Computerized Medical Imaging and Graphics 29 (2005) 223–233

Computerized Medical Imaging and Graphics

www.elsevier.com/locate/compmedimag

# Designing high-quality interactive multimedia learning modules

Camillan Huang

*Education and Multimedia Applications, Stanford University School of Medicine, SUMMIT @ Wallenberg Hall, 450 Serra Mall, Building 160, Stanford, CA 94305-2055, USA*

Received 6 February 2004; revised 25 August 2004; accepted 30 September 2004

**Abstract**

Modern research has broadened scientific knowledge and revealed the interdisciplinary nature of the sciences. For today's students, this advance translates to learning a more diverse range of concepts, usually in less time, and without supporting resources. Students can benefit from technology-enhanced learning supplements that unify concepts and are delivered on-demand over the Internet. Such supplements, like imaging informatics databases, serve as innovative references for biomedical information, but could improve their interaction interfaces to support learning. With information from these digital datasets, multimedia learning tools can be designed to transform learning into an active process where students can visualize relationships over time, interact with dynamic content, and immediately test their knowledge. This approach bridges knowledge gaps, fosters conceptual understanding, and builds problem-solving and critical thinking skills—all essential components to informatics training for science and medicine. Additional benefits include cost-free access and ease of dissemination over the Internet or CD-ROM. However, current methods for the design of multimedia learning modules are not standardized and lack strong instructional design.

Pressure from administrators at the top and students from the bottom are pushing faculty to use modern technology to address the learning needs and expectations of contemporary students. Yet, faculty lack adequate support and training to adopt this new approach. So how can faculty learn to create educational multimedia materials for their students? This paper provides guidelines on best practices in educational multimedia design, derived from the Virtual Labs Project at Stanford University. The development of a multimedia module consists of five phases: (1) understand the learning problem and the users needs; (2) design the content to harness the enabling technologies; (3) build multimedia materials with web style standards and human factors principles; (4) user testing; (5) Evaluate and improve design.


*Keywords:* Educational media; Interactive teaching for biology and medicine; Instructional web design; Physiology modules; Multimedia module design

## 1. Introduction and background

Technology is outpacing us. In the 20th century, technology has become a staple in our everyday lives and has catalyzed innovations in healthcare and biomedical research. This progression has enriched our lives and has brought about the need for imaging informatics databases. However, it has also become difficult for today's student to learn and assimilate the growing amount of content found in these databases (without misconceptions). Technology creates a second problem by changing the expectations of incoming students. Today's students are so surrounded by technology (computers, chat, email, and the web) that it is natural for them to expect coursework to incorporate similar standards. How can we, as teachers, incorporate technology into our teaching so that we can train our students for tomorrow? In turn, how can incorporating technology into our teaching benefit teachers?

## 2. Teaching: past, present, and future

Traditionally, print textbooks have been the standard reference and learning tool for students. In general, such textbooks are thorough (they cover a large number of topics in detail), well-organized, and incorporate the basics of the life sciences. However, textbooks are static, are not easily customized to different students and classes, and fail to adequately highlight the intersections between different disciplines. Textbooks also cannot provide students with information on the newest scientific breakthroughs since revisions are a major effort and they are costly to students.

0895-6111/$ - see front matter 
doi:10.1016/j.compmedimag.2004.09.017

Informatics can address the need that textbooks cannot provide. Informatics can be used to provide students with up-to-date information that can be disseminated freely through the Internet. A wealth of information datasets can be found in imaging informatics, like computerized tomography (CTs), magnetic resonance imaging (MRIs), functional MRIs, and positron emission tomography (PET) that can be centralized and distributed. Information in these databases may also include simulations and systems modeling. These datasets and patient histories are today's electronic medical encyclopedia and allow interdisciplinary users to integrate, visualize, and cross-reference different studies performed on areas in our body. However, this information often lacks a usable instructional interface necessary to transform the information from a reference tool into a powerful training tool to help students learn.

