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Learning Computer Graphics Using Virtual Reality Technologies Based on Constructivism – Case Study of the *WebDeGrator* System

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ABSTRACT

This study applies constructivist principles and Virtual Reality (VR) technology to the Web-based Interactive Design Graphics (*WebDeGrator*) system to improve learning computer graphics. The constructivist treatment provides students with access to their choice of source content, three-dimensional (3D) modeling tools and interactive behaviors in a virtual environment. In this study, we developed a VR-based learning system to simulate and adjust computer graphics through sculpture graphic algorithms in real-time. We will discuss the relationship between constructivism and VR technology and also how the *WebDeGrator* system encourages student-learning through VR technology.

INTRODUCTION

Virtual Reality (VR) is a computer-based technology that provides the visual, aural and tactile stimuli of a virtual world generated in real time. VR-based learning systems are being used more and more as a support or alternative to traditional instructional methods. Examples of existing courseware may be found in Antchev, Luhtalahti, Multisilta, Pohjolainen, and Suomela (1995), Fox (1996), Haga and Nishino (1995), Hubler and Assad (1995), Jonassen and Mandl (1990), Marsh and Kumar (1992), Marshall, Hurley, McIntosh-Smith, Martin, and Stephens (1994) and Wolf (1995). Distance learning using the Internet has been established and developed in the Computer-Assisted

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Learning (CAL) system (Youngblut, 1998). In this paper, a VR-based system is developed for users to design and learn sculptured curves and surfaces on a personal computer in an interactive way. This graphics system has a friendly operating procession interface and is implemented based on the OpenGL functions, which are capable of showing complex two-dimensional (2D) and three-dimensional (3D) graphics. The platform for this learning system is a network browser or VR-based browser.

Constructivism (Jonassen, 1996) describes how knowledge is constructed and stands for the idea that imposing symbolic representations to enable communication requires previous meaning negotiation, leading to a compromise. VR experiences are designed for a single user fit perfectly into this theory. This is a fundamental a theory for learning in virtual environments, because the symbolic formalism is diminished. Immersion in a virtual world permits users to experience the same kind of interaction with objects as in the real world. If non-symbolic knowledge and learning are closely related to an action, then interaction with the virtual world can contribute to knowledge construction. As a result, there is a controversy about the real effects of VR on learning and cognition. Preliminary results indicate that VR can:

1. Improve learning performance: Some documented experiences note that there is a significant increase in user performance in understanding abstract problems when exploring 3D worlds with objects that represent the abstract entities (Carpenter & Anderson, 1996).
2. Facilitate usability and enhance high interaction: for the navigation and manipulation of synthetic environments (Mikroupoulos, & Nikolou, 1996).
3. Revive unreachable learning experiences (Kato, Kawanobe, Kakuta, Hosoya, & Fikuhara, 1996).
4. Stimulate high levels of involvement and give multiple perspective sensorial experiences (Dede, Salzman, & Loftin, 1996).
5. Foster learner accessibility (Lumbreras, Sánchez, & Barcia, 1996).

Recently, several famous computer companies have proposed combining 3D graphics and VR capabilities with the Internet. The designer of Virtual Reality Modeling Language (VRML) said: “because the world is not flat” (Bricken, 1991). Most media currently supported by the WWW are using 2D media; for example, text, images and 2D animation. There are only a few 3D graphics and VR media available for users on the Internet. In this paper, constructivist education technologies are used to improve the effectiveness of learning system dynamics in CAD courses. This VR-based learning system is called

Web-based Interactive Design Graphics (*WebDeGrator*). The design of a *WebDeGrator* learning system and related educational and VR technological themes are presented and discussed.

WEBDEGRATOR SYSTEM BASED ON INTERNET

The networking technology of the Internet is scalable. That is, the network's components, wiring, and protocols can connect together and provide services along with resource sharing between two computers on a local network or among millions of computers across an Internet network. In addition, Internet technology is platform independent. It works well with PC, Macintosh, and Unix computers in any combination. Because of its scalability and interoperability, Internet technology has grown to replace special-purpose, proprietary networks in many organizations. Many times, these in-house Intranets are not connected to the Internet and are used solely to carry on the private work of the organization. In many cases, in-house document sharing, file sharing and message sharing systems based on TCP/IP protocols are taking over much of the work formerly entrusted to proprietary systems. One of the main purposes of in-house Intranets and the WWW Internet is to deliver information to persons with the need to know. Intuitively, these are information processing and delivery systems, which are no different in purpose from the 'data processing' systems back in the old days. Only the technology and its associated capabilities have changed.

