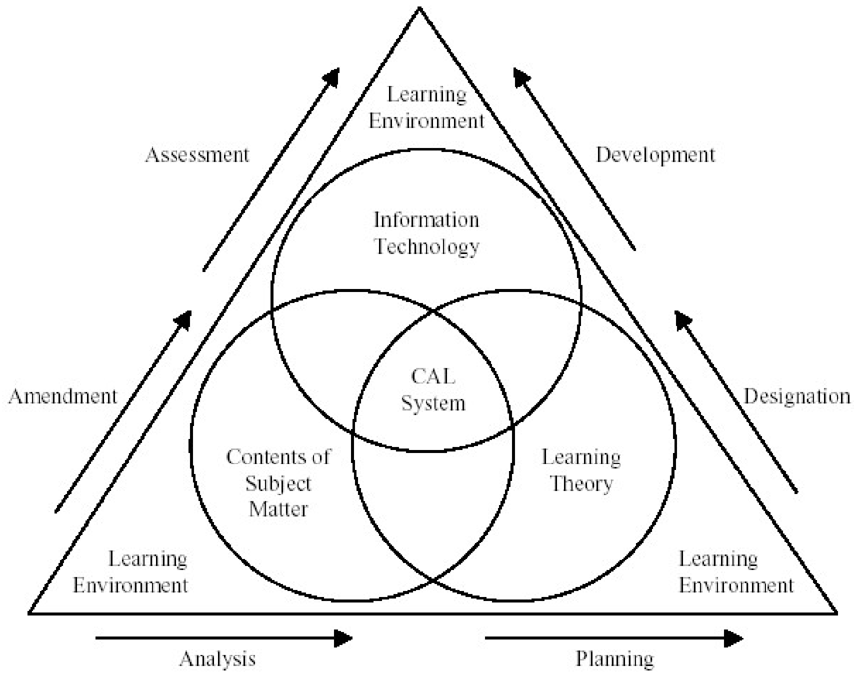

Figure 1: Architecture of the CAL system with interactive multimedia

Therefore, it brings this virtual learning system with Web3D application into consideration. According to Tai *et al.* (1998); Tai *et al.*'s (2001) Computer Assisted Learning (CAL) design theory, four components are necessary for building the CAL system with interactive multimedia – the learning theory foundation, the information technology, the contents of subject of matter and the learning environment. In addition, there are six stages of the Life Cycle Approach are utilized to develop the CAL system by means of iterating feedback and amendments, which includes analysis, planning, designation, development, assessment and amendment. The architecture of the CAL system with interactive multimedia is illustrated in Figure 1.

Based on the proposed construction model, a virtual learning environment for improving spatial visualization skills has been designed. The following section, describes the methodology adopted to develop this system.

METHODOLOGY

Web3D technology

As many innovative technologies, Web3D came along with its initial parent – Virtual Reality. Web3D's original incarnation began in 1994 with the development of Virtual Reality Modelling Language (VRML) through the efforts of the community of Internet developers and Silicon Graphics. In general term, Web3D applications can provide basic interactive, real-time 3D animation as well as virtual objects that can be manipulated and spaces that can be navigated. It is now proven that interacting with a 3D informational environment as we do with the physical world is immensely effective at facilitating perception and learning. Because of this, it is reasonable to expect that interactive 3D will eventually be used everywhere. This technology is incorporated in the development of the 3D Spatial Visualization environment, to enhance the SVS of CAD users.

