具備互動式三維媒體特性之網路學習環境：
以空間座標轉換為例

A Web-based Learning Environment with Interactive 3D Media: Spatial Coordinate Transformation as an Example

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摘要

本研究的目的在建構一個具備互動式 3D 媒體的網路學習環境。由於電腦運算能力的進步，我們得以將電腦做為功能強大的教學媒體。對各個特定的領域而言，為提升電腦教學系統傳遞知識予學生的效果，選擇適當的媒體形式來表達知識是系統設計重要的考量因素。而使用電腦做為教學媒體，可提供較其他媒體為佳的學習經驗，扮演「認知媒體」的角色。我們並以電腦圖學及線性代數中空間座標轉換的概念為主題，做為本研究的領域知識，使用 3D 電腦繪圖及動畫的技術來幫助學生學習數學上的空間概念。我們設計了一個稱為 CooTutor 的雛形系統，嘗試在網路學習環境中加入了「3D 黑板」的功能，以清楚地表達座標系統及空間座標轉換的抽象概念。此外，為了讓學生更專注於教材(相較於「網路衝浪」式的瀏覽行為)以及使多媒體呈現的整合更具認知上的意義，我們的系統讓使用者可以直接操控 3D 場景，在文字文件與 3D 場景間也提供了豐富的互動功能。長期而言，本系統將結合智慧型教學系統(Intelligent Tutoring System)的理念，建構一個具認知媒體特性且適性化之網路學習環境。

關鍵詞：數位學習、認知媒體、互動式三維媒體、電腦圖學教育

Abstract

The objective of this research is on developing a Web-based learning environment with interactive 3D media. The increasing computing power allows us to use computers as powerful educational media. For each particular domain, appropriate media representation has been an essential factor for a computer-based education system to deliver knowledge to students. As cognitive media, computers are effective tools that can provide better learning experiences than other means. We use spatial coordinate transformation in computer graphics and linear algebra as an example and employ 3D computer graphics and animation techniques to facilitate students in learning spatial mathematic concepts. We have designed a prototype system called CooTutor and tried to integrate the "3D blackboard" into the web-based learning environment to describe abstract concepts about coordinate system and spatial coordinate transformation. Besides, in order to keep students involved in the material (compared to web surfing behavior), and make the combination of different media presentation more meaningful cognitively, we have designed direct navigation inside the 3D blackboard and rich interactivity between textual documents and the 3D blackboard. In the long run, we would like to integrate the ITS (Intelligent Tutoring System) techniques into this system and construct an adaptive Web-based learning environment featuring cognitive media.

Keywords: E-learning, Cognitive Media, Interactive 3D Media, Computer Graphics Education

1. Introduction

The increasing availability of Internet leads to the birth and growth of Web-based learning (WBL) that has become a paradigm of how people utilize computers in education today. The impact of WBL on education is enormous and could be the most significant one among other technologies ever used in education. Instructional designs, curriculum plans, and even students' learning behavior are greatly affected by this technology. People can conveniently access learning material at any time and any place. The goal of life-long learning and distant learning is more likely to be achieved with WBL. It is obvious that the WBL paradigm solves the problem of learning material delivery under physical time-space limitation that exists in the past. This feature makes computers become an important tool and strategy in today's educational practice.

Besides the problem of time-space limitation, another issue in education is related to the concept of 'delivery'—the effectiveness of delivering concepts with different instructional method and media. Representing domain knowledge in suitable media types is important in facilitating learner-centered knowledge construction, or in short, making the contents easy to understand by learners. For computer-based educational system, this issue must be considered for better learning effects. The main concern is not what students could see on the computer monitors, but what students could learn and how well they learn in this environment. Contrast to the time-space limitation problem, the knowledge delivery issue correlates more closely and directly with learning itself, but this issue has not been deeply discussed in the WBL literature.