Websites can be located through the browser using special addresses called ***Uniform Resource Locator*** (URL) that are recognized by the http protocol. These addresses specify the website and the location of the web pages at that site. The *WebDeGrator* system is based on the Internet and integrates network

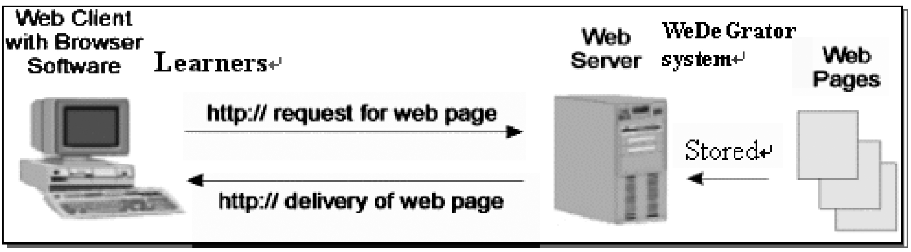

Fig. 1. Request and access to and from web pages.

CAD and VR technologies. The system program is stored in a web server. The student can use the client server to learn through the Internet (See Fig. 1).

COMPARING INTERACTIVE VIRTUAL REALITY (VR) AND MULTIMEDIA

Virtual Reality (VR) is the interaction by users with 3D models that behave like the real world. Virtual reality exploits the phenomenal visual skills of man in the fields of pattern, structure and object detection in images for the analysis of abstract data or prospective designs. The *WebDeGrator* system provides a 3D VR-based environment for the student to learn CAD courses. However, VR-based learning systems are not yet available on a large scale to support these processes in school environments, but it may be still possible to address these issues through what may termed degrees of ‘virtuality’. In examining the relationship between multimedia and VR, Hedberg and Alexander (1996) proposed that the defining attributes of VR could produce better interaction than multimedia. For this reason, the *WebDeGrator* system uses VR technology to advance the learning effect.

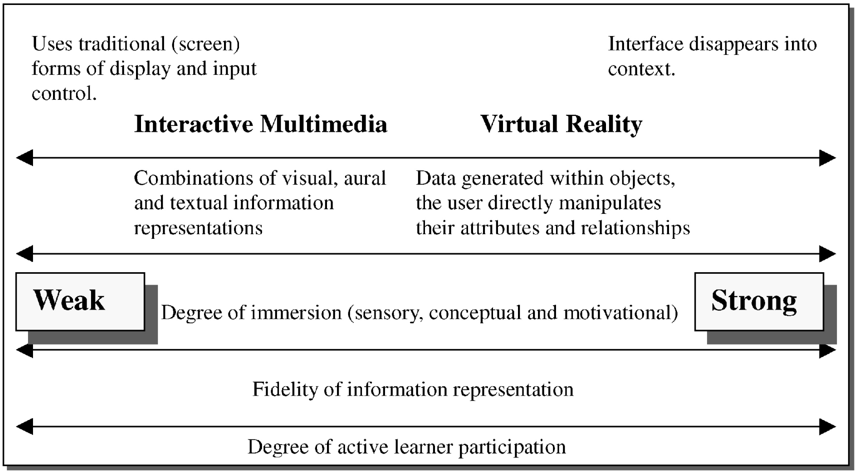

Fig. 2. Comparative from interactive VR and multimedia (Hedberg, & Alexander, 1996).

VIRTUAL REALITY (VR)-BASED LEARNING THEORIES – CONSTRUCTIVISM

This study describes the relationship between the learning theory known as constructivism and the use of 3D interactive environments as a constructivist-learning tool. Constructivism is a learning theory that describes the process of knowledge construction. Though constructivism is a learning theory, it is the application of what are often referred to as 'constructivist practices' (Zemelman, Daniels, & Hyde, 1993) in the classroom and elsewhere that provide support for the knowledge-construction process. By definition, knowledge construction is an active, rather than passive process. The process of constructing one's knowledge can involve both cognitive (Cunningham, 1988, 1993) and physical constructions (Harel & Papert, 1991) of meaning, through the development of mental models or schemas (Johnson-Laird, 1980), as well as physical or virtual representations of knowledge (Duffy & Jonassen, 1992; McLellan, 1996; Mones-Hattal & Mandes, 1995; Papert, 1993; Winn, 1993, 1994; Winn & Bricken, 1992; Winn, Hoffman, & Osberg, 1995). Duffy and Jonassen (1992) felt that today's educational technology practices should indeed be couched in the constructivist paradigm. This plays out in terms of developing systems that are situated in the real world as much as possible and are as experiential as possible. The goal is to design and present authentic learning opportunities in which individuals have the freedom and the opportunity to ground their experience in a manner appropriate to them.

