# The learning of CAD for construction: technical abilities or visual ?

Vian Ahmed[1], Lamine Mahdjoubi[2],
Xian Feng[3] and Matthew Leach[4]

ABSTRACT | The increasing demands of the construction industry for individuals with good IT skills add continuous pressures on higher education to improve their methods of teaching. CAD training, as an important part of IT training for construction students, is becoming an essential part of the curriculum in most built environment schools.

However, general CAD training is mostly concerned with providing students with technical skills rather than the initial ability of spatial visualisation. Indeed, existing training methods of CAD applications, do not take into consideration students' learning styles, and the differences in their spatial visualisation abilities. Considering that CAD students need to perform various activities within CAD applications to develop an understanding of building concepts and components, their spatial visualisation abilities and their learning style, remain the main barriers.

This paper identifies the learning strategies required to assist with the learning of 3D modelling and describes a new approach adopted to examine students' Special Visualisation Skills. The paper also describes innovative e-learning approaches developed to reinforce students' learning of 3D CAD, tracking their progress and highlighting qualitative measures of their effectiveness.

KEYWORDS | 3D modelling, e-learning in construction, CAL, CAA

## 1 Introduction and background

IT training is an integral part of construction higher education, which is now demanding effective teaching and learning methods to develop student's related skills. For most construction students, the predominant experience of IT training is in CAD applications. The use of which helps to develop general computer skills that are increasingly vital in their professional practice. Therefore, providing effective CAD training places challenges on most construction schools in the UK. These challenges do not only depend on the methods of delivering IT training, they also rely on students' learning styles and their spatial visualisationskills, which define the way their learning is shaped. Consequently, for effective learning, individuals'

1. School of Construction Property Management, Salford University, Manchester, M5 4WT , UK
2. Faculty of the Built Environment, University of West of England, Bristol, BS16 1QY, UK
3,4. School of Engineering the Built Environment, University of Wolverhampton, WV1 1SB, UK

multiple intelligences and related learning styles should be taken into consideration.

Spatial intelligence and spatial abilities are considered critical factors in graphical learning and their subset. Spatial visualisation ability is deemed to be an essential skill for both construction and CAD learning [1]. Therefore, it is through enhancing the spatial visualisation skills, that individuals can improve their communicating when planning, designing and implementing CAD techniques. However, recognising the lack of these skills is a problem, which is often confused with the effectiveness of the methods of delivery. It is therefore important to develop an understanding of the process of learning, individuals' learning styles and spatial visualisation abilities, and the influence of these factors on an individuals way of thinking.

## The Concept of Learning

Theorists disagree in their definition of learning. Most accept that it is a relatively permanent change in a person brought about by their interaction with their environment [2 & 3]. It is therefore important to distinguish between learning, which occurs continuously and unconsciously, and learning for improvement, which must be consciously sought and directed. The latter is the type of learning addressed in this paper.

According to the behavioural theory, a major factor affecting learning is a subject's motivation. The motivation can be seen as learners' expected benefits, such as increased knowledge or improved skill [4]. Since students will have made a conscious choice to attend university, it will be assumed that this motivation is already in existence and '*learning for improvement'* starts taking place. All that is required is to confirm the belief that improvement is taking place, to re-enforce this motivation. However, to improve the learning process of 3D CAD, it is important to develop an understanding of students' learning styles and the concepts of spatial visualisation skills.

## Learning Styles

Literature reflects the numerous attempts to classify the basic ways in which learning styles differ, each using different terms to address these styles [2, 5, 6]. However, theorists agree that an individual's style significantly affects the manner in which information is habitually processed during learning and thinking, and that this can have a significant effect on the efficiency and effectiveness of learning. However, one of the main concerns in this paper is that these theories have not translated into practice, and that, in designing and delivering educational methods, there is often the assumption that all individuals learn in a similar manner. This approach ignores the important issue of differences in learning style. According to [6] of the experiential school of thoughts, 'in any learning there is a conflict or tension between the polarities of at least two dimensions. The first of these dimensions has the concrete here-and-now experience at one pole, and abstract conceptualisation at the other (feeling versus thinking). The second dimension has practical action and experimentation at one pole and detached reflective observation at the other (doing versus watching)'. Learning by doing is the mode of learning employed when learning 2D and 3D CAD concepts.

Cognitive theorists however, address learning styles as an indication of how people differ in ways of translating information received. For example [5], diagnosed two independent dimensions of cognitive styles. The Wholist-Analytic dimension and Verbal-imagery dimension. A person's position on one dimension of learning does not affect their position on the other. However the way they behave, results from the joint influence of both dimensions, indicating how people differ in two basic ways. Figure 1, illustrates Riding's diagnoses of the cognitive dimensions for learning.