The concept of Spatial Coordinate Transformation (or SCT for short) is an important foundation for students to learn advanced computer graphics topics. A syllabus survey in computer graphics education [16] shows that geometric transformations including 2D and 3D are the major topics that most computer graphics educators care about. From the view of learning, this topic possesses two unique attributes:

(1) Abstract thinking is required. The concept of complicated geometric transformation can not always be experienced in the real world, so students have to construct a virtual world in his/her mind to assist learning. Therefore, the cognitive effort is high for students. It is typically a difficult task for an instructor to clearly describe these concepts without suitable communication tools. Students could be easily confused because of lacking abstract thinking skills.

(2) Multimedia presentation is needed. For in-depth understanding of this topic, mathematical descriptions are inevitable. So for clear description of these concepts, multi-symbol systems are required inherently. At least, the mathematical matrix representation, text-based description and the diagram-based representation are all required.

Requiring these two attributes (or criteria) may not be easily met in classroom-based instructional designs and educational media typically.

Our research is based on the observation that appropriate media representation and instructional designs should be a main concern for better knowledge delivery in Web-based learning environments (WBLE). The attributes of SCT leaning should be the criteria that have to be considered for media use and instructional designs. For abstract concepts that are better to be explained through instantiation and visualization with examples in SCT, text books tend to clarify them by pictorial diagrams. However, when the concepts imply dynamic processes, what the best text books could offer is usually a series of static frames.

Computer graphics and animation techniques could benefit SCT teaching. The difficulties in teaching SCT we just mentioned could be nicely solved by employing 3D computer graphics as educational media because of their capabilities of describing spatial concepts and facilitating specific instructional designs. Graphics greatly impact on human's perception. Though it is recognized that most students prefer pictorial visual experience rather than typical text medium empirically, we cannot ignore the potential of text, mathematical symbols in learning SCT and other science contexts. Reading, writing, and thinking in these symbol systems are fundamental skills that students should have. Web-based learning should provide appropriate scaffold for students to acquire these skills. We propose to incorporate suitable interactivity between different media in the learning environment. Two kinds of interactions are considered in our system. One is the navigation functionalities in 3D environment, and the other is the communication between textual documents and 3D scene.

The ITS (intelligent tutoring system) researches have developed considerable techniques to personalize the courses offered to students. For effective knowledge acquisition, students with different knowledge background and different skill levels on the topic should receive fit-to-size learning material, including documents, examples and questions. We notice the importance of adaptivity and its influence on learning. Adequate student modeling and course sequencing are performed in the proposed architecture.

The contribution of this research focuses on two aspects:

(1) an innovative idea of integrating interactive 3D media into Web hypermedia for teaching SCT, and

(2) integrating ITS techniques for adaptive content presentation and navigation support in the media-rich environment.

In this paper, we mainly describe our work from the first aspect, the interactive 3D media aspect. Our media use and instructional design is based on an interdisciplinary theoretical foundation. Besides, we will describe the proposed architecture and current implementation of this system from an overall view.

2. Theoretical Background of Learning with Media

The term 'media' could be defined from different angles within wide extent. In [7], an appropriate definition of media is "Media are a diverse range of technologies and process that humans use to explore, express or communicate ideas."

Examining characteristics of media could help us to realize media in depth. These characteristics are its *technology*, *symbol systems* and *processing capabilities* [10]. For instance, books, television and computers are technologies; Text, pictures, sound and 3D representations are symbol systems, and information is encoded in these modes. The feasibility of information retrieval on the Web is one kind of processing capabilities that television does not have [10].

The debate of the effects of learning with media has been discussed for long. The critical point is that *whether media influence learning or not*. It is important to notice that Clark claims that only instructional methods benefit learning but media do not [4], and Kozma's point is "media and method are inseparable"[10]. For developing WBLE, this argument actually reminds us to take instructional design as a main concern and to take advantage of the characteristics of computers and the Web on designing WBLE.

For Web hypermedia, it is almost impossible to replace some characteristics such as hyperlink by other technologies (ex. TV or books). Computers' capabilities enable novel instructional design that cannot be easily achieved by other technologies. When we consider media use in WBL, it is better to integrate them into instructional methods tightly by taking cognitive effects into consideration.