Many researchers and educational practitioners believe that VR technology has provided new insights to support education. For instance, VR's capability to facilitate constructivist-learning activities is one of its key advantages. The individual engaged in learning should have the opportunity to inquire and to develop understanding from their own and others' perspectives when constructing knowledge. This position is supported by the work of Cunningham (1992), Belenky, Clinchy, Goldberger, & Tarule (1986), Noddings (1984), Norman (1993), Adams (1989) and Adams and Hamm (1988), who reported on the effectiveness of this approach for helping students learn. The concept of "learning by doing" (Bruner, 1990) is certainly not new; however, allowing the student to learn by doing within the classroom context is a departure from traditional methods, one which virtual reality enables (DeVries & Zan, 1995; Lewis, 1993). As an experiential learning tool, virtual reality is an enactive knowledge-creation environment. In this study, each environment we developed contained a combination of real-world analogs and abstract representations, providing students with an opportunity to learn and share information with others. However, the integration of VR in the classroom, whether a design process or an experiential learning tool, is still in its infancy though some research has been conducted (Byrne, 1993, 1996; Osberg, 1993a; Merickel, 1992; Rose, 1996; Winn et al., 1995). Furthermore, there is great interest in making the most of what we bring to the learning process in the use of VR (Bowers, 1988; Bowers, Weaver, & Morgan, 1992; Norman, 1993; Osberg, 1993a), instead of focusing on the flash and dazzle of the technology itself.

Constructivism has emerged in the last decade as an alternate pedagogy closely related to the advancement in educational technology. Interest in constructivism has blossomed considerably as conventional instruction and assessment techniques have been criticized for their inflexibility. There is a trend that educational scheme is turning into more flexible, open-ended, adaptive, and multi-dimensional instructional techniques as well as more qualitative, observation-based methods of evaluation. As a result, many educational technologists embrace constructivism and this is proven with the excess of multimedia and computer-based software spreading from the constructivist premises. In the course of adopting constructivism, this proposed graphics system makes an ideal foundation to comply with this new theory in terms of establishing open, informal and virtual learning environments.

CONSTRUCTIVISM LEARNING ON THE *WEBDEGRATOR*

Constructivism, according to McLellan (1996a, b), is based on the developmental stages theorized by Piaget. Learning occurs and develops through interacting with one's environment, exploring this environment and the construction of knowledge from these experiences. Such a constructivist perspective to learning has implications for the use of *WebDeGrator* as well as for the design of a CAD curriculum. In Figure 3, when a student learns each individual knowledge construct in a slightly different way, no two experiences are exactly alike. The *WebDeGrator* learning system easily adapts to this perspective, where each student (or groups of students) is provided with an interactive learning environment to construct his or her own knowledge representations. VR technologies provide a unique method for enhancing user visualization of complex 3D graphics and environments. By experience and environmental interaction, users can more readily perceive the dimensional relationships of graphics typically portrayed through static

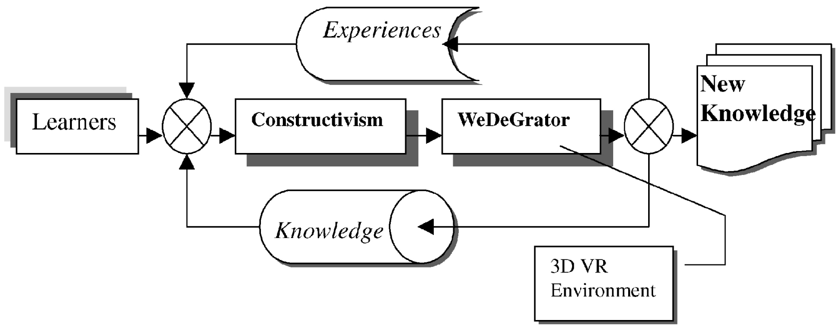

Fig. 3. The constructivist contributions to *WebDeGrator* (Sung & Ou, 2000a).

multiview or pictorial representations. Figure 3 shows that this research has already succeeded in applying the principles of constructivism and VR technology to *WebDeGrator* by integration of the knowledge and experiences in a VR-based learning process. Moreover, this learning system will produce new knowledge through knowledge constructs and experiences, repeatedly.

THE STRUCTURE OF THE *WEBDEGRATOR* SYSTEM

Learning curve and surface design in a computer graphics course is a challenging task owing to its complicated mathematics, accounting for why most instructors often omit this aspect during the progress of the course. Most major computer-aided design systems have supported curves and surfaces, especially Bézier B-spline and NURBS. Moreover, many computer science educators believe that curve and surface design is not curriculum-related even though software engineers and programmers are required to have expertise in computer graphics and computer-aided design (Farin, 1999). In our previous researches, we succeeded in developing a CAD curriculum analysis and design (Sung & Ou, 2000a). We have previously proposed using virtual reality modeling to improve training techniques (Sung & Ou, 2000b). For this reason, a pedagogical interface tool, *WebDeGrator* has also succeeded in solving many of the issues in teaching curve and surface design. *WebDeGrator* is extremely simple and can be easily implemented on a network. The performance platform is a VR-browser that can be used with any computer operation system.

Bézier, B-spline and NURBS algorithms (Piegl, & Tiller, 1997)
This *WebDeGrator* addresses all three types of parametric curves and surfaces that is, Bézier, B-spline and NURBS. Our discussion starts with the hierarchy of these curves and surfaces:

(1) *Bézier curves*. The Bézier curve uses polynomials for its coordinate functions, in which the power basis and Bézier forms are mathematically equivalent.