*The Wholist-Analytic dimension*, determines whether individuals take a whole view of things or see things in parts. This dimension, affects the way in which people think about, view and respond to information

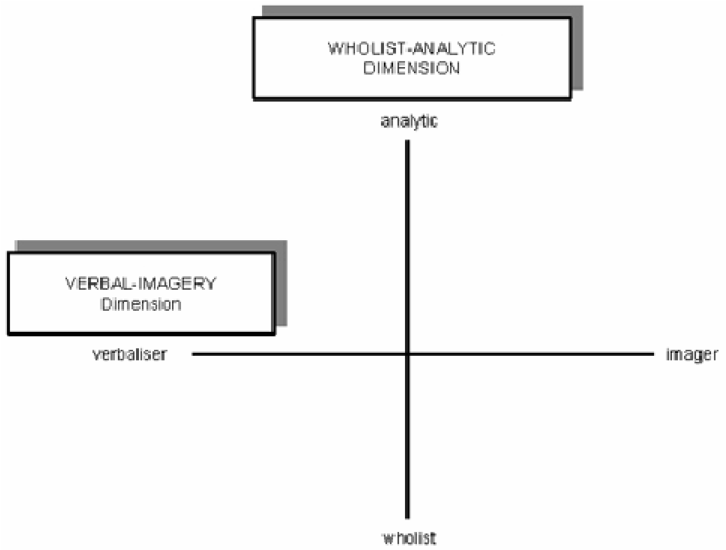


**Figure 1.** Riding's Learning Style Diagnostics (Riding, 1996)

and situations. The strength of the Wholist is that when considering information or situations they see the whole 'picture' and can see situations in their overall context. This will make it less likely that they will have extreme views or attitudes. The negative aspect of the style is that they find difficulty in separating out a situation into its parts. By contrast, Analytics will see a situation as a collection of parts and will often focus on one or two aspects of the situation at a time to the exclusion of the others. Their positive ability is that they analyse a situation into the parts, and this allows them to come more quickly to the heart of any problem. They are good at seeing similarities and detecting difficulties. However, their negative aspect is that they may not be able to get a balanced view of the whole, and their exclusion of the others may bias a situation out of its proper proportion. Intermediates are likely to be between the two. They are able to have a view between the extremes which should allow some of the advantages of both, Wholists and Analytics. Figure 2a illustrates how the information might be perceived by this dimension.

*The Verbal-imagery dimension*, determines whether individuals are outgoing and verbal, or more inward and often think in mental pictures or images. **The Verbal-Imagery Dimension** has two fundamental effects that have implications for behaviour, job performance, and relationships; the way information is represented, and the external/internal focus of attention. Figure 2b shows how information is perceived by this dimension.

As far as the learning of 3D concepts is concerned, it is important that individuals generate visual and imagery representations of these concepts, and that these concepts are seen to be a critical strategy for the learning of 3D CAD modelling.

Therefore it is important that, individuals who are involved in the learning of CAD modelling, develop their Wholist and Analytic cognitive styles. This however, cannot be separated from the development of their Spatial Visualisation abilities.

### Spatial Visualisations Skills

This is defined as the ability to mentally manipulate, rotate, twist or invert pictorially presented objects [7]. The importance of Spatial Visualisation Abilities are