The idea of using computers as cognitive media in education are proposed by researchers based on different theoretical foundation and observation. Some are from the aspect of educational media use [7] while others are based on multimedia studies [13]. The explanations of cognitive media by these works are not quite the same, but it is evident that most studies notice the debate we just mentioned. The consensus is clear that media should be used meaningfully and related to learning itself directly. Recker et al. define cognitive media as: "Cognitive media are based on a cognitive theory of the inferential and learning processes of human users, and encapsulate different methods or strategies for problem solving and learning." [13] We propose to deliver contents in the most appropriate way which may consists of various kinds of media and methods.

Some researches on ITS (intelligent tutoring systems) and cognitive sciences consider computers as cognitive tools which imply that computers are tools to assist learners to accomplish cognitive tasks [9]. Different descriptions of computer's role in education—cognitive 'media' and cognitive 'tools'— could be observed by different disciplines. But it also reveals that computers' capabilities are powerful and unique. As media, computer systems can store, deliver and represent contents. As tools, computers can help people to think, reason, and create ideas, which should be the elements of meaningful learning.

In short, we have a good foundation to clarify the potential of media in the system we proposed. We model and visualize SCT concepts in 3D scenes. Modeling itself is an instructional method, but it is not easy to be achieved without computer graphics techniques. The instructional method is almost not separable from the media, the 3D scene.

3. Related Works

3.1. 3D display in computer-based educational system

Several works in the literature focus on embedding 3D display into learning environments. Specifically, Virtual Reality (VR) receives considerable attentions by researchers. VR technology offers realistic, immersive and interactive environments to model and simulate the actual world. Users are able to perform objects manipulation and scene navigation in this type of environments. The VR paradigm—integrating navigation functionalities into flat screen display to form the complete 3D perception and cognition—has been used widely by computer games and Web 3D applications. [14], [15] and [17] are good examples of this approach in education. Among them, [14] is for space and life science education; [15] is for training operating skills of vessel machines; [17] is for safety training in chemistry laboratories.

The main objective of VR is pursuing the 'reality', that is, to make the virtual world more realistic. Besides VR, there exists another approach that employing 3D computer graphics techniques to represent data, information and concepts in the 3D media. In other words, the purpose of this approach is to model and visualize concepts what only exist in textual or mathematical symbol systems, which is very important for many fields of scientific researches. Visualization is also beneficial for delivering scientific knowledge [5]. Instances that employed this approach cover almost all science education areas. However, most of these instances are not designed for WBL; or on the other hand, most WBL does not consider adding the 3D visualization ability.

3.2. Intelligent tutoring on the Web

The development of ITS (intelligent tutoring systems) in the past 20 years accumulates substantial results based on AI and cognitive science researches. Most generic ITS architectures propose to build a good student model. The student model reflects systems' beliefs on students' mastery level on particular concepts. Furthermore, it is the driving force that enables the system to perform individualized tutoring to students [9]. By extending the generic architecture of ITS, various types of ITS have been developed based on different domains, pedagogical strategies and factors believed to affect learning [11][15][17].

With the rapid development of the Internet, some work has attempted to deploy ITS on the Web. These systems retain most features of generic ITS architecture [11]. Among these approaches, adaptive hypermedia is one that imports ITS techniques such as student modeling and course sequencing into Web hypermedia [2][3]. Adaptive hypermedia systems construct personalized view to large information, which enhances the effects of accessing information. For WBL, the adaptive design could share learners' cognitive load and reduce the hypermedia disorientation.

4. CooTutor System

The CooTutor (Coordinate Tutor) system proposed in this paper is a Web-based learning environment with interactive 3D media for SCT teaching and learning. From learners' view, it is like an enhanced text book with interactive 3D media and adaptive learning material. We describe the proposed architecture and its characteristics in this section.

