Cyber-Learning in Cyberworlds

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EXECUTIVE SUMMARY

This article discusses the problems of teaching computer graphics and shape modeling in large and distributed classes using visual cyberworlds—shared information worlds on the Web. Cyberworlds allow for providing personal mentoring to the students with different cultural and educational backgrounds. The Virtual Campus of Nanyang Technological University is such a cyberworld, which is being used for teaching computer graphics and shape modeling. A part of this cyberworld is the Virtual Shape Modeling Laboratory. It is used by the computer graphics students for designing geometric shapes defined with analytical formulas. Augmenting the existing ways of electronic education with cyberworlds appears to be useful which was proved by the final exam results and overall attitude of the students.

Keywords: collaborative learning; computer-based training; computer science education; course Web site; distance education; distance learning; Internet-based instruction; online classroom; virtual campus; virtual communities; Web-based courses; Web-based learning; Web-based teaching; Web-delivered education

ORGANIZATIONAL BACKGROUND

"Nanyang" in Chinese means "south seas"—a reference to the Southeast Asian region. Back in the 1940s and 1950s, many Chinese from mainland China ventured south to seek their fortunes in new lands. Malaya—now Singapore and Malaysia—was then known as "Nanyang" to the Chinese. After World War II, it was decided to start a university in Singapore that would provide tertiary education in Chinese in the region. On March 23, 1953, 523 acres of land was donated to the new Nanyang University, which was known as "Nan Tah" in Chinese. The modern Nanyang Technological University (NTU) (http://www.ntu.edu.sg) originated from Nan Tah. It is a comprehensive university designed to meet the needs of Singapore and the region. The university offers undergraduate and graduate courses in different areas of accountancy and business; art, design and media; bioengineering; biological sciences; chemical and biomedical engineering; chemical and biomolecular engineering; civil and environmental engineering; communication and information; computer engineering and computer science; electrical and electronic engineering;

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humanities and social sciences; materials science and engineering; mechanical and aerospace engineering; physical and mathematical sciences; and secondary school education.

NTU occupies a large beautiful Jurong Campus with very hilly terrain, located in the western part of Singapore. The campus has many buildings with quite sophisticated futuristic architecture, some of them designed by the famous Japanese architect, Kenzo Tange.

All the university's facilities and resources are freely available over the Internet and can be accessed by everyone on the campus network (fixed line and wireless) and from outside the campus through the Internet. By using the university's mobile service one can connect to the selected e-services from virtually anywhere with mobile phones and PDAs. This existing high-tech infrastructure and the university's commitment to its permanent improvement, as well as a very great number of local and international students (near 17,000 undergraduate and 7,500 graduate students), there is motivation for rapid development of electronic education at NTU to augment and enrich the traditional ways of teaching in the classrooms.

Computer graphics is one of the flagship areas of research of the School of Computer Engineering (SCE) at NTU (http://www.ntu.edu.sg/sce). SCE has three research centers oriented to and around solving problems of computer graphics. These are Center for Graphics and Imaging Technologies (CGIT), Center for Advanced Media Technologies (CAMTech), and GameLab. CGIT *(*http://www.cgit.ntu.edu.sg) serves as the focal point for graphics and imaging related research and development activities among the university, industry, and business. Projects which CIGIT runs are computer and animation, geometric modeling, scientific and medical visualization, multimedia and training system, computer vision and imaging processing, and intelligent agents for visual computing. CAMTech (http://www.camtech.ntu.edu.sg) is a joint research and development center between the Fraunhofer Institute for Computer Graphics (IGD) of Darmstadt, Germany (http://www.igd.fhg.de) and NTU. Projects which CAMTech runs include but are not limited to multimedia in education and commerce, geographical information systems, scientific and medical visualization, virtual engineering, virtual and augmented environments for medical applications, new media for cultural heritage, mixed reality for engineering, next generation learning, and environments for life sciences. Finally, the GameLab's (http://www.gamelab.ntu.edu.sg) mission is to continually explore and extend frontiers of game technology to create highly immersive and experiential games for the widest range of applications. The university's strength in the area of computer graphics has been reinforced by the series of international conferences on cyberworlds organized by SCE in Singapore and in other countries. The topic of cyberworlds and their application to education is discussed in this article.