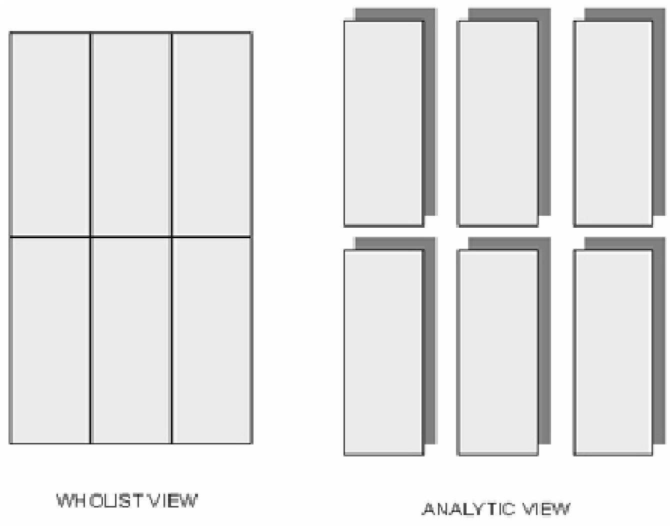


**Figure 2a.** Riding's Wholist-Analytic view

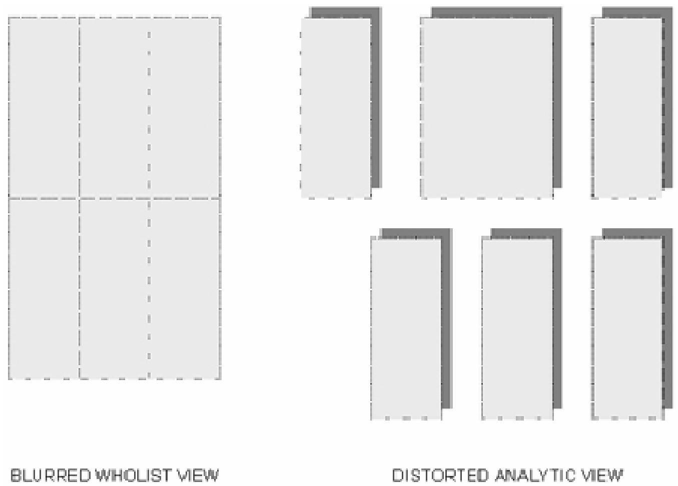


**Figure 2b.** Riding's Verbal-Imagery view

not only restricted within construction but also noted by related researchers in a variety of teaching and learning domains [8, 9, 10]. In construction education, students undertaking CAD training require the ability to mentally visualise the building components involving 2D and 3D representation, and ultimately rely on their ability to work with the spatial factor of building concepts. The multi-faceted spatial ability of students will then help to conceptualise links between the precise building and the abstract model of the building.

Theoretically, the visual-spatial barrier can be removed by enhancing individual's spatial visualisation skills and their imagery learning style, via proper instructions. The rest of this paper describes an approach adopted to identify students' Spatial Visualisation Abilities. It also seeks to examine whether students abilities are influenced by their background (gender and level of study). Based on these findings, the paper also proposes innovative approaches used within the teaching of 3D CAD modelling that aim at improving students' Wholist-Analytic Imagery styles and enhance their Spatial Visualisation Abilities. Qualitative and quantitative measures of the effectives of these tools are also produced.

## 2 Methodology

To develop an innovative e-learning environment that will reinforce students' learning of 3D CAD and track their performance and progress, the following approach was adopted:

– A 'Spatial Visualisation Instrument' was designed to identify students' spatial visualisation abilities.
– An innovative e-learning environment was developed to provide students with an effective and independent approach to learning.
– On-line Computer Aided Assessment exercises were developed for formative assessment, to identify gaps in the learning process and reinforce learning.

The implementation of the above approach is intended to students enter a cycle of self-directed study and assessment after each lecture, until the required level of competency is reached, as shown in Figure 3. In the first phase, students are expected to follow the demonstrations of building a model given by the instructors in the computer laboratory, followed by self learning exercises distributed via tutorial sheets. The students are then expected to reinforce their learning, by following the instructions demonstrated via the visual demonstration and experiment with developing the demonstrated models themselves. Follow their understanding of the steps given in the visual demonstrations, students can then take the assessment. After successive cycles, the questions will become familiar, but this is deliberate since they reflect the required knowledge. In this way, the integrated components are geared to transform students' learning. Following the tutorials, and completing the assessment exercises, learning can be achieved with relatively little understanding of the underlying techniques. It is believed, that the assignments, used as part of the course, will foster deeper learning by requiring the students to formulate their own plans, adapt the knowledge to different situations, and reinforce their learning for improvement.

The rest of this paper, describe the approaches adopted for the teaching of 3D CAD in more details.

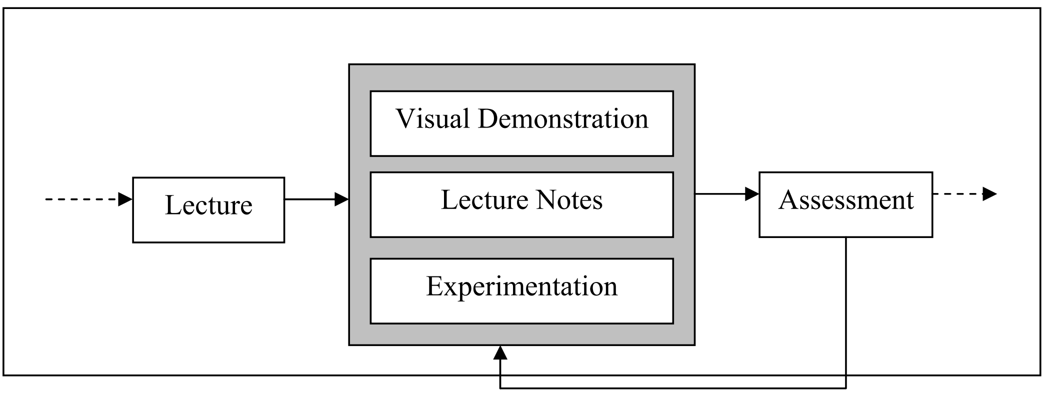


**Figure 3.** A simple model demonstrating the various components linked together, in a one-week block, to aid the teaching of 3D modelling visual concepts and techniques