An nth-degree Bézier curve is defined by

$$C(u) = \sum_{i=0}^{n} B_{i,n}(u)P_i, \quad 0 \leq u \leq 1 \tag{1}$$

The basic (blending) function, $\{B_i, n(u)\}$, is the classical nth-degree Bernstein polynomials given by

$$B_{i,n}(u) = \frac{n!}{i!(n-i)!} u^i (1-u)^{n-i} \tag{2}$$

The geometric coefficient of this form, $\{P_i\}$ is called control points. Notice that the definition, Equation 1, requires that $u \in [0, 1]$.
(2) *Bézier surfaces*. Non-rational Bézier surfaces are obtained by taking a bi-directional net of control points and products of the univariate Bernstein polynomials.

$$S(u,v) = \sum_{i=0}^{n} \sum_{j=0}^{m} B_{i,n}(u) B_{j,m}(v) P_{i,j}, \quad 0 \leq u, v \leq 1 \tag{3}$$

The basic function $B_i, n(u)$ and $B_j, m(v)$.
(3) *B-spline curves*. A pth-degree B-spline curve is defined by

$$C(u) = \sum_{i=0}^{n} N_{i,p}(u)P_i, \quad a \leq u \leq b \tag{4}$$

where $\{P_i\}$ is the control point, and $\{N_i, p(u)\}$ are the pth-degree B-spline basis functions (Eq. 5) defined on the non-periodic (and non-uniform) knot vector ($m + 1$ knots). Unless stated otherwise, assume that $a = 0$ and $b = 1$.

$$N_{i,p}(u) = \frac{u - u_i}{u_{i+p} - u_i} N_{i,p-1}(u) + \frac{u_{i+p+1} - u}{u_{i+p+1} - u_{i+1}} N_{i+1,p-1}(u) \tag{5}$$

$$N_{i,0}(u) = \begin{cases} 1 & \text{if} \quad u_i \leq u < u_{i+1} \\ 0 & \quad \text{otherwise} \end{cases} \tag{6}$$

The polygon formed by $\{P_i\}$ is called the control polygon.

$$U = \left\{ \underbrace{a, \ldots, a,}_{p+1} u_{p+1}, \ldots, u_{m-p-1}, \underbrace{b, \ldots, b}_{p+1} \right\} \tag{7}$$

(4) *B-spline surfaces*. A B-spline surface is obtained by taking a bi-directional net of control points, two knot vectors and the products of the univariate B-spline functions.

$$S(u,v) = \sum_{i=0}^{n} \sum_{j=0}^{m} N_{i,p}(u) N_{j,q}(v) P_{i,j}, \quad 0 \leq u, v \leq 1 \tag{8}$$

with

$$U = \left\{ \underbrace{0, \ldots, 0,}_{p+1} u_{p+1}, \ldots, u_{r-p-1}, \underbrace{1}_{p+1}, \ldots, 1 \right\} \tag{9}$$

$$V = \left\{ \underbrace{0, \ldots, 0,}_{q+1} u_{q+1}, \ldots, u_{s-q-1}, \underbrace{1}_{q+1}, \ldots, 1 \right\} \tag{10}$$

U has $r + 1$ knots, and V has $s + 1$.

$$r = n + p + 1 \qquad \text{and} \qquad s = m + q + 1 \tag{11}$$

(5) *NURBS curves*. A pth-degree NURBS curve is defined by

$$C(u) = \frac{\sum_{i=0}^{n} N_{i,p}(u) w_i P_i}{\sum_{i=0}^{n} N_{i,p}(u) w_i}, \quad a \leq u \leq b \tag{12}$$

where $\{P_i\}$ are the control points (forming a control polygon), $\{W_i\}$ are the weights and $\{N_i, p(u)\}$ are the pth-degree B-spline basis functions defined on the non-periodic (and non-uniform) knot vector.

$$U = \left\{ \underbrace{a, \ldots, a,}_{p+1} u_{p+1}, \ldots, u_{m-p-1}, \underbrace{b, \ldots, b}_{p+1} \right\} \tag{13}$$

(6) *NURBS surfaces*. A NURBS surface of degree p in the u direction and degree q in the v direction is a bivariate vector-valued piecewise rational function of the following form

$$S(u,v) = \frac{\sum_{i=0}^{n}\sum_{j=0}^{m} N_{i,p}(u)N_{j,q}(v)w_{i,j}p_{i,j}}{\sum_{i=0}^{n}\sum_{j=0}^{m} N_{i,p}(u)N_{j,q}(v)w_{i,j}}, \quad 0 \leq u,v \leq 1 \tag{14}$$

$\{P_{i,j}\}$ forms a bi-directional control net, $\{W_{i,j}\}$ are the weights and the $\{N_{i,p}(u)\}$ and $\{N_{j,q}(v)\}$ are the non-rational B-spline basis functions defined on the knot vectors

$$U = \left\{ \underbrace{0,\ldots,0,}_{p+1} u_{p+1},\ldots,u_{r-p-1}, \underbrace{1,\ldots,1}_{p+1} \right\} \tag{15}$$

$$V = \left\{ \underbrace{0,\ldots,0,}_{q+1} u_{q+1},\ldots,u_{s-q-1}, \underbrace{1,\ldots,1}_{q+1} \right\} \tag{16}$$

where r and s are like the values in Equation 11.