SETTING THE STAGE

Electronic education is one of the priority directions at NTU. The university's e-learning platform, edveNTUre (http://edventure.ntu.edu.sg), is based on the BlackBoard Academic Suite software (http://www.blackboard.com), and several other companion software tools, such as AcuLearn video streaming software tools (http://www.aculearn.com). It is extensively used by the NTU professors to enhance their lectures, tutorials, and labs. Since its introduction in 2001, edveNTUre has developed from a rather exotic way of publishing lecture materials and occasional visits by the students to the present time, when it has become a mandatory and important part of each course with thousands of visits each day. Besides providing teaching materials such as lecture notes, slides, streaming audio/video presentations, and extra materials, it can be used for setting up online quizzes, discussion groups, and uploading assignments. This is done in line with the present common electronic education technology which assumes putting on the Web course materials that can be further fortified with elements of interaction such as discussion groups and quizzes. However, it was noticed that this approach, which was quite successful and inspiring

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for the students at the beginning, appears to lose its initial appeal and attraction. Apparently, the temptation to provide more and more information electronically for each course far exceeded the pace and information workload of conventional teaching and thus resulted in disorientation and exhaustion of the students whose abilities significantly vary. As such, there is a need in new ways to augment and improve the existing technologies of electronic education.

In this connection, the ultimate goal of electronic education should be to provide personal mentoring to each student through smart virtual instructors, media rich course content, and online experiences, rather than just through publishing the course materials on the Web. This becomes especially essential when large or distributed classes are being taught. In particular, there is a strong need in such advanced electronic education for teaching computer graphics, which requires both background in mathematics and geometric mentality. Traditional project-based ways of teaching computer graphics often appear boring and not really motivating for the students, since many of them do not necessarily see their future professional career in designing and developing sophisticated graphics tools. Also, quite often the course work offered to them assumes using laboratory-based equipment and software, which may not be available in other labs and at home. This also contributes towards a negative attitude and strain due to the possible problems with accessing these facilities. Distant students located outside the university, even in other countries, may have no way at all of working with other students on the projects and thus will feel left behind.

Using and creating cyberworlds appears to be an excellent educational tool for achieving personal mentoring when teaching large classes of students. Cyberworlds are information worlds built on the Web. These shared cyberspaces may be designed both with visual appearances and without it. Cyberworlds have been widely used in educational settings of different types and have promising potential for supporting learning communities because of their capability to provide a social arena where students and teachers can meet, thus overcoming the barriers of the physical world (Neal, 1997). In addition, the virtual space provides a dynamic and flexible environment where learners, especially distributed ones, can share information and form the environment according to their needs (Prasolova-Førland & Divitini, 2002). Currently, cyberworlds are successfully used for science (Shin, 2003), children (Gerval, 2003) and archeological education (Green, 2003). Creating cyberworlds as an educational tool for teaching computer science is described in (Gutiérrez, 2004).

The following section presents three cases of using cyberworlds for teaching computer graphics. In order to put the presentation of these cases into a bigger perspective, we will provide a short overview of the existing design solutions within educational cyberworlds, especially 3D ones. Positioning the cases within the body of related work will allow for showing the contribution and novelty more clearly, as well as providing an additional ground for discussions. It will also allow for comparing these cases with the similar ones in other educational institutions.

There exists a wide range of 3D educational cyberworlds, for example, within the Active Worlds Educational Universe (AWEDU, http://www.activeworlds.com/edu/index.asp). The metaphors behind the design of virtual places are quite diverse: from replication of real universities to other planets. The worlds are also used for different purposes: from demonstrations of art and scientific concepts to meetings between physically remote students. In order to be able to analyze and describe different cases and design metaphors in a systematic way, as well as to see more clearly the connection between different design metaphors and the underlying learning goals, we have developed a characterization framework, which is presented in more detail in Prasolova-Førland (2005).

Shortly, we characterize 3D educational cyberworlds in terms of outlook, structure and roles. We consider outlook in terms of to what extent the virtual place resembles a real one and

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to what extent the place looks like a "frontier." The former consideration is particularly relevant to the cases presented later. Several universities and schools introduced virtual representations of themselves, often providing an analogy of the corresponding places in the real world. Examples include iUni representing Indiana University (http://iuni.slis.indiana.edu), eCollege (see, i.e., http://www.vlearn3d.org/collaboration*)*, Virtual Design Studio (Maher, 2000), and worlds in Active Worlds Educational Universe (AWEDU, http://www.activeworlds.com/edu/index.asp). The rooms and the buildings of virtual campuses give an idea about the social environment, personal office space and available equipment and provide a "familiar" atmosphere for the visitors (Maher, 1999). This also applies to the Virtual Campus of NTU as it will be described later. Other examples include "realistic" virtual laboratories (e.g., virtual vet clinic in Vetumuni; see, for example, http://www.vlearn3d.org/collaboration), museums, hospitals and so forth. The "frontier" in this context denotes the ability to "conquer" new virtual space and extend its horizons (Schroeder, Huxor, & Smith, 2001), for example, adding new buildings as opposed to the corresponding limitations of doing this in reality.