## The Spatial Visualisation Instrument

A Spatial Visualisation Assessment Instrument (SVAI) was designed to assess students' Spatial Visualisation Abilities. The development of this instrument was inspired by the work of [7], who produced a web-based tool that aimed at improving people's spatial intelligence skills. The different levels of spatial intelligence skills in Anon's method was adopted and reproduced by embedding an automatic marking system. The SVAI consists of 25 questions, which are categorised into five parts that relate to the corresponding factors of spatial visualisation skills. Part A is the spatial factor of Image holding and comparing – which is closely associated with Part B: the Planar Rotation as the most basic of the operations in human's spatial brain – the abilities to imagine and manipulate the abstract object mentally. Part C is the spatial factor of orientation. This is to test the essential ability of imagining an object in 2D or 3D as viewed from various directions. Part D is the test of Kinetic Imagery which relates to the ability of manipulating or rotating an object in imagination – imaging it as it changes position in space moving in any axis. Part E examines the spatial ability of mentally modifying or re-assembling elements within a 3D component. All these five parts of the test assist in measuring and identifying individuals' spatial visualisation skills.

The questions progress from the easiest to the most difficulty. Each question is given in the form of an illustrated test object, and another five corresponding objects for the answer. Students are expected to select the answer object which matches the test object (Figure 4).

## The Data File

The results from the test are programmed to be automatically collected and transferred from the web-based interface to the database, which is set up on a server. The database is designed in Microsoft Access, allowing for each entry to be assigned to the student number and their personal details. The personal detail

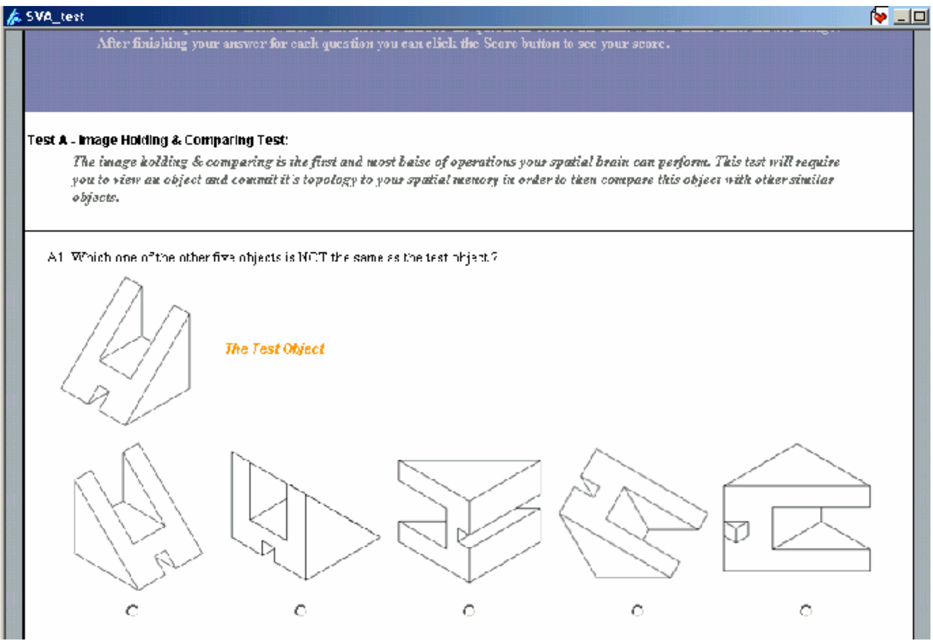


**Figure 4.** Spatial Visualisation Assessment Instrument

include students' name, course of study, level of study and gender. The results are automatically presented (at the end of the test) as a percentage, and are divided by section to reflect the different spatial visualisation skills within the categories identified in the test.

### Sample Survey

An initial sample of 32 undergraduate 'CAD and construction' students from the school of Engineering and the Built Environment, at University of Wolverhampton attempted the Spatial Visualisation Skills assessment, but only 21 responses were valid. Among the 21 subjects, 7 were females and 14 were male. Also 10 were level one students, 8 were level two students, and the remainder were level three students. Although, this sample size is not statistically robust, it does, however, provide some indication of students' performance.