The Program Structure of the *WebDeGrator* System

The implementation of the *WebDeGrator* system is based mainly on the OpenGL functions that are capable of showing complex 2D and 3D graphics (Wright Jr. & Sweet, 2000). The web-based system consists of both Curve and Surface Modeling (See Fig. 4). We previously constructed a program package for modeling and analyzing parametric curves called the ‘Curves Modeling’ (CM) method. This study constructed a program package for modeling and analyzing parametric surface methods called ‘Surfaces Modeling’ (SM). The operating platform for this learning system is a network browser and VR-based browser. Users can draw curves or surfaces by assigning the necessary points in graphics window. When the user has accomplished setting the control points, he can drag a control point on the curve or surface to modify the graphics in real-time. The user can then save the files or change other variable values on the curves or surfaces such as weight, color. . ., etc. The user can also convert the browser graphics into a VRML file that can be realized on a VR browser.

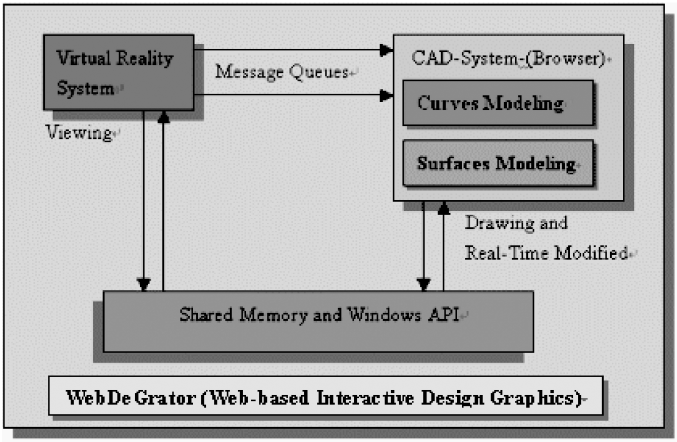

Fig. 4. Interactive Real-Time Computer Graphics System.

The purpose of this study is to develop an integrative graphics learning system in real-time. Drawing complex curves and surfaces in a network browser instantaneously is an innovative technology. In this work, we have combined the Web with CAD to create a new approach to teach curve and surface graphics.

WEBDEGRATOR SYSTEM'S OPERATING PROCESS AND INTERFACE

The flow of the system is as follows: (See Fig. 5)

(1) Learners register to use the system. An ID number is given after registration. The ID number is used to identify the learner because a log of all learning histories is recorded during the operation of the system. These recorded data are used for learner feedback (See Fig. 6 (b)).
(2) The web-based interface shows the system auto run and main menu features. Learners can choose any item by clicking the hyperlink on the page, (See Fig. 6 (a)). These selections include on-line documents; enter the 3D virtual world and Q&A. (See Fig. 7 (a)). When a learner chooses one of these items, he or she will begin learning the sculptured surface and curve courses. If the learner enters the 3D virtual world, he will come in to the learning cores (See Fig. 7 (b)).

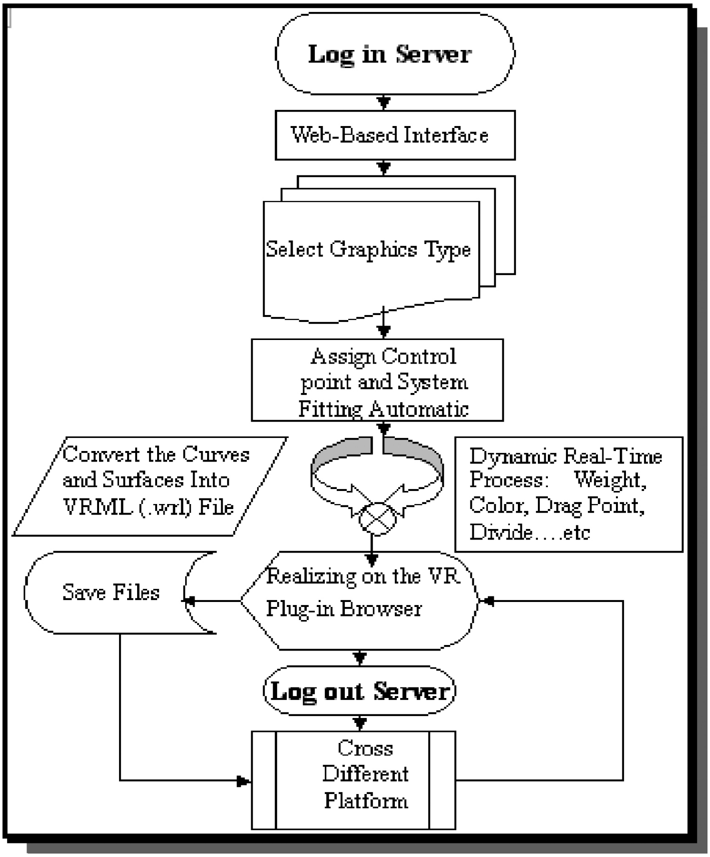

Fig. 5. System's operating process and interface.

