ED-MEDIA, World Conference on Educational Multimedia, Hypermedia & Telecommunications, Orlando, FL, June 26–30, 2006, pp. 2282–2289

Implementation and Evaluation of a 3D Multi Modal Learning Environment

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Abstract: We developed and tested a multimedia education system, called LEMMA, which allows educators without programming experience to design 3D interactive multi-modal tutorials. For the learner, our system aims to leverage advantages of interactive computer visualizations and the navigational benefits of hypermedia. LEMMA supports upcoming design principles in computer-aided education, such as modularity and reusability, facilitated through a storyboard-style authoring environment that promotes consistency among multiple media, including text, speech, 3D visualizations, and 2D and 3D interaction. We created a first tutorial about "Rotational Rigid Body Dynamics" and applied it in an undergraduate physics course, using an interactive reach-through screen as our medium of choice for 3D visualization and interaction. This paper introduces the system itself, the methodology the system uses and provides the results of an initial user evaluation.

Introduction

While the general benefits of multi media learning environments are fairly well understood (e.g. Mayer 2001), the field is still in need of concrete design principles and guidelines for making best use of the capabilities of hypermedia interaction. For approaching this problem, we present LEMMA, a “Learning Environment with Multi-Media Augmentations”. The system is designed to develop, evaluate and evolve multi modal learning content of various kinds. LEMMA consists of two parts: an authoring system that enables teachers to prepare course topics as highly interactive hypermedia presentations, and an interactive learning environment that enables students to learn the prepared material at their own pace through an interface that offers multiple modalities, including spoken and written text and 2D and 3D imagery. The system, which can be presented on conventional desktop computers or 3D immersive display environments, supports a student’s learning experience with tangible 3D interaction and easy-to-use navigation capabilities. Researchers from the fields of media informatics, computer science, and education, as well as physics educators contributed to this ongoing project. We deployed and evaluated LEMMA in an undergraduate physics course, authoring and presenting tutorials for topics on rotational dynamics, and based on these, we present results and observations in three major areas:

- *Authoring for E-Learning*: We establish the benefit of modular multimedia building blocks for adapting learning content and of high-level authoring support for maintaining consistency among different media.

- *Comparison with classroom learning*: Students who interacted with LEMMA (without additional teacher intervention) performed equally well on a knowledge transfer test when compared to students covering the same material through a class lecture. However, a survey reveals that students still consider classroom learning advantageous.
- *Guidelines for the design of interactive multimedia learning content:* Based on our evaluations and observations, we present several initial guidelines and design principles that improved the efficacy and acceptance of our multimedia content.

After an overview regarding selected related work, we present the functionality of LEMMA, its system architecture, a summary of our design decisions, and the outcome of a first user study with undergraduate physics students. We conclude the paper with a discussion of the lessons learned and an outlook on future research.

Related work

Presentation and interaction capabilities of modern computing platforms, which include multi-modal rendering, personalized interactivity and real-time simulation, have long been deemed highly suitable for application in the field of education (Osberg 1992). The constructivist approach to education, which emphasizes the learner's own practical experience with the learning material (Mantonavi 2001, National Research Council 2000) suggests the employment of hands-on experimental learning techniques that can be readily supported by the simulation and interaction capabilities of today's multimedia computers. However, mature standards or approved guidelines for computer-aided learning do not exist, and the benefits of reusable learning content are not systematically exploited. With LEMMA's authoring environment educators can develop and improve learning content without requiring knowledge of a programming language. The multi-modal fashion in which the content is presented to the learner and tangible 3D interaction are two key concepts supporting the learning process (Osberg et al. 1997).
LEMMA is mainly related to research on *Virtual Reality (VR) in education* and *reusability and standardization of learning content*. Regarding the latter, one of the most promising efforts might be IMS Learning Designs (IMS Global Learning Consortium n.d.). IMS LD is an XML specification that describes a markup format for encoding knowledge content in a reusable fashion, with the potential to be rendered in various ways. LEMMA also uses XML, but where IMS LD uses the metaphor of a theater, LEMMA is based on the idea of a storyboard (combination of book and events). Chen et al. (2005) provide a sequencing engine and Harper et al. (2005) a design tool for IMS LD, which both have their respective counterparts in LEMMA and the LEMMA authoring environment. A related educational tool using virtual and augmented reality is Construct3D (Kaufmann & Schmalstieg 2002), which uses an immersive augmented reality approach to teach geometry. The main difference is that Construct3D is mainly designed for human collaboration, while LEMMA's approach is that of a computer-guided tutorial. While collaboration is possible with LEMMA, it is not evaluated in this first study, as the focus is more on how to re-iterate and therefore evolve reusable learning contents. NewtonWorld (Dede et al. 1996) is an immersive physics tutorial for linear dynamics. LEMMA, on the other hand, is not designed primarily for physics education or immersive learning per se, but targets more the design aspect of computer tutorials.

