FORMATIVE DESIGN OF A VIRTUAL LEARNING ENVIRONMENT

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ABSTRACT

Current technology for 3D visualization, modeling and interaction allows the construction of attractive virtual environments for study of anatomy, surgery and other biomedical fields. The formative methodology for designing such environments is uncharted, but necessary before committing to large scale development. We present one such methodology undertaken during the design of a learning environment for biology for high school and middle school students. We expect to extend this design methodology to the development of environments for the teaching of medical subjects.

INTRODUCTION

We have designed and implemented a prototype web-based virtual 3D environment for teaching vertebrate biology for high school and middle school students. This 3D learning environment, which we called Frog Island, contains a Virtual Frog along with a rich array of related resources (images, sounds, data, and simulations) that students and teachers can use to study the biology of frogs. Working closely with biology teachers and students, we developed a new Web-based approach for teaching biological principles: engage students in an interactive, engaging, self-paced, virtual environment which contains a rich array of multimedia learning resources. The virtual creature, and the tools to explore, dissect and reconstruct it, will complement existing techniques such as class lectures, textbooks, lab experiments, and dissections, with the objective of allowing students to interact with, experiment on, and perform goal-based exploratory and constructive exercises in virtual environments.

The process of designing this virtual environment involved numerous stakeholders: middle and high school teachers of biology; students from middle and high schools; computer scientists; education researchers; biology researchers; and a surgeon. The original goal was to create a virtual creature that students could dissect on computer (see Figure 1). The virtual creature would consist of a 3D volumetric rendering derived from computer tomography of an actual creature. Students would be able to do simulated endoscopic examination as well as simulated surgery on the virtual creature. During the process of formative design, we met with all the stakeholders, while we developed a prototype virtual creature using cross-sectional images of a frog from Lawrence Berkeley National Laboratory (Johnston 1994). What we learned in these investigations, led us to greatly expand our original goal. The Virtual Creature that students could explore in various ways evolved into a simulated 3D learning environment, Frog Island, and which contains the original Virtual Frog along with a rich array of related resources that students and teachers can use to study the biology of frogs - images, sounds, data, and simulations

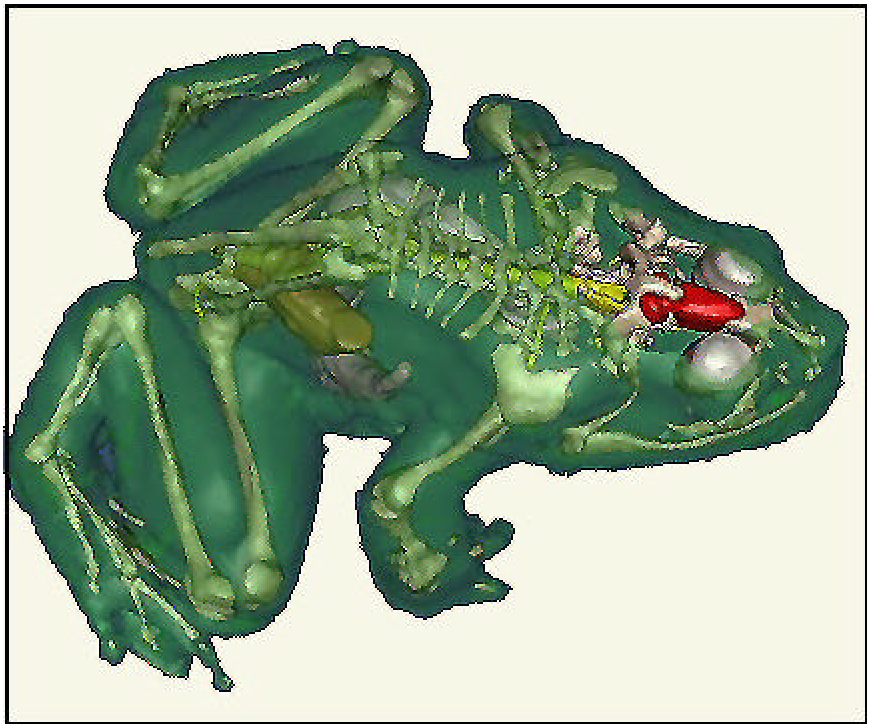

Figure 1: A manipulable 3D Virtual Frog shown with various organ systems.