The 3D blackboard and most client-side elements have been implemented in current version of CooTutor. A basic server-client structure is also constructed. The features of adaptability in the proposed architecture are not fully imple-
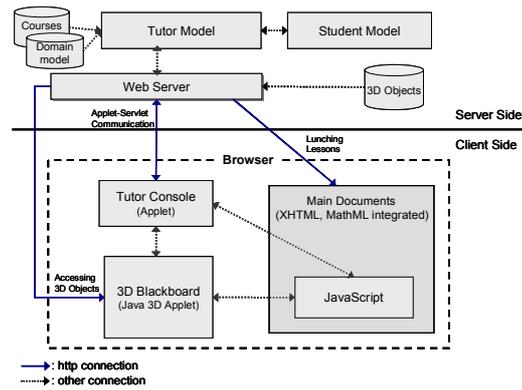

Figure 1. CooTutor system architecture

mented, and will be further integrated into CooTutor.

4.1. System architecture

Since CooTutor is developed to fit the Web, the inherent server-client pattern affects the architecture of the system. The contemporary E-Learning standard, SCORM (Sharable Content Object Reference Model) offers a good reference of generic WBLE architecture [1]. We shape CooTutor's run-time environment to meet the integration requirement of interactive 3D media. The architecture is illustrated in Figure 1.

As Figure 1 shows, at the client side, three main elements form the user interface of the learning area. The *main document* area presents textual documents, including textual explanation and mathematical symbols. Some JavaScript functions are coded in the documents to present 3D contents, which are visualized in the *3D Blackboard* module. The interactivity between textual documents and 3D contents are achieved by JavaScript functions. We will describe the user interface and its interactions further in the followed section.

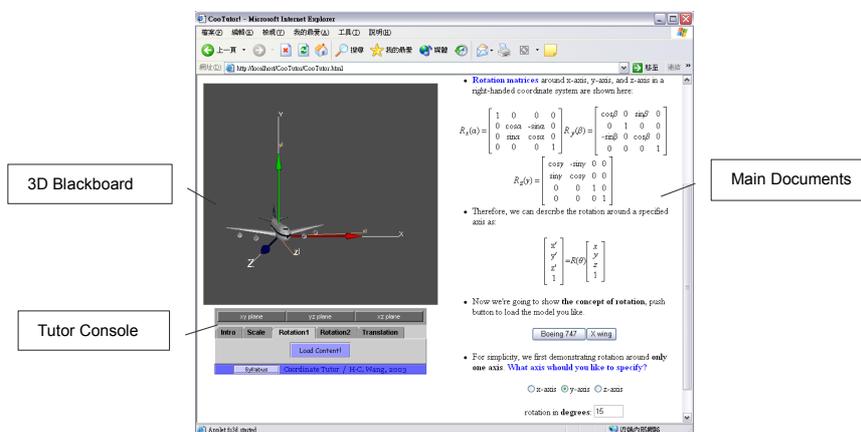All learning resources at the server side are delivered through the HTTP protocol to the cli-

Figure 2. User interface as the learning area

ent side. The tutor model performs course sequencing mechanism, and the student model performs student modeling. The delivery of student modeling data and sequencing results between server-client is established by using Java applet-servlet communication.

4.2. User interface with interactive 3D media

The appearance of user interface is illustrated in Figure 2. The interface consists of three elements: the *tutor console*, *main documents* area, and the *3D blackboard*.

Tutor console takes the responsibility of client-side management including course dispatching, user status collecting, and further communicating with the server. It is implemented as a Java applet and possesses the capabilities of applet-applet, applet-JavaScript, and applet-servlet communication in order to communicate with 3D blackboard, main documents and the server, respectively. The tutor console is like a control center resides at the client side, to assure this media-rich and information-rich environment works compactly.

The main documents area is where learning materials are presented. In CooTutor, a lesson is a basic presentation unit. For the needs of presenting multi-symbol systems (i.e. text and mathematical matrix notation), lessons are authored in XML format. By XML's functionalities of Namespace, XLink and XSLT, we can combine MathML (for mathematic symbols presentation) and XHTML (for typical hypermedia) compactly, to generate a text-book-like presentation on the Web.