By structure, in this context, we understand mutual relations between different parts of the virtual environment, for example, the mutual position of rooms within a virtual campus or the spatial organization of buildings in a 3D world. The structure can be rigid and predefined by teachers/administrators or flexibly created and modified by the users. The factors defining the structure of a cyberworld could be quite different: from the existing social structures, as in, for example, Viras (Prasolova-Førland & Divitini, 2003), and structure of the "physical counterpart" of a virtual university to the structure of a certain course, for example, Virtual Syllabus (Dickey, 2000). The components constituting the structure can be "visible" such as buildings or "topological," such as connecting teleportation links between different parts of the place.

Also, a cyberworld can play several, often overlapping roles, such as meeting place, for example, meeting areas and classrooms in eCollege/AWEDU; information space, for example, collaborative Document Space (Borner, 2001); virtual stage, for example, scenography design classes in Cybergen/AWEDU (http://www.activeworlds.com/edu/index.asp); demonstrations/exhibitions and workplace, such as areas for science education and for creating and demonstrating student projects in SciCentr and SciFair (Corbit & DeVarco, 2000). For a deeper characterization and analysis of each role, we identify the creator of the world (e.g., teacher or students), the major purpose (e.g., formal meetings or socializing, demonstration of art, or scientific concepts) and the corresponding design features and facilities to support this purpose, such as design elements to create corresponding atmosphere (e.g., a "vet clinic" theme in Vetumini), roads and walks to support user navigation and interactive elements.

CASE DESCRIPTION

In this article we describe three projects contributing to developing cyberworlds while teaching computer graphics. These are Virtual Campus of Nanyang Technological University (http://www.ntu.edu.sg/home/assourin/vircampus.html), Function-based Web Visualization (http://www.ntu.edu.sg/home/assourin/FVRML.htm), and Interactive Function-based Shape Modeling (http://www.ntu.edu.sg/home/assourin/Intshape.html).

The main idea of using our approach to teaching computer graphics is that the students are able to use simple mathematical formulas for defining complex geometric shapes, appearances, and transformations. Using any Internet connected personal computer, they are able to connect to the cyberworld, which allows them to design sophisticated shapes as well as discuss and share with other students the created models. Other ways of teaching including online lectures and interactive consultations with the robot-instructor and real lecturers are available for the students as well. This approach, in fact, combining fun and education, allowed us to create more

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motivation and achieve better results when teaching computer graphics to some 450 students per semester with very different educational and cultural backgrounds.

Case 1: Virtual Campus as a Place for Collaborative Learning and Socializing

The Virtual Campus was created to address the problems in connection with traditional modes of education identified in the previous section. The Virtual Campus of NTU is a shared virtual world built with Virtual Reality Modeling Language and Blaxxun Contact 7 communication platform (http://www.blaxxun.com). It is a virtual model of the real campus of Nanyang Technological University. The whole Virtual Campus including VRML models of the land, buildings, interiors, avatars, and texture images is stored in only about 15 Mb of files and can be accessed from any Internet-connected personal computer (Figure 1). In this cyberspace, visitors can turn themselves into virtually anything. Some choose to look like fancy-dressed people, some turn themselves into sports cars, and some appear as sparkling clouds or fire balls.

Among the users visiting the Virtual Campus, the following major groups can be identified. Most visitors to the Virtual Campus are computer graphics students, who come to study concepts of virtual reality and shape modeling. There are also local students who easily navigate the familiar 3D environment, go to their favorite places, or meet with friends in their hostel rooms (Figure 2). The third group consists of strangers from around the world, including potential new students, meeting together on this hospitable land. Foreign guests usually just wander around and chat, astonished by the size of what is probably the biggest shared cyberspace of this kind. The Virtual Campus often serves as a guide for the foreign students who consider studying at the university. By visiting the Virtual Campus they can familiarize themselves with the real campus and its facilities before coming to Singapore.

Features supporting the given educational goals include those providing the illusion of the real campus. For example, there are dusks and dawns in this cyberspace, which follow Singapore time, but the Virtual Campus never sleeps. Since the Virtual Campus is also a place for research on crowd simulation and shared cyberspaces, it, like the “real” one, is not static, and its content