METHOD

We present here the methodology of formative design used in this project. Our initial hypothesis drove our early development: that virtual dissection would provide many advantages to supplement biology teaching even where the teaching included real dissection.

We supplemented in-house design with numerous interviews, presentations and discussions with groups that were teaching or learning biology, or were researching the process of education. The needs presented by these groups strongly influenced our design of the virtual resource. The final form of the resource included some of the concepts in the original formulation but went well beyond, to include a rich array of learning resources on frogs, their habitat, their anatomy and physiology, as well as larger questions such as the ethics of experimentation and the relation of frogs to humans.

RESULTS

We present the results so as to indicate how the formative design process altered and shaped the development of the actual resource.

Teacher Meetings 1

Middle and high school biology teachers were interviewed about current methods in teaching biology, and reactions were obtained to the use of a virtual creature for teaching. We expected a detailed analysis of the utility of the proposed virtual dissection resource, and the manner in which such a resource might be integrated into the biology curriculum. We found that biology teachers use numerous activities and media to convey concepts. An example, in middle school, is drawing an outline of each student and asking them to fill in a sketch of the skeleton. Instead of focusing on factual content, such as anatomical identification, they teach integrative concepts such as the relation of form and function, development, or comparison across species.

While they were enthusiastic about computer support in biology, they were dubious about a resource that focused solely on realistic dissection. In place of realism, they were interested in obtaining information that linked the anatomy to habitat adaptation, behavior, or physiology.

Student Meetings 1

Middle and high school students were interviewed to understand what they like, and do not like about how they learn biology, and obtaining reactions to the use of a virtual creature. They reported the use of textbooks and numerous other resources, including movies, museums and dissection. They did not mention, as separate resources, the types of activities highlighted by the teachers. Books that tell a story, such as the Magic Schoolbus series, held their interest. Newer technology, such as interactive CD-ROMs, were reported as being more interesting than passive presentations such as by videotape. Students wanted to interact with the content, select and follow information, and manipulate 3D objects.

The concept of virtual creatures was attractive. Younger children wanted to build new creatures. Older ones were more interested in richness of content and in realism. While many students were interested in doing simulated surgery on realistic representations, some preferred removal of all “gross” features, such as blood. All felt that haptic feedback, such as feeling the surface of the tissues, would be useful in learning. Older students were interested in abstractions, such as brain function. Younger ones wanted to make bones move. Humor, music and speech were desired by most, with younger children preferring more cartoon-like effects. Byron and Reeves [1] maintain that it takes very little for people to impute a personality to a media device.

One of the groups came from a background that was less affluent than the others, with an impoverished biology learning experience. This group emphasized the importance and centrality of a competent teacher, of group learning where no student felt alone, and of demonstrations that precede exploration. Computers and virtual creatures were judged as being of considerable use if they made learning “fun, real, simple, interesting and relaxing.”

Software Review

A large selection of commercially available biology teaching software was viewed and analyzed for content, interface and pedagogical style. Most had good production values and high quality media. However, most were judged as presenting static information, with low interactivity. Some interesting tools were noted, such as a magnifying glass that also acted as an “xray eye. Many were oriented to anatomical presentation and identification, accompanied by movies to illustrate selected function.

The pedagogical approach was one of presentation and questions. Almost none used a model-based approach to present information and allow interaction. One physics program (not biology) allowed the construction of mechanical models, such as jointed structures, with forces and displacements. However, there was a significant learning curve before one could develop useful models.