Educational media, in contrast, can be powerful to train students and is considered the next generation of learning materials. Designed to complement traditional educational methods and information datasets, educational media can supplement core material with animations, interactivity, and visual design. Unlike traditional textbooks, educational media is dynamic, easily customizable, and can be designed with an interdisciplinary approach. It can also be used to teach content in a way traditional teaching materials cannot—for example, animations of mechanisms and processes can help students visualize how biological systems work together. Once taught, interactive media can be used to ensure that students have learned key concepts and understand the basics. In addition, students are more likely to adopt these materials since they are influenced by a world of computers, media, and the Internet.

For teachers, multimedia education can help explain difficult concepts more clearly than a textbook or PowerPoint lecture. When students are able to manipulate experimental factors to see cause-and-effect relationships, they move beyond rote memorization and passive learning to truly understand the material. Educational media can also be designed to correct common misconceptions by targeting difficult or frequently misunderstood concepts.

So what is educational media? There is a trend to move content into the digital medium PowerPoint (Microsoft, Redmond, WA)—but it is still passive and has only limited animation and video support. In addition, many 'interactive modules' contain no more interaction than a click to advance to the next page. True educational media should incorporate dynamic animations, interactivity, and visual design to stimulate, challenge, and test students. The design of a good instructional interface requires an integrated design approach that incorporates best practices from in education, human computer interaction, and instructional technology.

As an example, the Virtual Labs Project, funded by the Howard Hughes Medical Institute, is an initiative to augment the core undergraduate courses in biology at Stanford University. This is achieved by delivering interactive multimedia over the Internet to teach big picture and difficult concepts in physiologic systems (cardiovascular, gastrointestinal, respiratory, renal, vision, cranial nerves, and other mini modules). The concepts in these modules create a foundation not only for the life sciences and medicine, but also for an increasing number of interdisciplines, such as biomedicine, medical informatics, and bioengineering.

For example, if a medical student understands how the kidney produces and concentrates urine, he or she will be better able to understand how diuretic drugs work. A researcher, who learns about the molecular aspects of the concentrating mechanism, could apply this knowledge to understand how sodium influences body fluid maintenance. A bioengineer could apply the same knowledge to design a more efficient kidney dialysis system.

From 2000 to the present, Virtual Labs has tested their interactive multimedia modules on thousands of students in Stanford classrooms and those of our collaborators. And with over 500 pages of development experience, Virtual Labs has developed best practices to aid future module development. These best practices can be applied to any scientific concept.

### *2.1. How do we create new educational media resources?*

Key to the success of the VL modules, and educational media materials, lies in the presentation of information that integrates an appropriate media technique (imaging dataset, technical illustration, animation, interactivity) with best practices in learning (Table 1). In addition, VL emphasizes a user-centric design, that is, we make design decisions based on human factors and match them to the user's needs and expectations. This paper will incorporate these design strategies into a detailed protocol to help guide module development by faculty and a multimedia development team.

When designed correctly, a multimedia module can visually stimulate a student and transform learning into an active, engaging process. A good design [24,25] will allow students to (1) visualize difficult and naturally dynamic concepts, (2) promote active learning, problem-solving, and critical thinking with interactive simulations and virtual environments, (3) interact with the content with

Table 1
The table below lists the pedagogical and human–computer interaction design principles behind Virtual Labs

| Design principle | Reference |
|---|---|
| How people learn | [1–3] |
| Instructional design and evaluation | [4–10] |
| Interaction design usability, and human factors | [11–15] |
| Presentation of information: visual perception, style guides, design strategies | [16–21] |
| Motivational strategies | [22,23] |

self-quizzes, and (4) access content anytime, anywhere, at any pace.

## 3. Interactive media design: from concept to reality

This section describes the design process for educational media production. It begins by providing special considerations for user-centric design, then discusses the required planning, finishing with an introduction to the five phases of development.

### *3.1. Design for your users' needs and expectations*

It is important to consider the user's perspective and learning method when designing an educational media module. During the entire process, keep the user's voice in your head. Specifically, ask yourself what the students need to support their learning and fulfill their expectations. The following is a list of questions that should be answered by and for the user.