### Survey Results

- An error frequency analysis was conducted to identify difficulties faced by the students at different stages of the test. The results showed that students faced common difficulties with parts D and E of the test. These parts required high level of spatial visualisation skills.
- Students' Spatial Visualisation Skills in relation to their level of study were analysed. An average score of the students' performance was obtained for each level of study indicating that, students in Level 2 and Level 3 obtained a considerably higher score when compared with Level 1 students. Figure 5a shows a graphical representation of these results.
- Students' performance were also analysed in relation their gender. The results show that male students have better Spatial Visualisation Skills than female students in each part of the test. Female scores were particularly low in parts D and E of the test (Figure 5b).

In summary the preliminary analysis of these results, suggest serious gaps in students' spatial learning skills. This is a contributing factor to students' lack of ability to learn CAD tools. Unfortunately, this is often

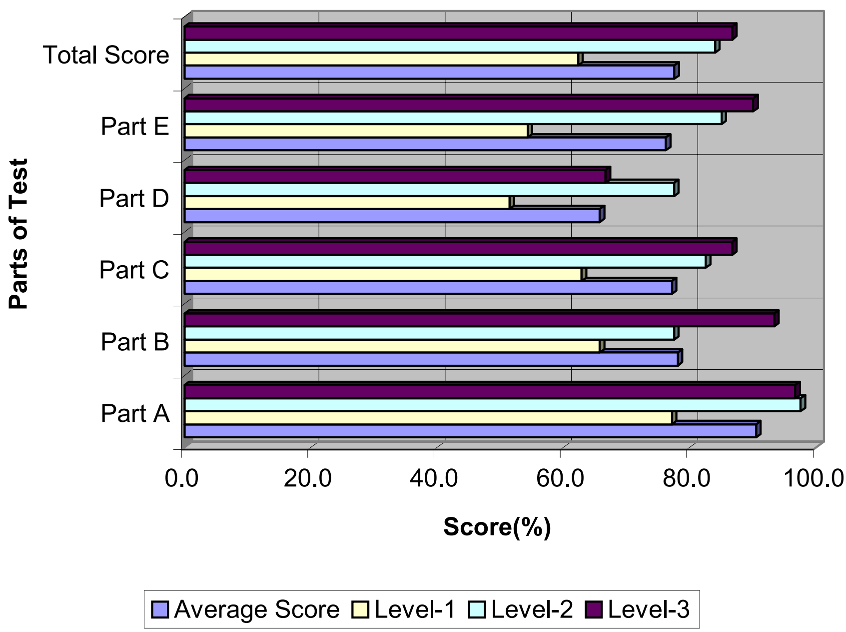


**Figure 5a:** The Average Scores of Students at Different Level of Study

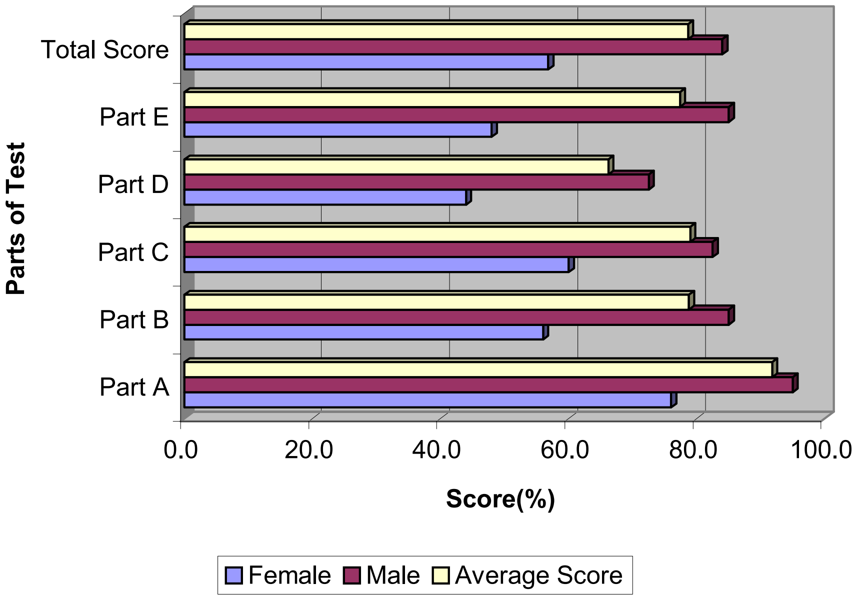


**Figure 5b:** Students' performance according to their gender

related to the traditional methods of delivery of CAD education. It is often difficult for educators to strike a balance between overcoming technical issues in the teaching of CAD skills and addressing cognitive issues relating to the imagery styles and the spatial visualisation skills. Accordingly, a new approach has been adopted to aid CAD learners in coping with both of these issues.