Figure 1. A snapshot of the Virtual Campus

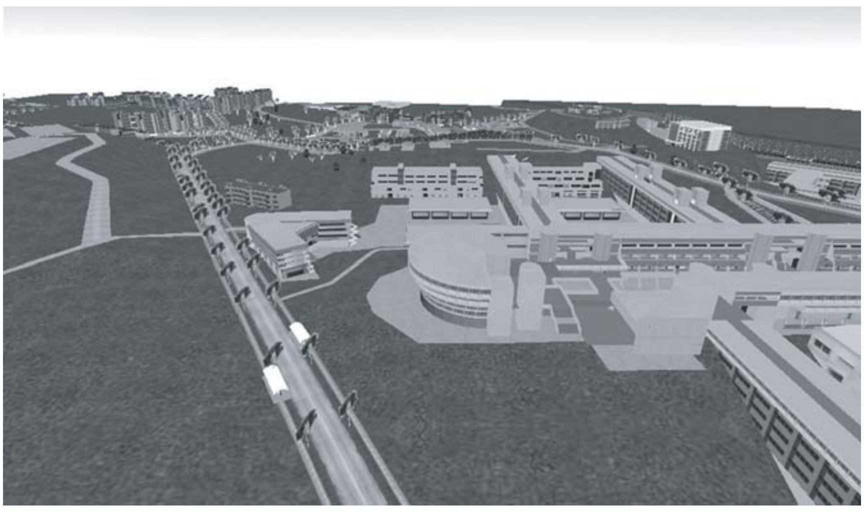

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Figure 2. One of the virtual student's room. The room has a "smart" environment. Each time a visitor comes to this room, some of the objects there relocates or replace others, as though somebody lives there. Registered visitors are able to set up their own home areas.

changes frequently. Many bots (robots) populate it. These are so-called avatars of students and professors who walk back and fourth between lecture theatres, libraries, and student hostels. There are also birds hovering in the sky and cars riding on the roads. The bots are programmed to behave realistically for the visitors. Some of these activities are stochastic, and some follow the real class time tables. Visitors can come across an avatar, which is in fact a bot, and it will take time before they understand it. Sometimes it may be a real person disguised as a bot to test human reaction on some avatar activities to be programmed.

Communication support is another important feature supporting collaborative learning and social activities as well as providing an enhanced learning experience. Virtual Campus is not only for wandering around and looking at other avatars. The visitors can talk to them. Blaxxun Contact provides the communication platform for it. It also allows for text-to-voice synthesis so that the visitors can hear their computer-simulated voices. These chats may involve all the visitors or can be organized into private chat groups. The first bot, which the visitors meet, will greet them immediately upon arrival (Figure 3). This bot is an avatar of one of the project students who contributed a lot to the Virtual Campus. Its "brain" is developed using AIML language, ALICE files (http://www.alicebot.org), and computer graphics terms from the textbook (Sourin, 2006), which this bot is incidentally selling to the current computer graphics students. Besides maintaining simple conversations, this cyber-instructor can quickly answer questions about computer graphics and virtual reality. This is an alternative to the 2D text consultation discussion group, which is a part of the respective course-site in the edveNTUre. There are also a few other agents wandering around. They are also "clones" of the former project students. In fact, each of the project students has a personal avatar copy in the Virtual Campus, thus contributing to the social environment.

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Figure 3. Robots and avatars

The third important feature of the Virtual Campus aims at supplementing the shortages of the existing e-learning platform by creating a rich social context around the learning process. The e-learning platform used in NTU (edveNTUre), being based on html Web pages, gives rather a "two-dimensional look" to the teaching process. In contrast and in addition to it, on the Virtual Campus, NTU professors are able to meet with their students in virtual 3D classrooms, "see" and communicate with each other, and so add more immersion and fun to education. Besides that, distant overseas students get a feeling of really being on the campus. Many features available in edveNTUre are also available on the Virtual Campus. Thus, some of the virtual lecture theaters and other places are linked to streaming multimedia presentations of current and pre-recorded lectures and events (Figure 4).

In addition to serving as a supplement to the "physical" campus and the 2D e-learning platform, Virtual Campus serves as a learning tool for computer graphics students, illustrating to them theoretical concepts of virtual reality, real time rendering, and shape modeling, as described in Case 2 and 3 below. It is used during lectures, as well as after classes for consultations.

Case 2: Interactive Function-Based Shape Modeling

One of the student assignments is "Implicit Fantasies." The students have to design sophisticated shapes using implicit functions, and to make them available in their virtual homes in the Virtual Campus. A part of this assignment is to be done in the Collaborative Shape Modeling Laboratory, which is one of the places of the Virtual Campus. This virtual laboratory can be entered either from the lobby of the School of Computer Engineering of the Virtual Campus or by a direct link from the list of the community places. Before going there, the visitors have to install a small software plug-in. This plug-in is an extension of VRML, which allows for defining geometric shapes by formulas—analytical definitions with parametric, implicit, and explicit functions. All these formulas are functions of three coordinates, which are either parametric or Cartesian coordinates of 3D shapes. When using our plug-in, these different representations can