Prototype Development

Sample programs were developed to view and interact with frog slice and 3D images. These were model-based programs. The user could rotate the 3D models on the screen, hide and show organs, locate selected organs, and observe movies of selected joint actions. A widely available Internet web site on “cyberanatomy” was selected as a prototype for Internet-based presentation of anatomy and of structure-function relationships. This site used the Virtual Reality Modeling Language (VRML) as the standard for its representation of 3D objects.

Teacher Meetings 2

Teachers met again to examine the prototypes for depth and flexibility, and to discuss the fit between current teaching methods and the prototypes. The realism of the frog slices was valued as a supplement to dissection. The interaction with the 3D models was felt to be useful only if it linked to other information or action. The sample cyberanatomy site was judged to be a very interesting presentation of 3D overview information with links to 2D details and to simulation of function. They encouraged us to expand on a site for frog biology that was similar to the cyberanatomy site, and to embed the realistic slices and organ views in tthis site.

Student Meetings 2

Students were observed for their reaction to the prototypes for content and level of engagement. They were politely unimpressed by any presentations that did not include interaction that took them to additional information.

Design of Learning Environment

Based on these meetings, we modified our design from a focus on dissection to a broader, more integrative view of biology. We developed the concept of a virtual world, Frog Island (described below), where students could explore many facets of frog biology. We planned to use a range of technologies: simple web pages for presentation of hyperlinked text and images, a 3D VRML world with different "lands" for different aspects of biology, in-depth 3D environments for more detailed interaction with anatomy, and interactive Java games where students could apply their knowledge to build creatures to compete with others.

Frog Island was implemented, with enough detail on selected topics such that it could be evaluated in a biology class. An underlying architecture was defined so that later users could add to the world or modify it.

Teachers in residence program:

Two teachers, from high school and middle school respectively, were invited to spend two weeks each working with Frog Island and its developers, and assessing the usefulness of the resource. During this time, there was intensive review and redesign of the environment with teachers. The following is an excerpt from an exit interview.

> "Patrick's perception of computer-based teaching tools changed as a result of interacting with our group. In addition to being an eye opening, professional development experience, he felt that he gained a greater appreciation of web technologies, in particular, the power of hyperlinks. Hyperlinks provide a very nice way of going into greater depth when needed without losing the train of thought. He is also more motivated to create his own web content and doesn't see programs such as Adam as "black box". Instead, he feels that he could also create his own computer-based teaching modules. In fact, if he had a software development department in his school, he would take advantage of it.
>
> Patrick thought the 3D models could convey about 25% of the useful knowledge and the other 75% would have to come from textual or other graphical data. For example, instead of just showing the various bones, their names, and how they are connected, he would like to see information on the various types of bones, their inner structure, and the different roles they play. He would like to see more demos and animated teaching modules that describe physiological processes. ….. Although teaching anatomy is important, Patrick feels that it is more important to teach physiology, in particular, human physiology. Frogs are a useful vehicle for teaching physiology and anatomy, but eventually, he would like to relate them back to the human body."

Completion of Learning Environment

Intensive interaction with teachers led to one significant addition to Frog Island: the addition of Lessons. These lessons provided a structure to the students' exploration of Frog Island (see below). The teachers-in-residence, working with biology undergraduates, developed a set of sample lessons. The teachers also helped to create a personality for the rangers, providing stylized dialog for interactions with the students.

Finally, we combed through the entire resource for minor errors and missing links. The final resource is available at: http://summit.stanford.edu/creatures/frog-island.html

Sample Lesson: Report on Frog Species

• Once on Frog Island, go to Habitat Land. There are three different ways to get there. First, you can click on the forward pointers on the marker posts until you reach Habitat Land. Second, you may steer yourself there using the control stick at the bottom of the 3-D screen. Habitat Land is located slightly to the right and ahead of where you start. Third, you may get there by clicking on the bar next to the control stick in the bottom of the 3-D screen.