The spatial visualisation skills test mentioned earlier in the paper, indicated that students at level one have the poorest spatial visualisation ability. This justifies their need for innovative modes of delivery that motivate their learning and aid their progress in an open and flexible environment. The rest of this paper reports on a 'computer aided learning visual simulation' developed to aid the learning process of 3D CAD software, with particular attention to the spatial visualisation details required for the learning of 3D modelling. Multimedia Computer Aided Assessment tools used for testing students' knowledge of 3D concepts are also described.

## 3 Virtual learning of Virtual Reality Modelling

Virtual Reality Modelling is initially taught at level 1 across a number of undergraduate awards that run within the Built Environment Division at the University of Wolverhampton. The traditional method of teaching Virtual Reality (VR) modelling purely depends on abstract instructions given to the students via tutorial sheets, which are downloaded from the Wolverhampton Online Learning Framework (WOLF). Tutorial sessions are then set up to helps students with difficulties faced from reading the abstract instructions. WOLF serves as the central access point, and allows students to login to a central server and access teaching materials relating to the studied modules. As it stands, WOLF has already proved to be a valuable teaching resource, but does not allow for interactive learning. However, to compliment the use of such learning resources, a number of Computer Aided Learning Tutorials were developed to assist with the learning of 3D Virtual Reality (VR) modelling using 3D Studio

Max software. The virtual learning demonstrations of VR modelling are also launched on WOLF, so they can be accessed on-line within and outside the university.

### Virtual Visual Demonstrations

The visual demonstrations were created using the Viewlet Builder software. This application allows for the production of demonstration movies that are viewed through a Flash player. The software in use, records the actions of demonstrators, as they create a 3D model using 3D Studio Max (See Figure 6). When viewed by the user, various controls are offered that affect the replay (such as pause, rewind, step-through etc). The nature of the simulations will be familiar to anyone who has experience with Microsoft PowerPoint. In essence, the software constructs a slideshow, but with the added advantages of animated visual demonstrations.

### Computer Aided Assessments

To reinforce students' learning of Virtual Reality Modelling and the use of 3D modelling software application, Computer Aided Assessment (CAA) tools were created. Although there is a number of Computer Aided Assessment software commercially available, 'Perception' software was used to develop the assessment exercises on this occasion. Perception is an on-line version of 'Question Mark', which became available in the late 1990. The use of on-line assessment exercises, gives students the flexibility and independency for learning. Perception allows for different styles of questions to be imbedded (e.g. multiple-choice questions, drag and drop questions, hot-spots and typing in keywords) and for an automatic marking systems. The assessment results are then sent to a database, to inform the educator of student's names, marks, time when the test was taken, duration of the test and the class average an standard deviation of the marks.

The CAA exercises were made available after each lecture, to be accessed by students from a central server. The results gathered after each test, were then used to identify any misconceptions or gaps in knowledge in