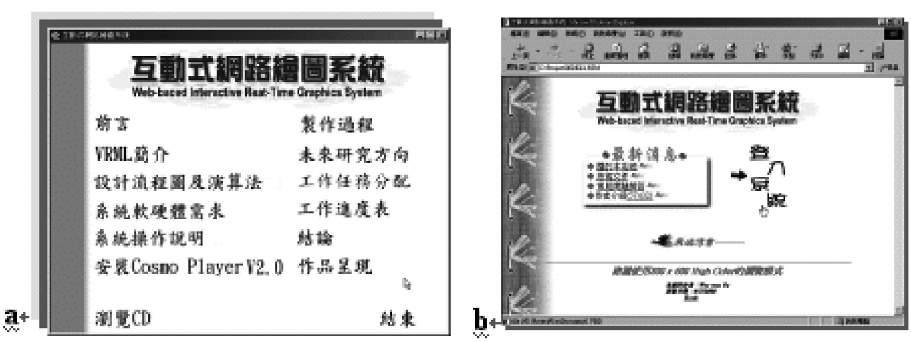

Fig. 6. (a) System auto run and main menu. (b) Login Server.

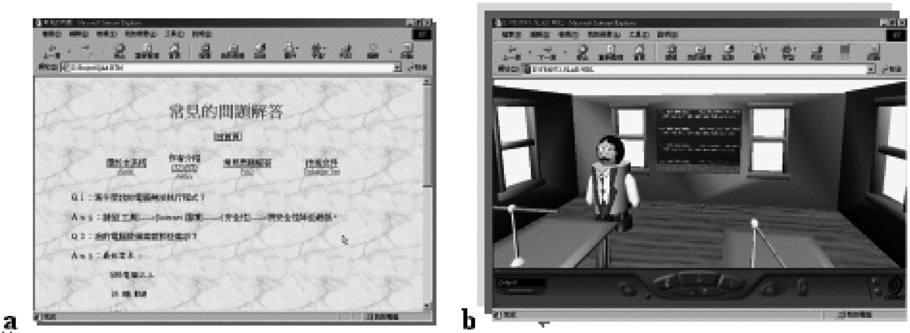

Fig. 7. (a) Online documents and Q&A. (b) Enter 3D virtual world and virtual classroom.

(3) After learners get into the 3D virtual world, they can see a virtual classroom and will be able to use the interactive real-time computer graphics system (See Fig. 8 (a) and (b)). The learners can click on the selected item to select the graphics type. These include Bézier surfaces and curves, B-spline surfaces and curves, surfaces and curves . . ., etc.
(4) After learning to select the graphics type, students can assign control points to the sculpture graphics arbitrarily. The *WebDeGrator* system will fit these control points automatically and generate sculptured surfaces and curves according to the learners' directions. (See Figs. 9 (a) and 10 (a))
(5) Students can learn to construct CAD-related knowledge and experiences through dynamic simulation and applications. These interactive features

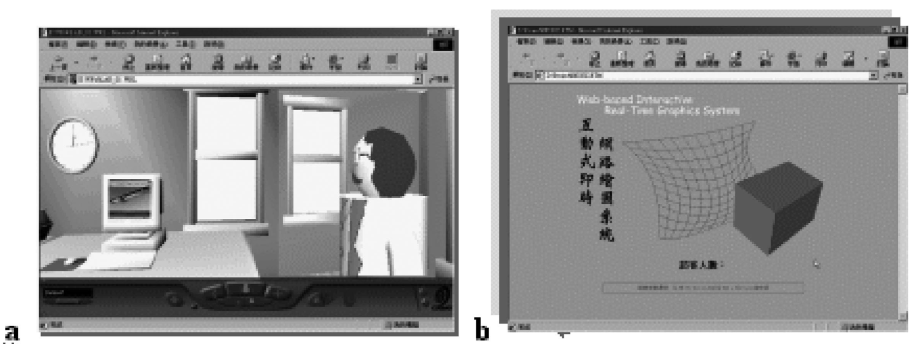

Fig. 8. (a) The environment for learning and designing. (b) Interactive real-time computer graphics system.