The 3D blackboard is the module that provides 3D spatial concept visualization and instantiation for better knowledge delivery. We shape our system by taking advantage of interactive 3D media but without missing the characteristics and benefits of other symbol systems. We design two kinds of interactions in our system: One is the interaction between 3D blackboard and learners. Learners are allowed to navigate the scene with following modes: zoom, pan and rotate to obtain a good view angle for better understanding of the contents. Further adaptive navigation support will be designed in the 3D module. Another kind of interaction is the one between textual documents and the 3D blackboard. Learners read the textual contents in the main documents area, and directly manipulate objects in 3D scenes by the controls (i.e. buttons, input fields, etc.) in the Web page. The causal links between concepts (in text medium) and instantiations (in 3D medium) are made according to the course contents. This design allows different media types to be integrated tightly and cognitively to form effective cognitive media. The stickiness of WBL materials is expected to be added through this design. That is, students are more likely to get involved in the contents to pursue deeper understanding. Better students' concentration, ability of thinking in symbols and deep understanding of the topic are our main considerations in designing the 3D blackboard.

The 3D blackboard is a Java 3D applet with the Applet-Browser communication functionality. The FastScript3D toolkit developed by Dr. Koehler [8] offers a substantial basis to develop this module. Particular JavaScript codes are integrated into the learning materials with the XML format. These JavaScript functions are scripts of modeling, manipulation and animation. By calling these functions, XML documents can change the status and contents inside the 3D blackboard directly.

4.3. Content adaptation

Typically, most Web pages (HTML-based) are static and monolithic, which makes the problem of presenting individualized contents on the Web challenging. Targeting at offering learners with fit-to-size contents, two main paths as described below could overcome the 'static problem' and achieve adaptability.

One path is on generating the content dynamically. Most data-driven Web applications generate the content at run-time based on users' requests and the data stored in database system. This is a popular and useful approach for most Web applications that need dynamic presentation (ex. link annotation, partial content adaptation) or table generating (ex. presenting data in the view fit to users' request). The emerging of XML enhances the separation of data and presentation on Web. Furthermore, with transformation and filtering techniques, XML allows applications to perform content adaptation at a more semantic level. For example, [11] demonstrates an architecture of content adaptation by employing XML technologies. But this approach has its shortcomings. For example, web page generated by this mechanism is a mix of 'knowledge pieces'. Though the result is adaptive to an individual's need indeed, it may look like a collection of parts, not a car. From learners' view, they are more like discrete presentations, regardless of the tailored contents. The knowledge 'glue' (i.e. words bridging fragments in this case) is absent here. Natural, expressive document generation is evidently related to NLP (natural language processing) issues, which are valuable to study but might increase the complexity of WBL substantially.
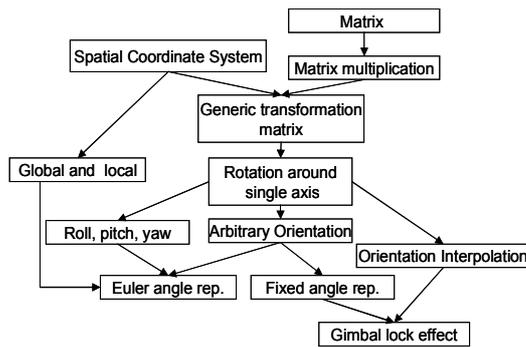
Another path is the static course sequenc-

Figure 3. Example of concept map as domain modeling

Figure 4. Lesson indexing by multidimensional attributes

ing approach [2]. Based on the student model and sequencing rules, systems are able to assess the best static content to different learners as well as the best sequence. The degree of adaptation is not as high as the dynamic generating approach. Nevertheless the sequencing approach is a simple and useful mechanism for delivering Web-based contexts. The possible 'knowledge pieces' problem does not appear in this approach since each unit to be sequenced has already been well authored as a human comprehensible article.

4.3.1.   Domain modeling

CooTutor adopts the sequencing approach, and a domain knowledge model is built as one of the back-driven forces of course sequencing. We propose a *concept map* structure to organize concepts as the domain model. [6] is a good reference of using concept map in ITS development. Nodes in a concept map represent concepts in the domain. However, these nodes are not lessons directly. Prerequisite relationships of concepts are explicitly modeled in this concept map. At run time, CooTutor performs dependency checking according to students' learning goal and background knowledge. If the student is eligible to learn the concept that the student targets at, an appropriate lesson at appropriate level will be presented by CooTutor; otherwise, series of lessons that complement the student's deficiency of prerequisite will be presented till the student reaches the goal. Figure 3 demonstrates part of the concept map structure in CooTutor. The arcs between nodes specify the prerequisite relationship. For example, for learning the concept "generic transformation matrix", "spatial coordinate system" and "matrix multiplication" are prerequisites that required to be learned as the background.