Web3D technology for developing spatial visualization skills

The characteristic three-dimension design environment in 3D modelling CAD training requires high spatial visualization and orientation abilities to interact with. However, as Mohler (1997) indicated, engaging a student, weak in visualization, with a 3-D modelling environment only magnifies the student's visualization weakness. Also the phenomenon he found within his research is that the students have significant problems in dealing with static 3-D environments, because they are generally used to dealing with "dynamic" environments in their daily lives. The computer simulation of dynamic world - the technology of virtual reality, can easily release these frustrations. Virtual reality technology makes it possible to present real sense of space, motion, time and spatial relationship. For developing the spatial visualization skills, as mentioned previously, it needs to help students to establish the links between visual stimuli, formation of representations and perceptual concept. The general method is the presentation of concrete physical models to give students an intuitive sense. With new development of virtual reality technology, the virtual model generated by computers can be the ultimate alterations for the real model, in which computer also can provide intensive interaction, animation, virtual manipulation and exploration. Besides, the new generation of Web3D technology not only inherits the VRML's distinct advantages of flexible accessibility, adaptability of virtual model, dynamic simulation and basic interaction, but also does integrate more new functions for presenting high quality realistic models, rich interactions between inside and outside of VR system, more flexibilities for programming and multimedia applications, such as animated material, audio, Flash applications and so on. For all the reasons listed above, Web3D is naturally considered to be a technology used in creating a new instruction system to the improvement of spatial visualization.

The Virtual Learning Environment for Improving SVS

The content of this system includes the features of Mental Rotation Task (MRT), Mental Cutting Task (MCT), Paper Folding Task (PFT) and Virtual Building Components (VBC). The information technology in this system is considered to include Web3D, HTML and Macromedia Flash. The instructional strategy based on learning theory integrates the problem based learning, interactive discovery learning, experiential learning and cognitive flexibility theory. In MRT, MCT and PFT of system, the learners are placed in an environment with the generic challenge of mental rotation, mental cutting and paper folding task. Meanwhile the system provides the virtual models relating the task, which learner can dynamically manipulate on the scene. This design offers the opportunity for learner to experience the intuitive sense of test object, at the same time, reinforce visual representations of mind for the task. Within the task, the wrong answers will react as letting learner re-try the task until the right answer which will lead to the simulated actions of object rotation, cutting and paper folding in animation. These animations will produce the intuitive sense for learner of what should be thought in their mind, and then guide learner to develop their own spatial thinking. By means of playing animations in different views of objects, it also helps the learner to reinforce the construction of knowledge within the cognitive process. The basic interfaces of MRT, MCT and PFT in this system are shown in Figure 2. The Virtual Learning Environment is also designed to have a VBC section for presenting **Virtual Building Components**, by which, the learner can improve their spatial visualization skills as well as understand the basic concept of building components. In this section, every individual building component is prepared in both 2-D drawing and 3-D realistic model. The 2-D drawings and 3-D model are