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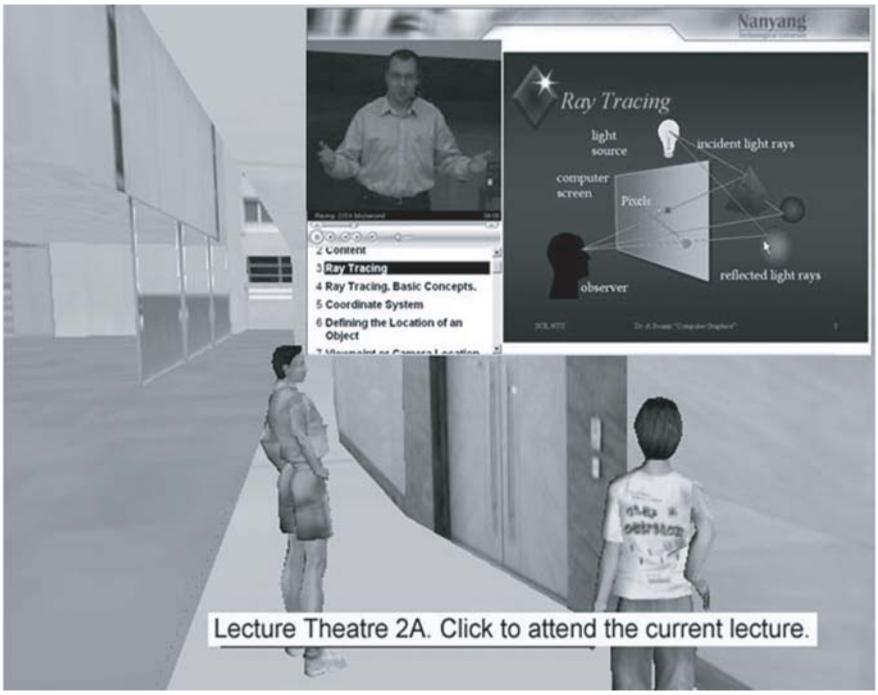
Figure 4. Combining VRML with streaming video recordings of lectures and events



be used concurrently for defining geometry and appearance of shapes. The shape's geometry can be defined by a basic geometric shape and its geometric texture, each defined with either parametric, implicit, or explicit functions. The appearance of the shape can be defined by either function-defined or fixed colors. Similar to the shape's geometry, parametric, implicit, or explicit functions can be used for defining the shape's color on its surface and inside it. This approach helps the students to easier understand the concepts of function-based shape modeling. Also, the synergy of using the three different representations results in the advanced quality and efficient solutions, which are impossible to achieve when these representations are used on their own. The theoretical foundations and further details of this hybrid approach to function-based shape modeling can be found in Levinski and Sourin (2004) and Liu and Sourin (2005), as well as in the project Web pages.

After the plug-in is installed, besides the regular VRML objects, function-defined shapes will become visible as well. There will be one big shape hovering in the middle of the room, as well as a few smaller fancy shapes displayed in different parts of the room (Figure 5).

The big shape is the one which the visitors can interactively modify. The smaller function-defined shapes are examples of the best works created by the students. The function-defined shapes can be placed at other part of the Virtual Campus, for example, to private virtual homes of the members. Several visitors may discuss the design in the chat box, type individual shape modeling commands or command scripts, and immediately see how the shape changes accordingly. The VRML description of the shape being modeled can be displayed at any time and saved

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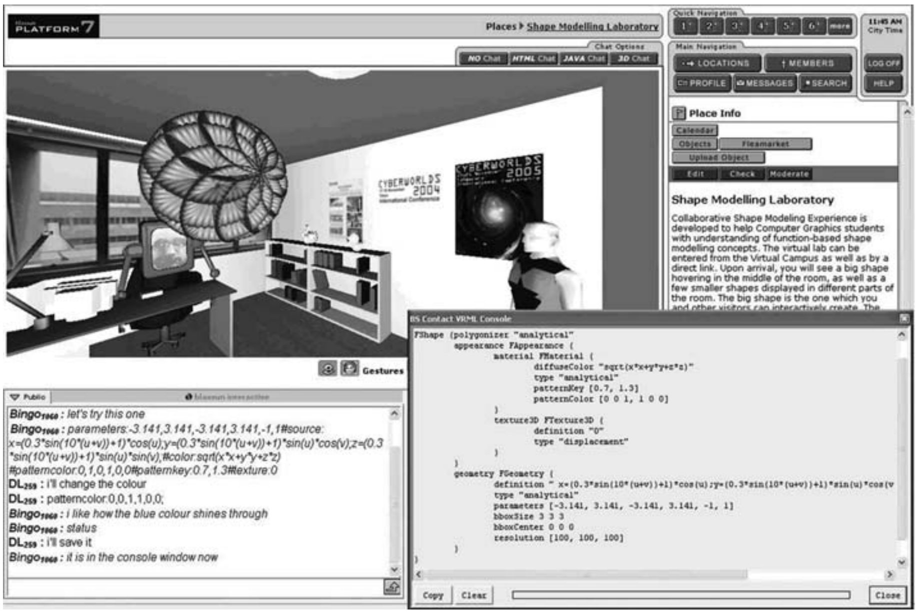
Figure 5. Collaborative Shape Modeling Laboratory



for future use. The example of a 3D scene, totally defined by a student with analytical implicit functions and rendered with POV-Ray (http://www.povray.org), is shown in Figure 6.