Since the most basic unit to be presented in CooTutor is a 'lesson', we have to consider an appropriate linkage between lessons and concepts. Most WBLE does not build the domain model explicitly. If they employ sequencing mechanis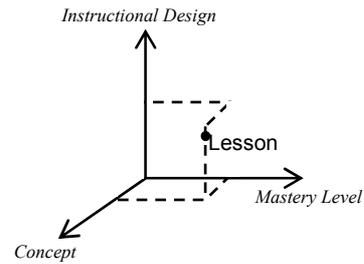ms, they sequence lessons (typically a group of pages) directly even if one page may contain several concepts and consist of various kinds of physical media types. This design causes problems. For example, if we have a research paper in PDF format that is related to many concepts, it is hard to determine when to present this paper and what are the relationships between this paper and other lessons. Sequencing at this level is too gross for effective adaptability.

In CooTutor, each lesson (the basic learning item to be presented) is indexed by *multidimensional attributes* as shown in Figure 4. We think Web-based hypermedia lessons should have the follow attributes: *concept, mastery level,* and *instructional design.* The concept attribute indicates concepts embedded in a lesson. Each lesson may have several concepts, and each concept could be embedded in several lessons. The mastery level attribute specifies what mastery level the lesson is designed for (for example, for a novice or an expert). The instructional design attribute indicates the instructional method and media use in the lesson. It should be an attribute based on the cognitive media concern. For example, an explanation with the 3D blackboard, a brief textual article, and a quiz are all examples of instructional designs.

By using the idea of multidimensional attributes, we can locate each lesson as a specific point in the attributes space. We establish the linkage between lessons, concepts, and other attributes. CooTutor performs course sequencing based on the concept map and the multidimensional attributes concern.

4.3.2.   Student modeling

CooTutor models learners' learning status by observing lessons that students have launched and the result of a quiz. Since each lesson is indexed by multidimensional attributes, CooTutor will trace students' mastery level of each concept and record the instructional design methods preferred by students.

"To model or not to model" is a critical issue that researchers have argued around [9]. It is
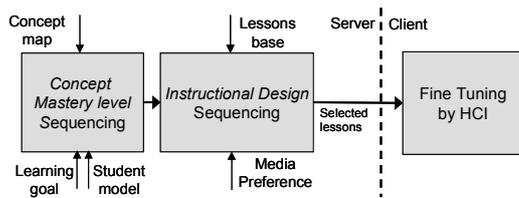
Figure 5. Course sequencing with multidimensional attributes

evident that if the goal is to diagnose students' misconception, even complicated pedagogical strategies, such as problem-solving activities, a fine grained student modeling mechanism is required. Whereas for the WBL context, effective student modeling may not needs to be a complex one. Clearly, the purpose of CooTutor is to maximize the benefits of cognitive media to convey ease–to-understand contents to students. So the student model that we are proposing is to achieve the course sequencing mechanism by providing adaptive content with cognitive media to different students.

4.3.3.　Course sequencing

The course sequencing mechanism is performed by the tutor model. By accounting for multidimensional attributes, CooTutor selects adaptive contents as Figure 5 shows. Selecting the lesson is a sequential process. The first step on the left, the concept and mastery level sequencing phase, will take the concept map (in Figure 3), students' learning goal, and the student model as inputs. The learning goal should be a concept node in the concept map, so the selector will be able to determine what concepts should be learned before the goal. After the first step, the output will be taken as the inputs to the second step, the instructional design sequencing phase. Based on individuals' media preference, a ordered set of hyperlinks pointing to lessons are dispatched to the client side. At the client side, the tutor console module can further tune the sequence based on human-computer interactions at real time.