System Functionality and Design

We developed two main LEMMA applications: one for authoring and one for letting students interact with the tutorial content. The authoring system was designed as a conventional desktop application, whereas the tutorial presenter, which supports 3D virtual reality content and interaction, is by default controlled via a 3D input device. This could be, for example, a data glove (Fig. 1 left), a tracked wand coupled with a mouse (Fig. 1 right) or any device supported by VRPN (Taylor 1998). Tutorials that only need 2D interaction can also be controlled with a conventional 2D mouse. We tested the tutorial presenter in two setups: the *desktop version*, in which we used an Essential Reality P5 Glove and two monitors, and the *immersive version*, in which a rear projection screen was used for narration and supplemental information (text and images) and an interactive FogScreen (DiVerdi et al. 2006) as the main visualization / interaction area. We decided to use this device because it allows for real 3D interaction, as there is no solid screen that would limit the user's movement. A tracked wand coupled with a

Bluetooth mouse was used as input device. All evaluation studies reported in the later sections of this paper were done with the immersive setup.

Figure 1. LEMMA in its desktop two-monitor configuration with data glove as input device (left), a student using LEMMA on the FogScreen (right). He generates a force vector (white) to rotate the displayed top (axis in red).

Learning Application

The interface of the learning environment consists of two views. The main view hosts visualizations and interaction. A second view, which can reside either on a separate or on the same screen, displays the tutorial text, additional 2D visualizations (pictures, formulas, etc.) and other related information. The student now can read along with the text on this screen and / or listen to the voice of the lecturer, which is synchronized with the text.
The control interface for the application, which is located entirely on the main view, resembles that of a web browser, building on the successful principles of hypermedia. Users can move between “Knowledge Nodes” - chapters or other designated positions in the tutorial. “Back” and “Forward” functions allow them to navigate around without worry of losing their previous position. This allows for example for looking up earlier content that may be useful at the current position in the tutorial and then returning easily. Furthermore, learners can create their own bookmarks if they anticipate returning to a certain position in the tutorial later. Chapters in the tutorial are listed as icons on the top of the screen. In contrast to a browser, the tutorials in LEMMA also have a sequential flow, like in a lecture, which is why some navigational controls are kept similar to those of a DVD player. The user can skip sentences sequentially, either forward or backward to read something again or let the computer read it again. A ‘Pause/Resume’ button gives the learner the possibility to stop and take a closer look if need be. During a paused tutorial, visualizations are still active and responsive for interaction. The tutorial is meant to alternate between sequences of explanation and demonstration and phases when the student is instructed to apply the new knowledge and experiment on the current visualization. Furthermore, as a first method of assessment, the educator can schedule multiple-choice tasks for the learner that might lead to the next portion of knowledge or ask the student to review former content.

Tutorial Content

The tutorials that an educator writes in the authoring environment are internally encoded in an XML representation that resembles a storyboard. A tutorial is composed of chapters, which include the tutorial’s text, descriptions of visualizations and events that take place during the tutorial. The encoding for the visualizations lists the visualization’s geometry, initial settings, and attributes of interactable objects in the scene (e.g. labels, what property to modify, etc.). Events are sequentially processed signals and effects that represent various ways for the author to control the flow of the tutorial. Some examples are:

- Highlighting arbitrary objects in the scene
- Controlling various switchable properties such as ‘pause/resume’, ‘freeze simulation’ or ‘gravity’
- Wait for another event