Case 3: Function-Based Web Visualization

Another student assignment, "Parametric Metamorphoses," is also based on the function-based VRML. In this exercise, the students have to define analytically how one shape defined by parametric formulas transforms into another one. This transformation, or morphing, is to be modeled as an animated shape conversion. Being liberated from writing any computer graphics codes besides a short fragment of VRML defining analytical formulas for two shapes and a formula for their morphing, the students are able to concentrate on the principal part of the shape modeling with parametric functions. The resulting VRML code is to be made a part of a 3D scene, which then will be included in the Virtual Campus as one of its meeting places, thus expanding the Virtual Campus to new horizons.

Besides the method of using analytical formulas with an immediate visual feedback, more complex function-based shape modeling can be done with the interactive shape modeling program developed for this project. The program offers an advanced set of interactive operations such as cutting, sculpting, embossing, engraving, and carving. It also allows for interactive painting both on the surface and inside the object. The colors become an integral part of the shape's model. As a result, the program allows for making realistic looking shapes, which are defined with very small function-defined models that can be rendered with any desired precision. The initial basic shape for modeling can be either defined analytically, or created interactively with simple basic shapes (Figure 7). The initial shape is then gradually modified by applying different interactive shape modeling and/or painting operations. The result of the modeling can be either saved in

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Figure 6. Function-defined scene designed in the Virtual Campus and ray traced with POV-Ray by an undergraduate computer graphics student

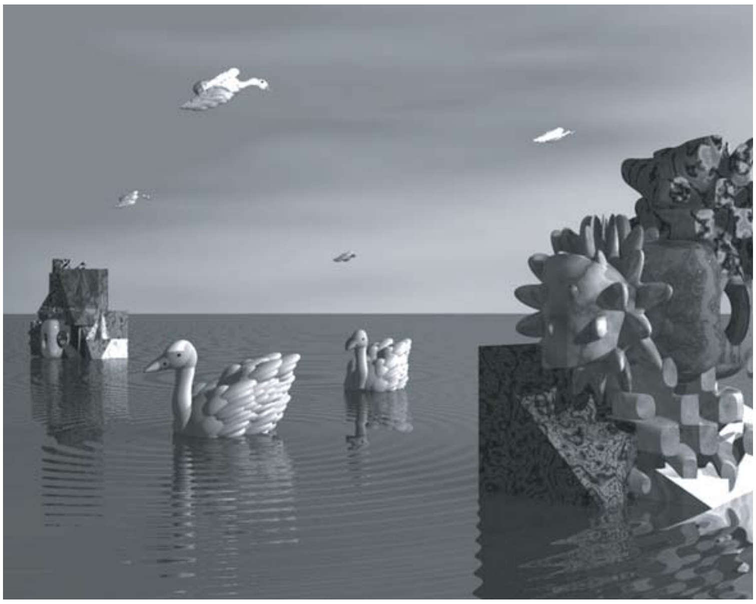
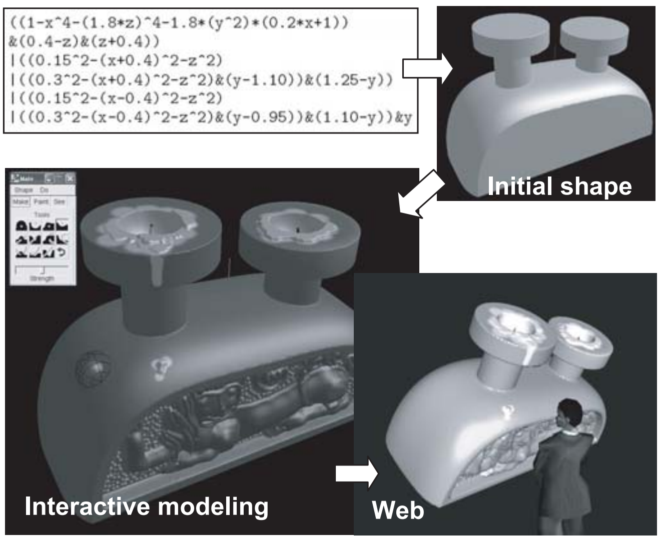


Figure 7. The basic shape is defined analytically, then it is interactively carved and painted, and finally imported to function-based extension of VRML for Web visualization and further modeling.