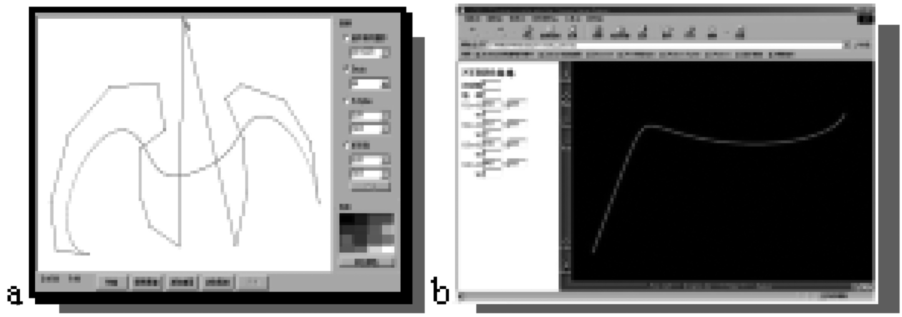

Fig. 9. (a) The Curve modeling interface. (b) Real-time simulations and adjustments for curve modeling.

include randomly assigning curve and surface control vertex points in the graphics windows, real-time local modified curves and surfaces by dragging these control vertex points, selecting various degrees and dimensions in fitting, adjusting the weight values to change the influence of the control vertex points on the graphics, drawing 3D curves and surfaces in the VR environment, graphics rotation, zoom in/out . . ., etc. (See Figs. 9(b) and 10 (b)).

(6) Students can save files or deliver their work anywhere and review other files for improving the design. Because of *WebDeGrator* system support operating systems, such as Windows and Linux, portable and cross difference-operating platforms, are facilitated (See Figs. 11, 12, and 13).

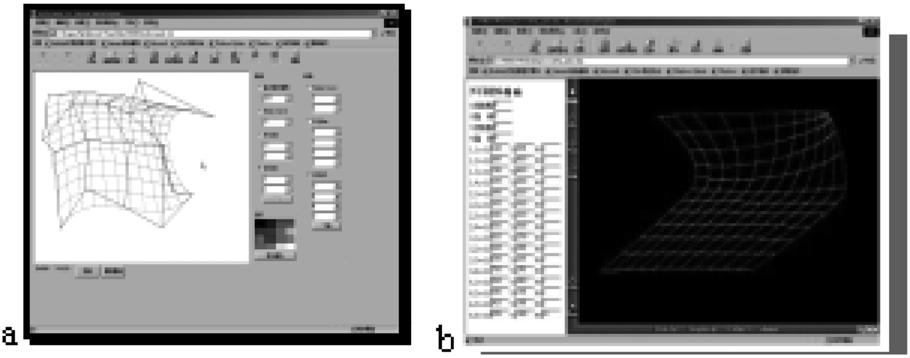

Fig. 10. (a) The Surface Modeling interface. (b) The Surface Modeling real-time simulations and adjustments.

IMPLEMENTATION AND ILLUSTRATIVE EXAMPLE

The following diagrams provide illustrative examples when implementing the *WebDeGrator* system. This study emphasizes the ability of this proposed new technology to be used to develop the following system. Some examples are shown in the figures below.

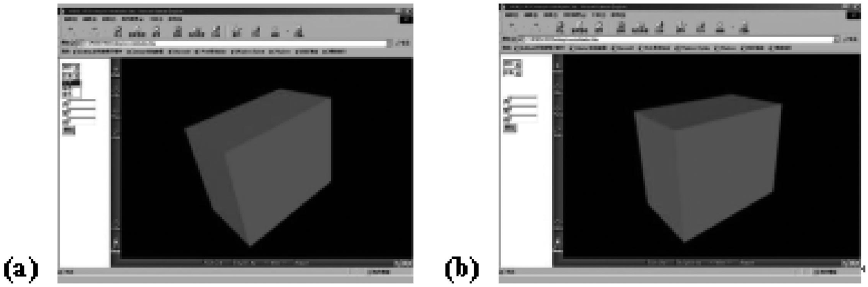

Fig. 11. (a) Setting or adjusting the weight values. (b) Real-time regular viewpoint by filling in the blanks on the left.

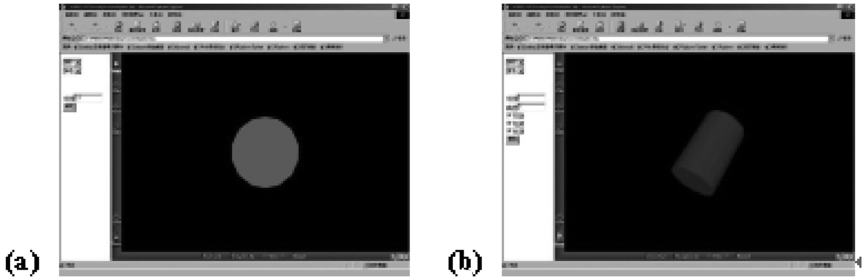

Fig. 12. (a) Selecting a control point and degree in various forms. (b) Illustration of a cylinder solid.