* Turn on/off 'interactable' items
* Grant / withdraw access to chapters

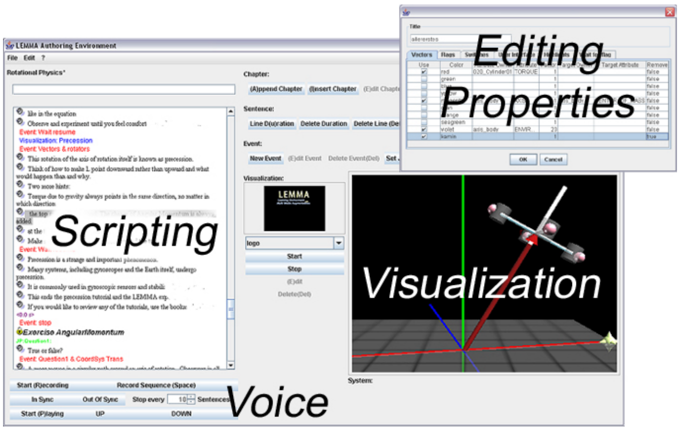

Figure 2. The Authoring Environment
(large labels for annotation purposes only)

Authoring Environment

One of the main drawbacks of computer-aided learning is that the content usually has to be generated by a person with considerable computer programming skills. In order to enable educators without technical expertise to design their own multimedia tutorials, LEMMA provides them with an authoring environment that takes care of data formats and low-level representations and ensures consistency of the content. The authoring environment (see Fig. 2) enables the author of a tutorial to conveniently write and modify the tutorial through a graphical user interface, without requiring any programming.
The text is edited like in a word processor, except that the author is assisted in grouping the text as chunks of sentences, which can easily be modified and enhanced by voice samples. The author records his or her voice along with the text lines, which are later played back in a synchronized fashion in the tutorial. All properties of the tutorial entities mentioned above (chapters, lines, visualizations, events) are modifiable through dialog boxes. Chapters can for example be access-restricted, so that the learner cannot use them before the author has given permission to do so through a scripted event. The learner might receive this permission after having completed another prerequisite chapter. Visualizations can be modeled in a conventional 3D modeler and exported to .osg format. The authoring environment reads in this representation of the 3D model and creates an XML description, which can be plugged into the tutorial at any position and be configured in place, again without ever dealing with XML itself. Coding is not necessary, be it for producing textual, audio, or visual 2D or 3D content.
There are various features that help the author keep the script consistent, such as visual feedback when a voice sample needs re-recording as the text was changed or a specifically blocked button when inserting a visualization is not possible at this position in the script. It was obvious after the first experiments, that the importance of such feedback can hardly be overestimated, as it is very difficult to develop a tutorial of that kind without the help from the software. This is mainly due to the sequential nature of the tutorial, while random access to any location in the tutorial by the user must be preserved as an option. The user may i.e. want to start the session in the middle of a chapter and the program has to make sure that the context of the particular position is present. This can be for example a visualization and various events like drawing a vector or displaying a formula. Therefore the authoring environment has to maintain the script in a consistent state that allows for this claim at all times and inform the user how to arrange the script accordingly.

Implementation

The system was implemented in Java, using OpenSceneGraph as its 3D graphics engine, accessed through JNI bindings (see Fig. 3).
Note that the physics engine is only a module that can easily be exchanged if the content should need a different kind of visualization than physics does, for example a module for simulating molecular interaction for a chemistry tutorial, or maps for geography.