• Once in Habitat Land, look for frogs. They may be on the ground, up in the trees, or in the water. To find out information about a particular frog, click on it.

• By clicking on the different frogs and reading about them, decide which frog species is the best candidate for creating a better jumper. Make sure you use other resources, such as encyclopedias, videos and magazine articles.

• When you have decided which frog to use, write a report about that frog species, using the information in Habitat Land, the Internet links available in Habitat Land, your text, encyclopedias, magazines, etc.. You should use at least 3 different sources.

• In your own words (if you must copy a sentence or two, put it in quotation marks and indicate where that sentence came from), make sure you cover the following topics:

Environment ?Where does the frog live? What is that area like? What adaptations does the frog have that help it survive in that environment?

Reproduction ? How does the frog reproduce? What environmental requirements does it have (like access to large bodies of water, periods of heavy rain, etc.)? Does it have any special mating behaviors?

Food Chain ? What does it eat? What eats it? What special adaptations does it have to help it find food or avoid being eaten?

Interactions With Humans (if any) ? What effect are humans having on the frog species, or what are special issues surrounding that frog species (like poison from some frogs being used by native peoples, etc.)?

A DESCRIPTION OF FROG ISLAND

Frog Island [4] is an environment where students embark on an exploration of a 3D virtual outdoor habitat and visit various ``huts'' to learn about topics such as anatomy, physiology (digestion, respiration, circulation), biomechanics, and diversity (see Figure 2). They have access to a workbook containing an outline of the various lesson plans. This will allow them to enter observations, to raise questions, or to enter answers to questions that are posed. The workbook will help students stay focused on a particular lesson plan without getting lost during the course of visiting various links. In addition to the workbook and VRML windows, there is also a supplementary window where relevant text, images, and videos can be displayed. To facilitate unstructured learning modes, students are also encouraged to explore the virtual environment on their own, interacting and noting any observations they may care to make.

The virtual habitat resembles a natural setting with ponds, grass, trees, and meadows. There are various theme-based activity huts and regions that provide students with various resources needed to complete their lesson plans and activities. The first hut that students are guided to is the Orientation hut. Here they get an overview of the environment, the learning goals, and the lesson plans they will encounter. A friendly ranger or nature interpreter provides the introductory remarks.

We have designed and/or developed the eight huts (A through H) for our prototype Frog Island environment

Students visit the orientation and diversity huts before embarking on the more challenging places such as the Biomechanics hut. Students can access in-depth information on specific topics by clicking on books on the reference shelf. In the Organs Systems hut,