By the concept map structure, we adopt an algorithmic approach to tackle these tasks. Though not yet integrated, rule engines could be employed in the independent tutor model as in the agent approach.
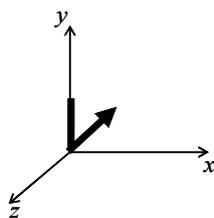
5.　Course Example

In this section, we use the concept of "Gimbal lock effect" as an example to demonstrate how CooTutor plays the role of cognitive media with interactive 3D media..

Gimbal lock is a problematic effect while using fixed angle representation or Euler angle representation in the SCT context. The scenario is when we describe an orientation in spatial coordinate by these representations. At some configuration, such as (0, 90, 0), we will lose one degree-of-freedom around the first axis (i.e. x-axis in general). At this configuration, the rotation around the x-axis will achieve the same effect as rotating around z-axis. So students and novices at computer graphics are easily perplexed by this obscure concept.

Text books try to explain this concept by amounts of figures. But the figure itself only offers 2D visual experience like Figure 6 (adopted from [12]), so it may cause some misunderstanding. Figure 6 is employed to express "the arrow points to negative z direction, and the configuration is now (0, 90, 0)", but it's quite easy to recognize that the arrow lies on the x-y plane, not the z-axis.

In CooTutor, we express spatial concepts as Figure 7 shows. With the capability of free navigation, CooTutor can express the concept much clearer than typical figures on books or even HTML-based web pages. In Figure 7, it is obvious that the plane's nose points to the negative z direction. Learners are able to construct this cognition from various view angles.

CooTutor explains the Gimbal lock concept as Figure 8 shows. The main document offers textual description of the concept. HTML buttons and input fields are embedded in the document at appropriate positions. Students can operate these controls and see what is happening in the 3D blackboard after percepting particular descriptions.

In the lesson, CooTutor asks students to first make the plane directed to the orientation (0, 90, 0), the orientation that encounters the Gimbal lock effect. After this operation, students can experiment with this problematic scenario repeatedly. This design scaffolds students to construct knowledge on their own. They may also
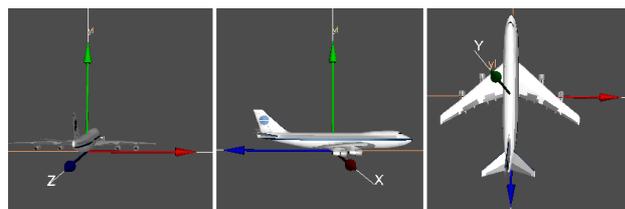

Figure 6. 2D description of spatial concepts

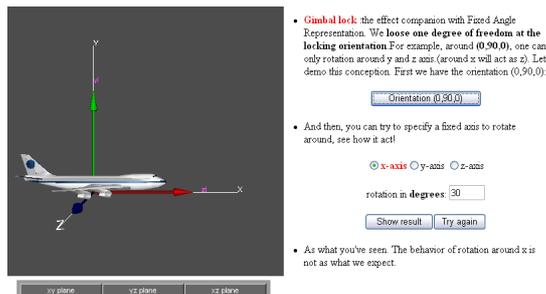Figure 7. Describing spatial concepts with 3D navigation

Figure 8. Presenting the "Gimbal lock" concept

also feel confused because this strange scenario is not what they think. This kind of confusion is different from the situation of unclear problem definition. It is a good one, called the "cognitive conflict", that leads students to explore the problem deeper and achieve the meaningful learning.

6. Conclusion and Future Work

This paper describes the theoretical background of cognitive media, and how we design CooTutor with interactive 3D media to achieve the goal. We also take a bird's eye view of the proposed architecture. By integrating WBL, interactive 3D media, and ITS techniques, we aim at constructing a learning environment for effective knowledge communication between computers and humans.

The development of CooTutor is still at the early stage. Our future works mainly focus on implementing all proposed features, and conducting pedagogical experiments on students to evaluate the effects of facilitating SCT learning. With these evaluation results, we will have a practical basis to improve CooTutor iteratively.

7. Acknowledgement

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