In parentheses are the phases (for details on Phases 1–5, see *Process*) during which these questions will be most critical during development.

- Show me what I will learn. (Phase 1–2)
  Clearly state the learning goals and learning outcomes of each page.
- Why should I care to learn this? (Phase 2)
  Give a real-world example of the concept to make it relevant to the student. Without giving a significant context to the student, the student may not understand the implications or know how to apply the principles of the concept.
- What can I do on the page? (Phase 2–3)
  Design the interactions on the page to engage the student and support learning. Consider teaching the concept by using interactions and visualizations that cannot be accomplished in a classroom or by a piece of paper.
- Tell me how I'm doing! (Phase 2, 3, 4)
  Design assessments to ensure that the students are learning the concepts. Include a way for students to self-gauge how well they have mastered the learning material.

### *3.2. Planning*

While considerations for the user are core to the development process, planning is also essential to effectively and efficiently develop a multimedia module. Each phase requires planning, teamwork, and flexibility. A careful initial plan will save time, costs, and team frustration during the downstream production. During the planning phase, the content expert/teacher presents the educational challenge to all team members. All team members—scientists, educators, technology specialists—draw upon their domain of expertise and brainstorm collectively to design a module that integrates what the users need with what they should learn (Fig. 1). A prototype is developed from the preliminary plans and then tested on typical users. Based on the user's feedback, the module returns to production and is redesigned for improvement. The original plan may often evolve due to resource restrictions, programming considerations, and user feedback. This flux is common since the development process evolves constantly and the team needs to be flexible to adapt. In the end, adaptability will keep the project on target with deadlines and with your user's needs. The following sections describe in detail how to complete each phase.

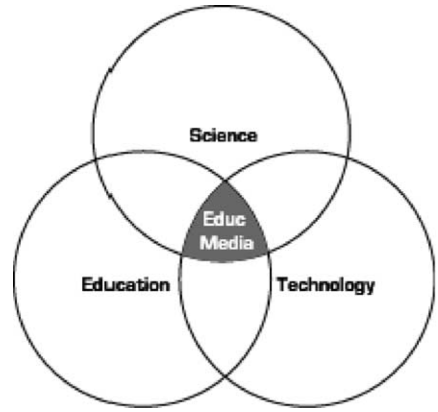


Fig. 1. *Interdisciplinary design.* Good educational media design results from integrating best practices in teaching and learning from the disciplines of science, education, and technology. The team consists of content experts from the sciences, education experts, and technology specialists. Together the team can create materials that integrate the best practices in teaching and learning from all disciplines.

### *3.3. Process*

The process of creating multimedia learning modules consists of five phases: (1) Understand, (2) Design, (3) Build, (4) Test, (5) Improve (Fig. 2). Phase 1 and 2 is primarily led by the content expert, while the multimedia development in Phase 3 is primarily performed by the development team. Phase 4 and 5 includes all team members and the users. Below is a brief description of the five phases.

- Phase 1. Understand—understand who will use the module *(target group)* and address how the module will help the users learn *(educational challenge, needs assessment).*
- Phase 2. Design—design the module for your user *(learning design)*, from a user's point of view *(user-centric).*
- Phase 3. Build—build interactivity and multimedia components using best practices *(media development and coding).*


Fig. 2. *Summary of module development process*. The figure above outlines the general project flow and the main phases in module development. Ideally, all team members—content experts, development team, and users—should be involved in the entire process. Shaded areas on the team members indicate areas where it is necessary for them to participate. A general framework [24] and evaluation methods [25] were discussed in previous published works.

- Phase 4. Test—see how well your users respond to the module *(user testing, usability heuristics).*
- Phase 5. improve—Evaluate how well students learned and how well the module performed *(evaluation of learning outcomes).*

The five phases above is expanded in detailed below. Each phase is broken down into several components and each component lists questions to help guide your thought process. As you go through each step, it will be helpful to write out the answers to each question. The answer to your questions should be shared with your team to provide groundwork and rationale for the project. These answers also serve as the reference point for the multimedia development and for yourself as you get the results from the users you test on.