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the proprietary function-based data format or in the function-based VRML code for further use in the Collaborative Shape Modeling Laboratory or in other shared virtual worlds.

Technological Resources and Constraints in the Organizational Context of the NTU

The presented cases provide an overview of the technological resources of the Virtual Campus as well as functionalities for a number of educational purposes. We will now make a short characterization of the Virtual Campus and its major design features according to the framework described in the previous section, thus highlighting the associated technological constraints in the given organizational context in a systematic manner. In terms of the outlook, the Virtual Campus is a very typical example of a very realistic, almost "photographic" resemblance of the real place—the real campus of NTU, as described above. For obvious reasons, it is impossible to recreate all the details, so there are certain limits to how "realistic" the environment looks, though it is still one of the most realistic educational environments at the moment. Also, some additional elements, not having direct counterparts in reality, such as the Collaborative Shape Modeling Laboratory, are added for enhanced educational experience. The "frontier element" is clearly less prominent here as the possible expansion, though not limited in terms of technology, is bounded by the physical layout of the university the world represents. The adopted metaphor is thus setting a standard for further expansions and alternations.

The structure of the Virtual Campus is rather rigid, due to the corresponding defining factors, such as the structure of the corresponding "physical" university, but also the existing affordances of the Blaxxun platform, which originally provides much less flexibility than analogous environments based on, for example, Active Worlds technology. The structure is mostly created by the teacher and project students as a planned activity and to a very small extent can be altered by other users, thus providing a certain constraint to the flexible Virtual Campus development in accordance with the changing educational and organizational needs. The major structural components, that is, the buildings of the campus, are connected in two ways: through the virtual doors, walks and roads, allowing the users to "walk," as well as with a set of teleportation links available through an integrated menu.

As mentioned before, most educational cyberworlds can play many roles at once, with some major roles and other peripheral. The most prominent role of the Virtual Campus is the "demonstration," both of the campus itself (e.g., for new or distant students) and of the possibilities and concepts of computer graphics and virtual reality. At the same time, it is a workplace for students working on computer graphics projects and courses, including the development and design of the campus itself, as well as a meeting place for students (both distant and local) and teachers for consultations and socializing. The "virtual stage" role is present, as in other virtual worlds, mostly due to the fact that the visitors express their identity in a different way than in real world and are "disguised" behind avatars and nicks. This role is also partly supported by the bots that play the roles of virtual humans, simulating conversations and providing a "crowd" effect. The role of information space is rather peripheral. The Virtual Campus can be seen as a place displaying general information about the campus organization, probably for new students, and contains otherwise some community resources such as links to lectures, some resources on modeling as well as materials in the computer graphics course, including student projects such as the models of dormitories. It is worth noting that the teacher and a number of project students play the major role in shaping the design and developing the metaphors. This might affect the balance between the intentions behind the different design choices and the actual usage of the virtual place.

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A number of facilities and design features are used to support the metaphors and corresponding educational goals. For example, there are dedicated areas for formal meetings and work, such as lecture halls and labs with corresponding tools for shape modeling. There are also meeting places for more informal use and socializing, designed as "parks," "mingling" areas, and dormitories. The mechanisms for information finding and retrieval are analogous to those in reality, for example, positioning and design of offices and other units where students can find different resources while walking around as on the real campus. Interactive functions such as the possibilities in certain cases to open virtual doors and move furniture, contribute to the demonstrational effect of the presented models. Also, the existing intelligent agents provide facilities for supporting different kinds of metaphors, for example, answering curriculum questions (workplace) or guiding the user around the campus (demonstration and information space). Still, the tools and resources provided are predominantly targeted at computer graphics students, only to a limited degree supporting the needs of students taking other courses.

Preliminary Results

Using the Virtual Campus in a one-semester course of computer graphics at NTU has resulted in a 14% increase of the mean exam mark and demonstrated that understanding of shape modeling concepts by the students has significantly improved. According to the students' feedback, the explanation for this phenomenon is in the ability of the cyberworlds to involve students in virtual discussions and collaborative works without the necessity of their physical presence in a classroom or lab. The students can easily share their works in cyberworlds and thus contribute to their expansion. In Figure 8, an example of a room developed by one of the undergraduate student is shown. This virtual room is used both as private meeting space of this

Figure 8. A shared virtual environment developed by a student. A moving shape on the left table is the student assignment "Parametric Metamorphoses."