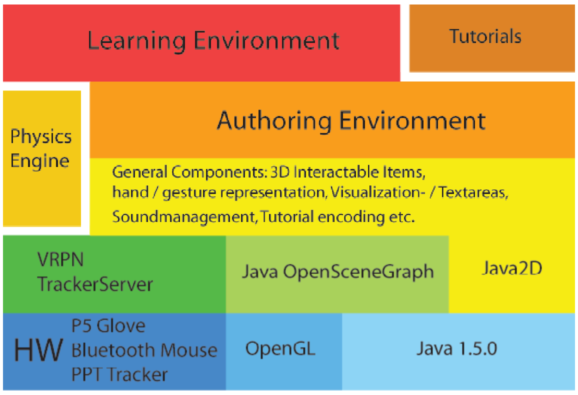

Figure 3. LEMMA Software Architecture

Design Decisions

One of the main goals of our approach is to provide the educator an easy way of generating and re-iterating the content to be taught. Tutorials are often written for one particular purpose and are not commonly reused. Our work is geared towards reusing previously established knowledge "modules", analogous to successful practices in software engineering.
Mayer's *multimedia principle* (Mayer 2001) advocates the use of text plus visualizations as beneficial for knowledge transfer to the student and for retention. Mayer also states in his *modality principle* that narration is superior to on-screen text. However, since different people prefer different channels for learning, a successful e-learning system should give the user a choice of written and narrated text together with visualizations. In general, the user should be given some control over how knowledge is presented. Complete control by the learner, however, can turn out to be counterproductive, since it causes a high cognitive load, especially for novice users. Therefore, we designed our system to provide automated guidance through the content materials, but also give the learner representation and navigation controls, such as, for example, voice on/off, pause and resume, slow down, go back, and the use of hyperlinks and bookmarks.
We attempt to keep the advantages of traditional learning media while introducing the benefits of multi-modal presentations and 3D interaction. A book's advantage is the permanent availability of whatever is included – the content does not stream by the learner like in a lecture or movie – it can be read repeatedly and at the user's pace. Disadvantages include its limited modality (only text and 2D visualizations, no interactive feedback) and the lack of hypertextuality, meaning that it takes an effort to look up referenced previous knowledge ("As seen in Eq. 8.2…"). The undisputed strength of classroom teaching is the interactivity between students and teacher and the collaborative pursuit of knowledge. Drawbacks include the limited time teachers have for each student, lack of individualized multimodal interaction, and the pressure on the student to not be embarrassed in front of classmates, resulting in a possible inhibition to participate.
LEMMA's tutorials feature computer-guided interaction, voice plus on-screen text (for easier reference) and 3D visualizations and interaction. Osberg et al. (1997) stress that "Interaction is a critical component to students' knowledge construction…" and "…virtual reality […] engages the whole body in a manner that is valuable for developing somatic memory". We share these observations and offer 3D tangible interaction as a central concept in LEMMA. With personalized interaction we aim to keep the focus on the learner and not on the technology (see

Osberg 1992) and encourage the student to instantly apply new knowledge in interactive scenes. The first topic area we targeted with LEMMA was a portion of undergraduate physics curricula, namely "Rotational Dynamics". To this end, we equipped the system with a simple physical simulation engine, and students from an actual physics course took an interactive LEMMA tutorial and were tested on various concepts afterwards.

LEMMA in Physics Education

Fifteen students from a freshman physics course participated in the study. The participants were between 18 to 19 years old, 13 males and 2 females with varying levels of experience with 3D interaction. The content of the physics tutorial was mainly designed and written by the physics lecturer who presented the course. Based on initial formative user studies, the lecturer and software designers structured the tutorial into a suitable form.

Usability

LEMMA, as a general learning application, can also teach its own functionality to the learner. The participants were told nothing about the system, except how to click the start button. After that, the system explained its capabilities to the users and let them go through different tasks to familiarize them with the functionality. The following observations were made during this first phase: All of the users understood instantly and intuitively how to use interactable items, which besides common buttons, switches and sliders, also included less familiar items such as draggers and vector input controllers: a device for generating forces. All but one of the users successfully mastered all of the navigational features. Only one had slight difficulties understanding the backward feature, as it differs a little from the backward feature in a browser (change page vs. position in a tutorial storyboard), and another student did not fully master the bookmarking feature. A task where the student should align a coordinate system with an axis by moving and rotating it tested true 3D interaction. Only 9 out of 15 initially managed to complete the task. This can be explained by most of the students being used to 2D mouse interaction (even in 3D environments) from desktop applications. They tried to perform a 2D-mouse-like technique with a controller that is supposed to be truly moved in 3D space. Those students that were less familiar with 3D applications had fewer difficulties with the new interaction techniques. Repeated practice successfully conveyed the concept of true 3D interaction with the FogScreen.