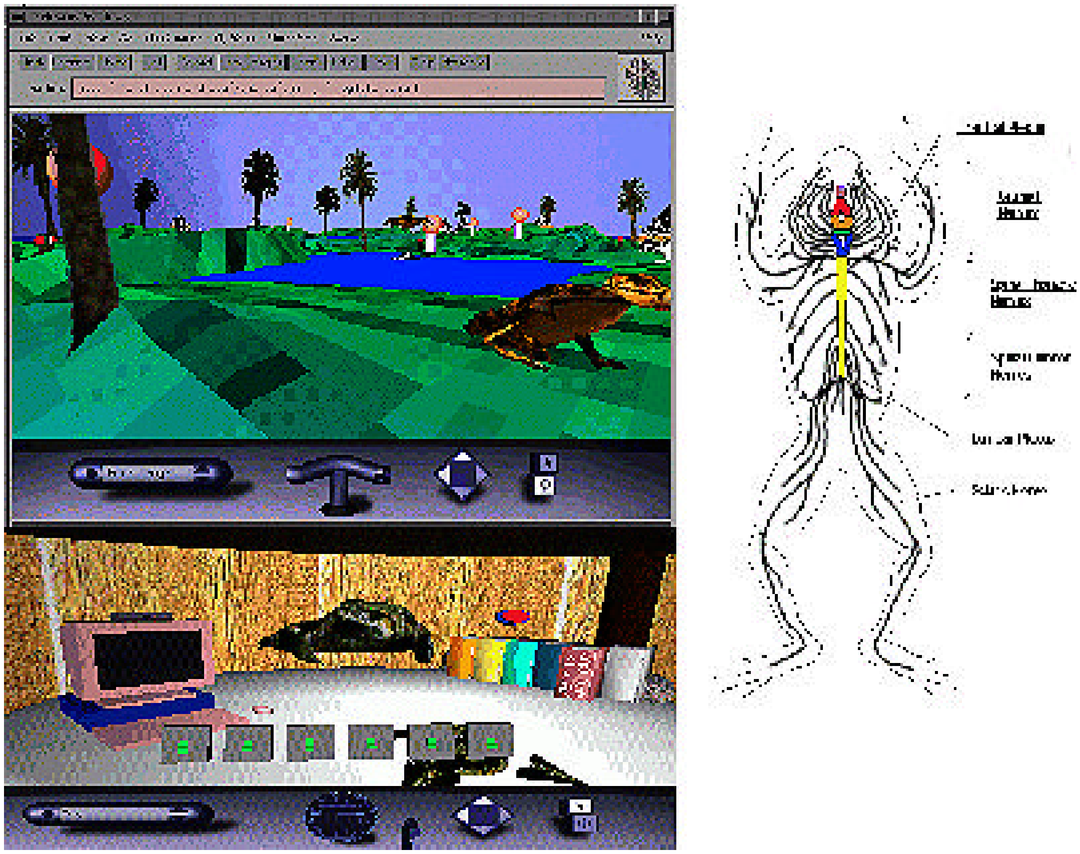

Figure 2: Scenes from the Frog Island 3D virtual world.

A. Orientation

B. Problem statement
1. theme-based approach
2. exploratory approach

C. Diversity and Habitat
1. genetic diversity
2. adaption

D. Skeleton
1. major bones
2. comparative structure
3. micro structure

E. Organ Systems
1. interactive 3D viewing
2. comparative anatomy
3. slice image viewer

F. Muscles
1. types
2. classification
3. function
4. lab experiments
5. advanced functions

G. Biomechanics
1. levers
2. locomotion
3. jumping frog contest

H. Bioethics
1. habitat preservation
2. playing god
3. “good” vs “bad” science

the internal organs of the virtual frog are revealed. By clicking on any organ on the frog, students can receive in depth information about that organ in the lower window. They can access the entire frog information frames database [2] by clicking on the computer screen next to the virtual frog.

CONCLUSION

Recently, fewer and fewer students have been choosing careers in mathematics, science, and engineering. More and more schools are having difficulty purchasing supplies and resources needed to teach physical and life sciences effectively. Innovative computer technologies can be to used to develop highly engaging, problem-based teaching modules that will allow students to explore science in virtual laboratories and other information rich settings. The process of design of these tools has been presented above.

Throughout our experience with the formative design process, the interplay between the hold of existing methods and the attraction of novel methods, and the importance of consulting with a large range of authors and users (teachers and students) have enlightened our path. As a result, we moved from our original plan of creating a single dissectable creature to creating Frog Island, a 3D, interactive, learning environment that is very different from our original design objective. The "Frog Island" space is augmented by virtual objects with pedagogically valid applications. The environment is flexible, and can be altered by individual teachers, and the content modulated for various levels of learning. This approach emphasizes the "pull" on technological innovation, contrasted with the all-too-familiar "push" style of attempted innovation. It emphasizes the need to incorporate educators, students, and researchers working with technology designers throughout the process.

The Virtual Creatures project has incorporated the collaborative efforts of specialists in education, biology, computer graphics, biomechanical engineering and education technology. We expect projects like this to help establish a benchmark of the type of research and development that is achievable only through such collaboration.

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