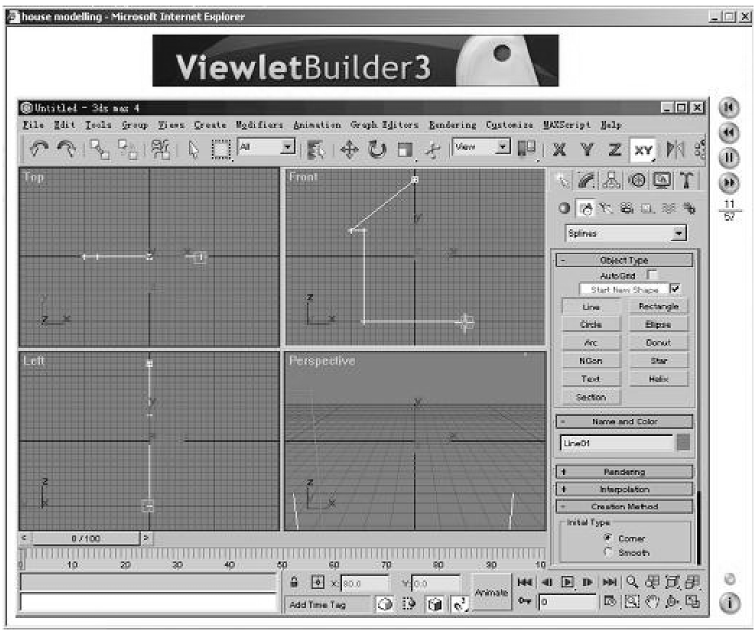


**Figure 6a.** A slide show demonstrating the initial steps for creating a 3d MODEL of a house using 3D StudioMax

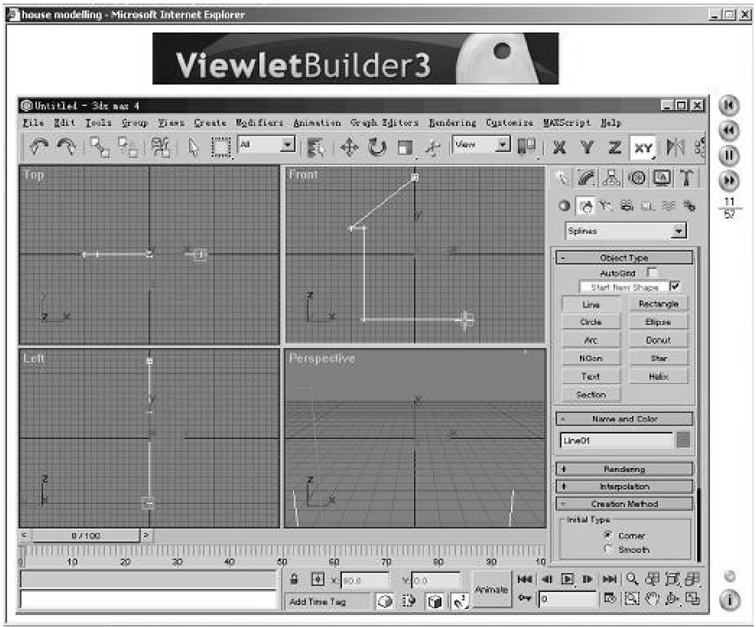


**Figure 6b.** A slide show demonstrating the final steps of the 3D model

order to gain an overview of student performance and to be revisited in future lectures. Figure 7 shows screen shots of a couple of Computer Aided Assessment exercises developed for the teaching of 3D CAD.

## 4 Results and general observations

The effectiveness of the Virtual Learning Environment described in previous sections was tested by a sample of 35 first year undergraduate students of the undergraduate degree within the CAD and construction section. This section offers a number of IT related awards, such as Interior Architectural Design, Architectural Design Technology and CAD & Construction. The selected sample consists of students from all these awards, who are required to study 'Digital modelling' as a core module and part of their requirement to fulfil their obligation towards the degree.

Although a number of Visual Simulations have been produced to demonstrate steps of building various models, a model of a house from start to finish was tested by the identified sample of students. Students' feedback was gathered via a questionnaire survey, to identify qualitative measures of the effectiveness of such tools, when compared with the traditional tutorial sessions. As a result, the followings were identified:

- 85% of the students preferred following the instructions via the Virtual Learning Environment to reading the tutorial notes. 15% of the students preferred paper based instructions.
- Students over the age of 21 (i.e., mature students) formed 38% of the sample population. 30%, who were novices with no prior knowledge of the software, felt that the VLE provided an excellent opportunity for promoting a flexible learning environment.
- 70% of the students were under the ages of 21. 57% of them felt that the VLE was an excellent tool. To