## 4. Phase 1: understand the problem and needs

Phase 1 focuses on the educational challenges of the student. These challenges are used to determine the design rationale of the module (for example, see Fig. 3). Draw upon your personal teaching experience and apply your classroom knowledge towards designing the module. The first issue to address is identifying what you want your students to learn (learning goal) and then how you plan to integrate what your students need and expectations.

1. Understand needs and goals.
   - Why do you want to build this multimedia module?
   - What do you want the outcome to be?
   - Who will your users be?
2. Determine learning goals.
   - What do you want the students to gain after using the module—in terms of knowledge, understanding, or skills?
   - How do you plan to have your students use the module and how would this module fit into your teaching curriculum?

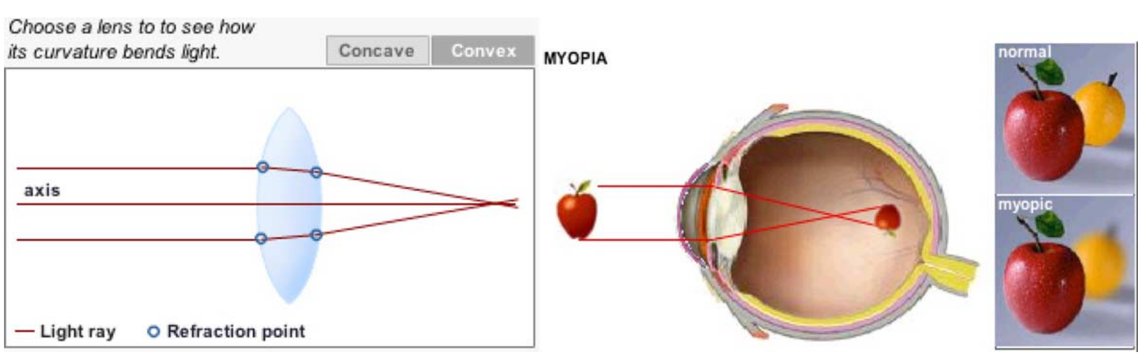


Fig. 3. *Design Rationale*. In Fall 2002, the Alliance for Lifelong Learning offered an online distance learning course called Art and Vision which explored the process of vision: how an object's color, texture, and shape is interpreted by the nervous system and the impact of visual diseases for artists. The students were post college graduate learners who were located around the world. Student materials included the textbook 'The Eye of the Artist' by Dr Michael Marmor, course guidebook, CD-ROM on vision from Virtual Labs, and access to a supporting website with videos, discussion forums, and weekly chat sessions. The module was customized to follow the curriculum in the book. The goal of the VL module supplement was to provide an integrated, interactive approach for students to learn the physiologic process of vision and apply these principles to understand how vision (or a lack of) affects art and vice versa. The figure above, left, illustrates the physics behind lenses and the one, right, shows how nearsightedness results from a change in the focusing power of the cornea. Both images show an animation of how light rays entering the eye are refracted. In a subsequent simulation lab (not shown), a student is given a myopic or hyperopic eye and the student prescribes the correct eye glasses prescription after dynamically adjusting the focal length of the lens to correct for the disorder. Meanwhile, a corresponding image from a first-person view also changes dynamically to reflect the changes in the focal length. Such content presented as a single static image would not engage a user as much as a dynamic image that the user could control and interact with. This type of interaction allows the user to make predictions about the action he or she is about to perform while receiving immediate feedback on his or her actions.

## 5. Phase 2: design the content for the module

Phase 2 walks through the thought process for identifying a concept and presenting it for the students in an engaging way that helps them learn. An example is shown in Fig. 4.