Deployment in actual physics coursework

Of the 15 participating students, nine used LEMMA to learn one lecture's worth of their course material (Angular Momentum, Torque and Precession) without having been introduced to it in class. They filled in a pre-tutorial questionnaire to assess their background and familiarity with VR, and then went through a self explanation of the system (average time 19 min), followed by the physics tutorial itself (average time 21 min), concluded by a self guided exploration (average time 6 min). After their experience with the system, they took a written test to verify the knowledge gained through the tutorial, and then filled a 20-item questionnaire evaluating their experience with the system. Sessions took a total of one to two hours. The other six students, serving as the control group, were introduced to the same material in the classical fashion of a classroom-based lecture. They also were quizzed on gained knowledge afterwards. The performance on the test was very similar for both groups (see Fig. 4).

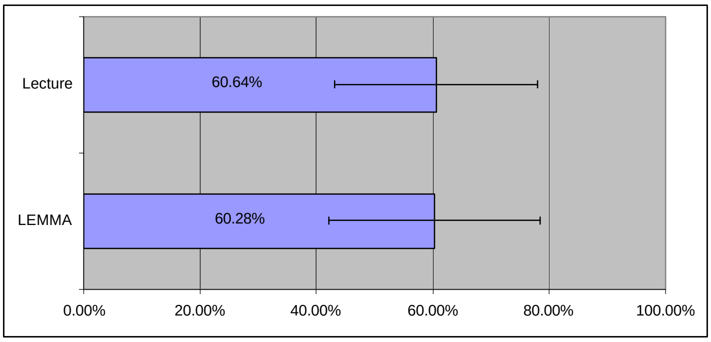

Figure 4. Comparison of performance in the test about the taught material.

According to this result both groups have learned a similar amount of knowledge, while the students using LEMMA spent less time on the actual content and additionally had to become familiar with a new user interface. Table 1. illustrates the answers to the most important questions the students gave in a post-study questionnaire. Most students really enjoyed using the system and were of the opinion that the tutorial provided useful visualizations for otherwise abstract concepts. The FogScreen as an interactable visualization canvas was found to be helpful for 3D perception and 3D control of a scene. Furthermore, most students found the multimodality was helpful for following and understanding the content and were little distracted by the novelty of the hardware. Nevertheless they were more of the opinion that they could learn the topics better with a human teacher in class, mainly because of the possibility to ask questions.

Question	**Average answer** (1 = "Strongly Disagree", 5 = "Strongly Agree")
Overall, I enjoyed using the system.	4.33
The tutorial provided useful visualizations for otherwise abstract concepts.	4.25
The interactive FogScreen helped 3D perception and 3D control of a scene.	4.33
The multimodality (text, speech, visualization, 3D interaction) helped me in following and understanding the content.	4.17
The novelty of the hardware and overall system distracted me from the physics content.	1.67
I believe that I can learn these topics in class more effectively.	3.08

Table 1. Answers (median) to the most important post-study questions

Authoring and design guidelines

During the study, the observation and comments of the students revealed some weaknesses of a particular sub-tutorial, namely the one on "Precession." Testing our design principle of easy content improvement, we re-iterated the tutorial (overall time investment: 2 hours) and had three more students try the system after the improvement. Two of the three students were able to develop a much-improved idea of Precession. The main issues spotted were too few breaks for knowledge deployment and too vague instructions on what to do with the new knowledge.
When asked for their personal opinion about the different modalities, different students gave very different answers. Some liked the combination of on-screen text, voice and visualizations, while others stated that they would have omitted the audio part, and one even would have preferred a paper book in combination with the interactive visualizations. In summary, we can list the following three informal design guidelines for storyboard-style e-learning:

- Provide multiple modalities as it is helpful and allows users to adjust presentations according to their preferences
- Deliver concrete user instructions in small chunks (long explanations result in attention loss), and
- Give the users opportunity to apply and test their newly gained knowledge (again triggered by short concrete instructions)

Another important observation was that the students were eager to discuss the learning content after the end of the study, and the interactive visualizations turned out to be a very suitable tool for discussing concepts while going through and manipulating the content together in a student – teacher situation. Therefore, LEMMA might have a high potential as a teaching and collaboration tool as well.