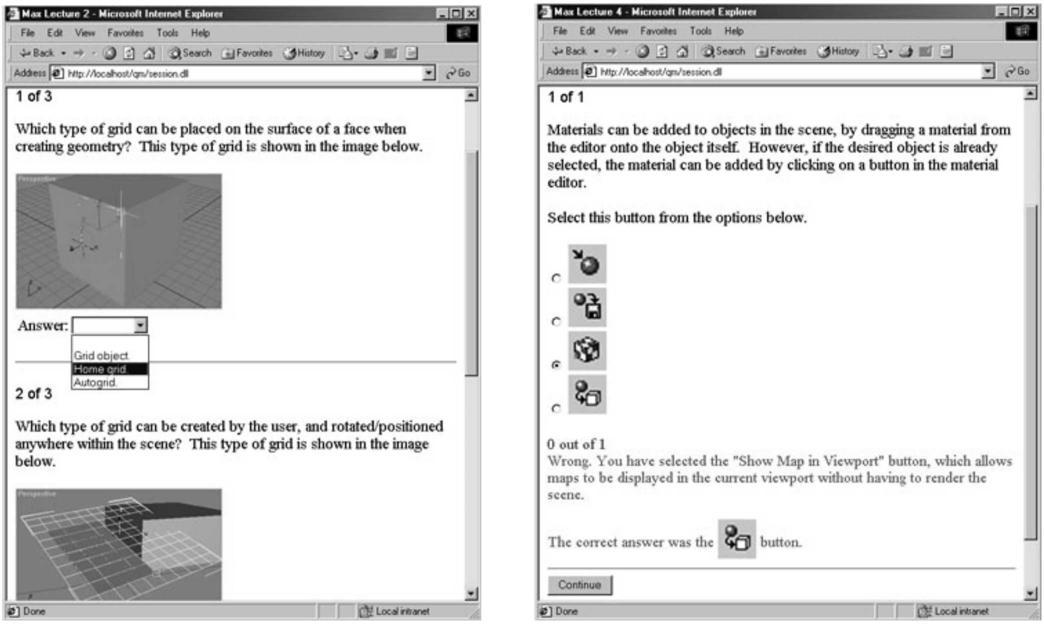


**Figure 7.** Screen shots for different styles of Computer Aided Assessment questions

the rest of the students it made no difference, since they had already had hands on experience with the software.

- When students' performance were compared in terms of time taken to progress with paper based exercises and Computer Based Instructions, it was found that students were quicker in following the instructions using the VLE than using the paper based instructions.
- The lecturer-student interaction time was deemed more effective using the VLE as students were able to pay attention to how to build the model rather than worry about interpreting the information correctly from a paper based copy.
- Students' feedback on Computer Aided Assessment tools was also very positive. 73% of the students felt that CAA was interactive and entertaining. 92% felt it added variety to their traditional learning methods. Novice students felt that CAA reinforced their learning of the 3D modelling software application.
- The number of hits to the web-site, showed that students accessed the site at weekends and evenings from outside the university, thus offering them a more flexible learning environment.

The spatial visualisation skill test mentioned earlier in the paper, indicated that students at level one have the poorest spatial visualisation ability. This justifies their need for innovative modes of delivery that motivate their learning and aid their progress in an open and flexible environment.

## 5 Summary & future work

The teaching of CAD is not an easy task. The challenges facing construction higher education to produce individuals with relevant CAD skills that can be applies in industry, are of two fold. The first are difficulties in identifying students' learning style and their spatial visualisation abilities, while the second are technical difficulties of learning CAD software. When innovative approaches were introduced to aid students' skills required for developing simple models, they provided improved guidance and open access.

As a result, students' performance in the class and their motivation to learning was noticeably increased, particularly by those who lack spatial visualisation abilities.

The Virtual Learning Demonstrations of 3D modelling proved effective in saving staff time for one–2-one interactions and allowing for an open and flexible learning environment. The embedded Computer Aided Assessment tools provided an excellent mechanism for reinforcing the learning process and tracking students' deficiency in learning. Since the establishment of this research, the whole of level 1 module has been reproduced using the VR virtual demonstrator together with CAA tools for each topic within the module.

Future research intends to bridge the gap between 2D and 3D spatial models, by developing a flexible learning environment that allows for the integration of any 2D CAD tutorial, which then links to a database of 3D objects. It is suggested that this approach will lead to an improved spatial visualisation of 3D models.

## REFERENCES

[1] Gaughran, B.: *The Graphics Code, Visualisation and CAD*. Flexible Automation and Intelligence Manufacturing Conference, Atlanta, USA. May '96.

[2] Smith, R.: *Learning how to learn: applied theory for adults*. Milton Keynes: Open University Press, 1996.

[3] Reed, E.: *The necessity of experience*. London: Yale, University Press,1996.

[4] Bigge, M.: *Learning theories for teachers*. 5th ed., New York: Harper-Collins, 1992.

[5] Riding, R.: Personal Style Awareness and Personal Development. Learning and Training Technology, Birmingham, 1996.

[6] Kolb. D.: Experiential Learning: Experience as a source of Learning and Development. New Jersey: Prentice-Hall, 1994.

[7] Anon, D.: Spatial Intelligence Home Page, http://www.ul.ie/~mearsa/9519211/, 2002.

[8] Brain, K., Jered, W. and Eric, H.: Improving Students' Spatial Visualisation Skills and Teachers' Pedagogical Content Knowledge by using On-Line Curriculum-Embedded Applets: Overview of a Research and Development Project, 2002.

[9] Charles, P. and Errol, M.: Spatial Ability, Visual Imagery and Academic Performance in Engineering Graphics. International Conference on Engineering Education. August 6–10, 2001 Oslo, Norway, (2001).

[10] Hitoshi, S., Sanae, S. and Hajime, Y.: The Use of Internet Technology for the Development of 3-D Spatial Skills. Proceedings of 2nd International Conference on Information Technology Based Higher Education and Training, Kumamoto, Japan, 2001, pp 4–6.