1. Pick a concept.
   - What concepts do your students repeatedly have a difficult time understanding?
   - Are these concepts essential, important, or common? Why are the essential concepts important for the student to learn?
   - What are the common misconceptions for each of these concepts?
   - How do you know if students are having a misconception and how have you corrected for it before?
   - What are the 'correct' models for each misconception?
2. Decide how to present the concept.
   - How could you present the material using technology enhancements so it makes learning easier?
   - Use the web to identify what resources exist. Identify websites that specifically address your educational challenge and websites that present material in a similar format.
     - What did you like about the websites you saw?
     - How would you improve it, given unlimited time and resources?

     Web research is essential to be exposed to other representations of the content. This process may find an educational tool that has already been created!
   - How will the student be challenged by what is presented in the module?
3. Design activities to engage and motivate the student.
   - What would your typical student find interesting about the topic?
   - How can you present the material so your target student is interested in it?
   - What is a real-world example of the concept? It is often helpful to use everyday examples so students can relate to the context.
4. Devise assessments to evaluate how well students learned.
   - How will your student have benefited from using these materials over traditional materials?
   - What do you hope your student will gain after using the module?
   - What is the test to see if your student understood this concept?
   - How will you know if the module was effective?

## 6. Phase 3: build the multimedia assets and interactivity

Phase 3 describes the process from assembling a multimedia development team to storyboarding ideas and prototyping the module.

### 6.1. The interdisciplinary development team

A solid team with the appropriate skills and teamwork is key to the success of a multimedia module. This team consists of experts in education, science teaching, and technology who collaborate to design the blueprint for the module. This interdisciplinary team should consist of:

- A project manager
- A content expert with teaching experience
- A multimedia development team
  - Graphic designers
  - Educational media developers/ learning designers
  - Programmers
- An evaluation expert
- The users!

### 6.2. Project manager

The project manager is the liaison between the stakeholder of the project, who is usually the funding agency or content expert, and the team members. The manager allocates tasks for the team and sets milestones, deliverables, and deadlines for the project, all within the proposed budget and resources. The manager should have a strong background in the sciences, technology, and education to understand how to allocate the time and resources for the tasks and provide the backbone for the interdisciplinary team.

### 6.3. Content expert and teacher

The content expert is often the expert in the scientific field and has extensive teaching experience. The content expert designs the student learning outcomes and learning goals for the module. This expert also helps to design user assessments to validate that the student has understood the module.

### 6.4. Graphic designer

The graphic designer must have artistic abilities and is trained in visual communication, visual design, and have extensive knowledge with Adobe Photoshop and Illustrator. The designer transforms the abstract learning content into a visual language and layout that communicates the learning outcomes and learning goals.

### 6.5. Educational media developer/learning designer

The educational media developer is trained in learning with technology design (human–computer interaction, user-centered design principles, user studies, iterative design, rapid prototyping, and evaluation). The developer designs the user interactions and validates the learning effectiveness of the module.