Limitations of the study

Due to limited time and participant numbers, no pre-test of the students' former knowledge about the content was executed. . However, the lecturer made sure that the participants had not seen the material in any previous lecture.
In the ScienceSpace project (Dede et al. 1996), one of the results was, that, "Single Session Usage of NewtonWorld was not enough to dramatically improve the user's mental models.". Similarly, in our case more sessions will be needed to find significant learning effects and reliably pinpoint the causes.
One of the ideas of LEMMA is to provide a learning environment in which students can learn at their own pace and uninhibited. Unfortunately, it was not entirely feasible to give the participants such a feeling, as they were still in an artificial situation under the observation of strangers and therefore sometimes appeared to rush.

Conclusions

Through our observations of users interacting with the system and through evaluation of a tutorial with the system, we can already provide a few hints on how to design multi media learning environments and content. Regarding the environment itself it seems to be of value to give the student the option of different modalities but leave it's particular utilization open. There is no evidence, but the notion, that the interactive setup enabling the student to experiment seems to work fine for building conceptual understanding. As a tool for designing educational content, the authoring environment's most important attributes are relief from technical details (encoding, consistency) and supporting feedback. When writing content for an educational system like LEMMA, the author should keep in mind to provide many occasions for experiments between small chunks of knowledge and to give very detailed instructions to the student.
We presented the concept, implementation and first evaluation of a multi media 3D learning environment. In a study with physics undergraduate students involving actual curriculum material, we found the system to be a valuable supplementary to daily coursework. Participants learned the content and enjoyed using the system. We think that with using LEMMA we will be able to spot beneficial learning patterns for computer-aided tutorials, as already a first re-iteration revealed fruitful improvements of our multimedia tutorials. More studies with multiple sessions and less variables will be necessary and may lead to guidelines for successful multimedia learning design. Additional high-potential studies include collaboration in teacher-to-student or student-to-student scenarios. Furthermore tutorials are intended for other areas such as chemistry, languages, or sports.

References

Chen, M., Chen, C., Cheng, Y., & Hsieh, C. (2005). On the development and implementation of a sequencing engine for IMS learning design specification. *International Conference on Advanced Learning Technologies*, 5-8 July 2005, 636 – 640.

Dede, C., Salzman, M.C., & Loftin, B. (1996). ScienceSpace: Virtual realities for learning complex and abstract scientific concepts. *Virtual Reality Annual International Symposium, VRAIS '96*, IEEE Computer Society Press, Los Alamitos, CA, 246-252, 271

DiVerdi, S., Rakkolainen, I., Höllerer, T., & Olwal, A. (2006). A Novel Walk-through 3D Display. *SPIE Electronic Imaging*, Stereoscopic Displays and Applications XVII, San Jose, CA, USA, January 15-18.

Harper, B., Agostinho, S., Bennett, S., Lukasiak, J., & Lockyer, L. (2005). Constructing high quality learning environments using learning designs and learning objects. *International Conference on Advanced Learning Technologies*, July, 5-8, 2005, 266 – 270.

IMS Global Learning Consortium (n.d.). *Learning design specification*. Retrieved October 20, 2005, from http://www.imsproject.org/learningdesign

Kaufmann, H., & Schmalstieg, D. (2002). Mathematics And Geometry Education With Collaborative Augmented Reality. *SIGGRAPH 2002 Conference Abstracts and Applications*, ACM Press, 37 - 41.

Mantovani, F. (2001). VR learning: Potential and Challenges for the Use of 3D Environments in Education and Training. *Towards Cyber-Psychology: Mind, Cognitions and Society in the Internet Age*, Chapter 12, IOS Press, Amsterdam.

Mayer, R.E. (2001). *Multimedia Learning*. Cambridge University Press, New York.

National Research Council (2000). *How People Learn. Brain, Mind, Experience and School.* National Academy Press, Washington D.C.

Osberg, K., Rose, H., Winn, W., Hollander, A., Hoffman, H., & Char, P. (1997). The Effect of Having Grade Seven Students Construct Virtual Environments on their Comprehension of Science. *Annual Meeting of the American Educational Research Assoc.*

Osberg, K. (1992). *Virtual Reality and Education: A Look at Both Sides of the Sword*. Retrieved October 20, 2005, from http://www.hitl.washington.edu/publications/r-93-7/

Taylor, R. (1998). *VRPN: Virtual Reality Peripheral Network*. Retrieved September 13, 2005, from http://www.cs.unc.edu/Research/vrpn/