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student and as a showcase for his assignment "Parametric Metamorphoses," which is placed on the table in front of the television. Students can work on their assignments online from homes wherever these homes are physically located. Also, when a conventional way of teaching computer graphics is used, there is always a certain inconsistency between the theoretical concepts studied and their practical applications, since only a limited part of the course is normally covered by the coursework. Our observations show that when the students work on their coursework in the cyberworld, which itself is created using computer graphics tools, then, gradually and without making any extra efforts, they get immersed in many concepts of computer graphics and can feel and touch real-time rendering, visualization and virtual reality. For example, on a number of occasions when consulting students on different modes of visualization, the instructor could ask them to switch the rendering mode of the VRML browser from smooth textured mode to flat polygons, wire-frame, or point modes. When creating their own environments, the students have to define the viewing distance and level-of-details for shapes with complex geometry – rather abstract concepts if they are only lectured. This everyday activity in the cyberworld, reinforced by the assignments, leads to better understanding through fun, and with a readily available option to ask for help from any other visitors or virtual instructors.

CURRENT CHALLENGES

Cyber-learning has already become an important and vital part of university education since conventional ways of teaching, when only lectures and practical exercises in a class are used, no longer satisfy the growing demands and challenges of modern education. Shared cyberworlds are efficient tools, which both illustrate how computer graphics, shape modeling, and virtual reality work and provide the students hands-on experiences by allowing them to contribute to these worlds. However, a number of challenges can be identified in connection with the introduction of cyberworlds as educational means at Nanyang Technological University:

Computational power. Function-based Web visualization is an efficient way of expanding shared VRML worlds. Many large VRML models, which require a big number of polygons, can be replaced with compact function-based models where shapes and their appearances are defined with small parametric, implicit, and explicit formulas. However, function-based approach to shape modeling assumes that the client computers are to be quite powerful since visualization of functions is computationally expensive. Modern off-the-shelf computers can easily visualize function-defined shapes with a moderate resolution; however, higher photo-realistic appearance may require either longer calculation times or an ability to use advance processor power of Grid computing. The challenge in this context is finding the balance between the cost and visualization efficiency in an educational context.

Choosing appropriate design metaphors. When using cyberworlds in different educational situations at NTU, it is important to choose appropriate design metaphors to meet the concrete educational goals. We have provided a short overview of the existing variety of educational cyberworlds as a background and framework for our cases. The challenge in this context is two-fold. First, it is necessary to analyze the adopted design metaphors and provided facilities in terms of to what extent they are suitable for teaching computer graphics and in general for creating a social and working environment for teachers and students of NTU. This also implies performing an iterative revision of the design according to the evolving user needs. Second, it is necessary to explore the possibilities for using VC in other educational situations, for example, for teaching other courses or various campus events.

Addressing limited student usage and attendance. Though the adopted design facilitates extensive meeting and information sharing activities, these functionalities are currently not exploited fully due to the limited student "attendance" and involvement of the different research

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and educational environments of the university (as the major visiting group are computer graphics students). This issue needs to be addressed as active student involvement and participation in the VC project will motivate them to contribute more actively to this community and in this way participate in shaping the design in the way it is most appropriate for their concrete needs.

Enriching Virtual Campus with resources. An important challenge in terms of integrating VC into the overall educational and organizational infrastructure is enriching it with resources of various kinds, for example, educational, informational, and entertainment-related. In this context, two sub-challenges can be identified. First, it is necessary to find out what resources will be most appropriate in the given situation for providing an adequate representation and support for common university activities and thus for motivating more active student participation. Second, it is necessary to identify the most appropriate ways of presenting these resources in VC in terms of associated design and functionality.

Insuring flexibility and simplicity of development. The flexibility and simplicity of the development is still limited and can be an inhibiting factor for broader student masses of NTU to use VC, as creating new objects require certain skills in computer graphics. A challenge in this context is to identify and provide the appropriate technical possibilities available for all employees and students of NTU, at the same time enforcing certain overall guidelines and rules to ensure a harmonic and consequent development of the VC.

Providing personal virtual mentors. With reference to the virtual instructors, it was noticed that though the students knew that they were talking to chat robots, some were still trying to share their personal problems with them, expecting to hear advice from somebody who is not a real person but still had a nice "trustworthy" visual appearance. This proved that it is worth developing a bank of virtual instructors with basically the same "brain" but different appearances such as different genders, voices, paces of speech, and so forth, to suit different audiences and cultural backgrounds. This will allow the students to have their own personal instructors to help them feel more comfortable in the educational cyberworld. Mixing up fun with education is yet another important concept to consider here.

Developing generic collaborative learning environments. Another challenge is to develop generic collaborative virtual laboratories, classrooms, and lecture theaters which can be used for teaching different subjects to distributed groups of students at NTU and other universities. This includes making user-friendly Web-based interfaces for tuning virtual instructors to different teaching areas and environments, based on the existing Virtual Campus of NTU.

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