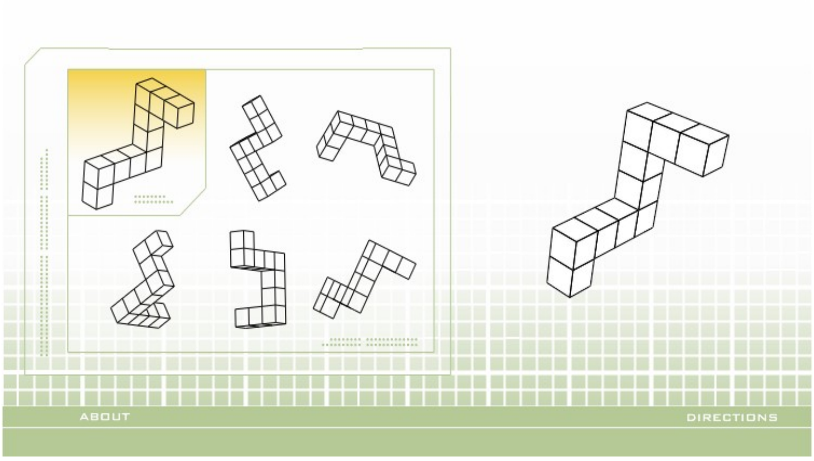

Figure2a: Mental Rotation Task

Figure 2b: Mental Cutting Task

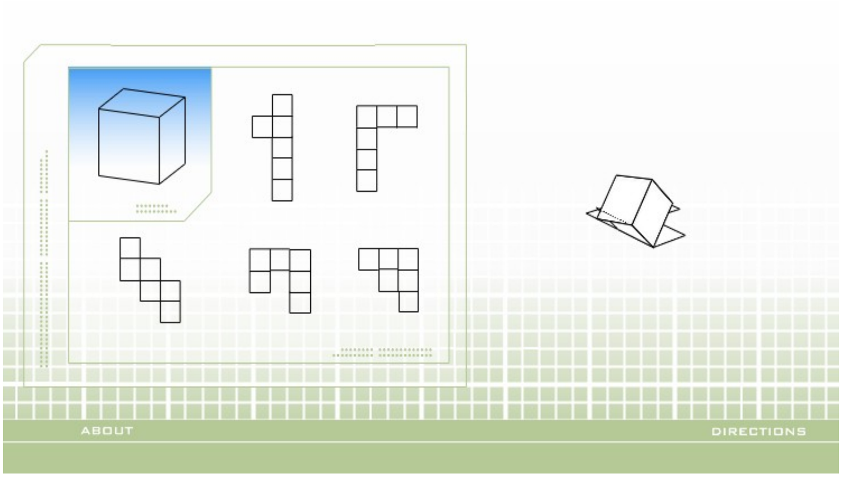

Figure 2c: Paper Folding task

dynamically linked. Once the learner clicks the 2-D drawing, it will trigger the action for presenting the 3-D model linked with this 2-D drawing. Also this action can be dual-direction, which helps to establish the perception of 2-D to 3-D and 3-D to 2-D. Besides, learner can manipulate the virtual model through any provided interactive tools, thereby, develop their spatial visualization skills. The other function of the system is to facilitate the understanding of the concept of building components. Through moving, rotating, zooming and triggering the assembling animations, the

Figure 3: Showing the interface for the virtual building components

learner can construct their own knowledge based on the interacting with virtual building components' structure, scale, material and dimension. The Web3D technology makes it possible to present the virtual model that endows with the comprehensive sense of real world object. As the result, the experience gained in this system can be further reflected in real environment. The spatial experience gained in this training through a standard manipulation manner used in most of 3D modelling system, also can easily transfer into any computer based 3D modelling system and help to release the frustrations while they first touch with these kinds of interface.

There are also some distinct advantages of this system:

- The Internet WWW based system allows the learner can access in any time, at any place.
- The unique interface of virtual reality in this system with realistic virtual presentations of the model promotes the motivation of learner to improve their spatial visualization skills.
- The parameterized virtual models with rich human-machine interactions offer more effective representations of real physical models.
- The new technology of Web3D, which integrates HTML, 3D models, 2D drawings, Flash and XML, provides great flexibility to systematize, modify, and maintain the system with entire transparent codes. See table 3

This system is to undergo further developments in the near future, based on the content the content of delivery and the teaching strategies. The system will then be tested on the Internet for its compatibility on different on platforms. Ultimately, assessment, validation and evaluation will be taken in the final stage. Combined with designed spatial ability test package, pre-test and post-test will be taken within the introduction of the instruction system for analysing the effectiveness. The main target of this test will be focused on freshman construction engineering students while undertaking their CAD course. The final results will be carried out for publications.

CONCLUSIONS

There are important learning barriers faced by engineering and built environment students to study graphic design courses, including CAD training. There is an emerging body of research, which suggests that students find it difficult to comprehend and visualize 3D abstract concepts, related to buildings, structures, furniture, spaces and products. It has been commonly acknowledged that students' capability of mental translation from 2D image to 3D model is linked to multiple aspects and that there are significant dissimilarities in term of spatial ability between various students. In addition, it has been established that existing tutorials and learning materials are not well suited to assist students in developing their spatial ability. It is increasingly acknowledged that there is a need for a new approach, which fosters CAD students' spatial visualization skills. The proposed innovative approach to virtual CAD training in construction has distinct characteristics. It is primarily concerned with enabling students to understand and visualize the 3D building components. It is the contention of this study that a thorough understanding of students' characteristics, learning styles and abilities combined with the exploitation of advances in Virtual Reality technology, especially online Virtual Reality applications, has the potential to offer an effective instruction tool for improving CAD students' spatial visualization skills. Although the virtual model presented by Web3D could not completely replace the sense of real models, but as an alteration of real models, the virtual models can be the addition resources using in spatial visualization education.

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