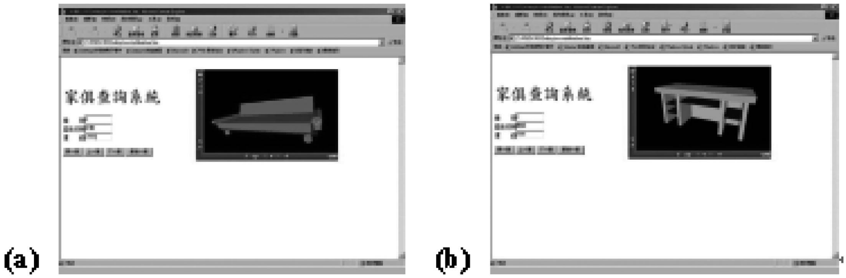

Fig. 13. (a) Queried by variety index. (b) Real-time dynamic view by dragging the 3D model.

SYSTEM EVALUATION AND DISCUSSIONS

A system evaluation was conducted to evaluate the performance of the system. The results from the system evaluation were used to revise the learning process to improve the system performance. We applied *Simpson's Taxonomy* (Simpson, 1967) and pre- and post-test examinations to the system evaluation. CAD and CAGD Students at National Central University of Taiwan, who were enrolled in the Automation & CAD team, participated in the test. Examination questions were classified according to Simpson's *seven classes*. Simpson provided a psychomotor taxonomy, with the aim of developing behavioral objectives, suitable for use in learning process evaluation based on constructivism. Simpson's Taxonomy is listed in the following:

1. *Perception*: Awareness of the environment, including sensory stimulation, cue selection and translation (relating perception to action).
2. *Set*: Preparation or readiness for action, involving mental set (the knowledge of steps to perform), physical set (the body in position to perform) and emotional set (the desire to perform).
3. *Guided Response* (*early stage of skill acquisition*): Behaviors exhibited under instructor guidance, including imitation (of a performance previously demonstrated) and trial and error (responding until the behavior is achieved).
4. *Mechanism* (*intermediate stage of skill acquisition*): Learned behavior is habitual, with some confidence and proficiency.
5. *Complex Overt Response* (*advanced stage of skill acquisition*): Behavior is skilled, involving complex movement patterns, which are quick, accurate and coordinated – resolution of uncertainty (performance without hesitation) and automatic performance (coordinated motor skill with ease).
6. *Adaptation*: Modification of movement patterns to fit special requirements or to meet a problem situation.
7. *Origination*: Creation of new movement patterns to fit a particular situation or specific problem. Learning outcomes emphasize creativity based upon highly developed skills.

The pre- and post-test examinations, 14 questions, each of which asked the student to assess his or her level of understanding, were compared. The level of understanding ranged from 0 to 5. In Table 1, we can see which score was better (Gather the average scores). Table 1 shows the results of the examination. Conclusions can be generalized from collection in Table 1:

Table 1. System Evaluation Result from the Pre- and Post-Test Examinations.

Simpson's Taxonomy	Questions classification	Pre-test scores(average)	Post-test score(average)
Perception	1,2	7.2	8.9
Set	3,4	5.3	9.2
Guided Response	5,6	6.5	8.6
Mechanism	7,8	6.4	9
Complex Overt Response	9,10	2.4	7.4
Adaptation	11,12	4.7	8.4
Origination	13,14	1.3	7.8
Total scores	14 questions	33.8	59.3
Standard deviation value σ	$\sqrt{\frac{n\sum x^2-(\sum x)^2}{n(n-1)}}$	2.216	0.660
Variation value	$\frac{n\sum x^2-(\sum x)^2}{n^2}$	4.211	0.373

1. After students used the *WebDeGrator* system, the system gained a lower standard deviation and variation values in the post-test score analysis. The standard deviation value reduced to 70.2%, and the variation value reduced to 91.1%. This result revealed that every student's learning outcome was promoted by using the *WebDeGrator* system.
2. The *WebDeGrator* system applied constructivism and VR technology that increased the student CAD and origination capabilities.
3. The *WebDeGrator* system reduced the gap between the students' origination capability and perception capability.
4. Simpson's Taxonomy from perception to origination is gradual sequence. Through this process, learners repeatedly construct knowledge and experiences. The learners become more proficient in the lower layers, such as perception, set, guided-response and mechanism. This improved proficiency encourages the learner to originate ideas and techniques and influence the learners to construct more correct knowledge and experiences.

CONCLUSION AND FUTURE WORK

The above instructional design principles and VR technologies can be used as guidelines in the environmental design of an interactive curriculum. Jonassen (1994) had much to say about constructivist learning environments. ‘‘Constructivist environments facilitate learning through collaboration, context and knowledge construction.’’ The *WebDeGrator* learning system succeeded in combining interactive VR and constructivism and utilizes these tenets of learning and creates experiences that contribute to increase the participants' proficiency by very closely emulating operations in the real world. An interesting area for future research is to investigate how to extend VR-learning systems and how to convert the network database and learning system into an intelligent learning system that can record every user's data with regard to his/her learning condition and status.

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