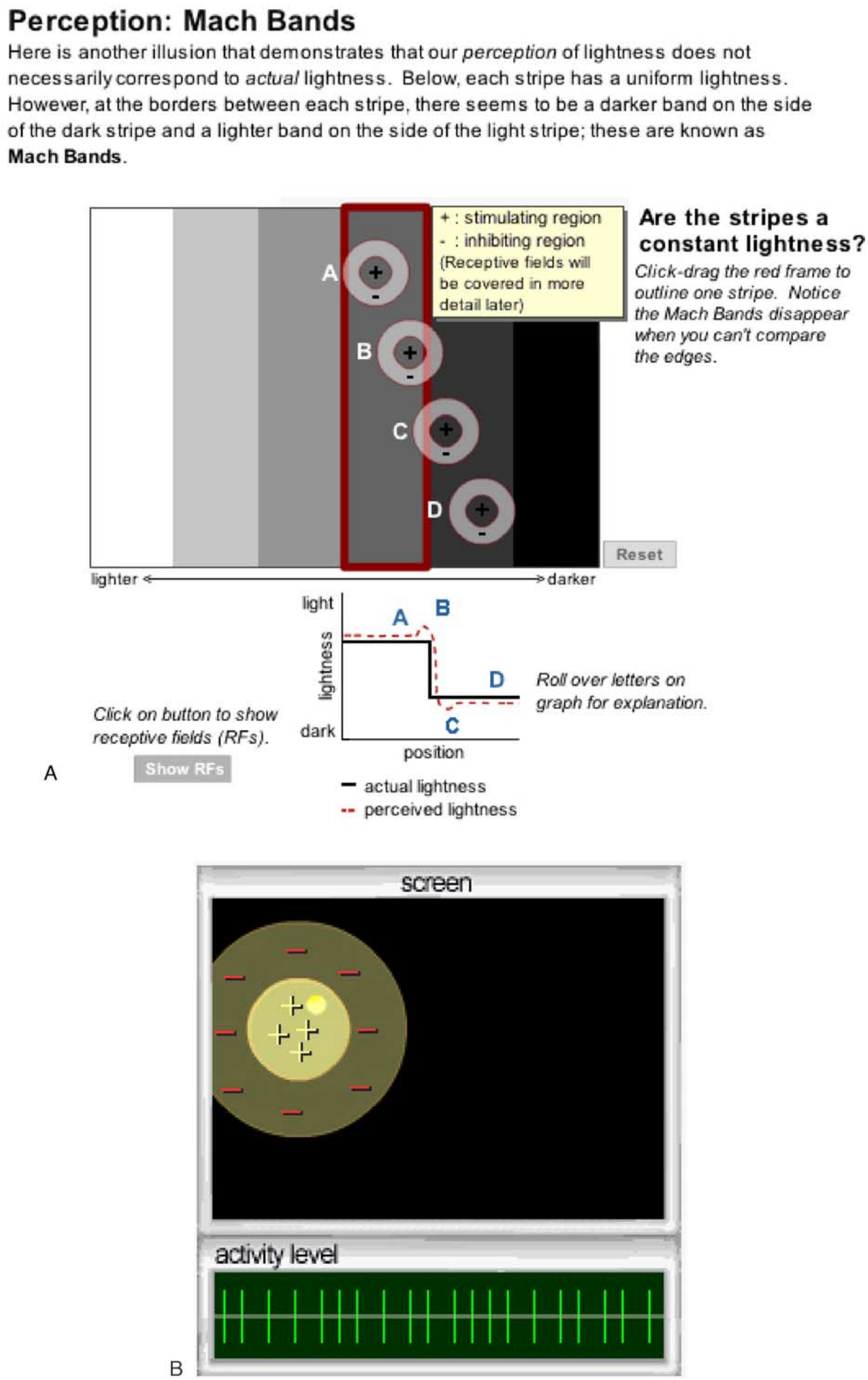


Fig. 4. *Content design*. One example topic, receptive fields, from the vision VL module is presented. We picked this topic because students struggle to understand how the physiologic concept of receptive fields creates the perception of contrast. A receptive field is defined as the set of stimulus or characteristics (light in this example) that a neuron optimally responds to. This concept is fundamental in understanding how the visual system constructs contrast. The visual system accomplishes this by constructing 'receptive fields' to respond to, filter, and process the incoming light stimulus. This transformation is difficult since it requires knowledge of retinal anatomy, movement of light through the retina, and the interaction of neurons. A. To represent how contrast is created, we incorporated a common illusion to illustrate the example. When the user comes to this page, he or she is instructed to look at the borders between the stripes and observe the appearance of a small gradient, called Mach Bands, at the intersection of each border. The neighboring stripe helps to enhance the crispness of the edges by making the one edge darker on one side of the edge and lighter on the other. The user can remove the illusion by moving the thick rectangular outline to remove the influence of the neighboring stripe. Without allowing a user to control what he or she sees, the user may be apt to absorb the information passively instead of actively understanding the results of his or her actions. B. Using a virtual lab with animations, a student can learn about receptive fields. This virtual lab was designed to allow the user to perform a simulated experiment of the original scientific discovery of receptive fields by Hubel and Wiesel [28]. This principle is often represented as a series of static figures where a spot of light is shown somewhere on each concentric circle and a graph shows the resulting

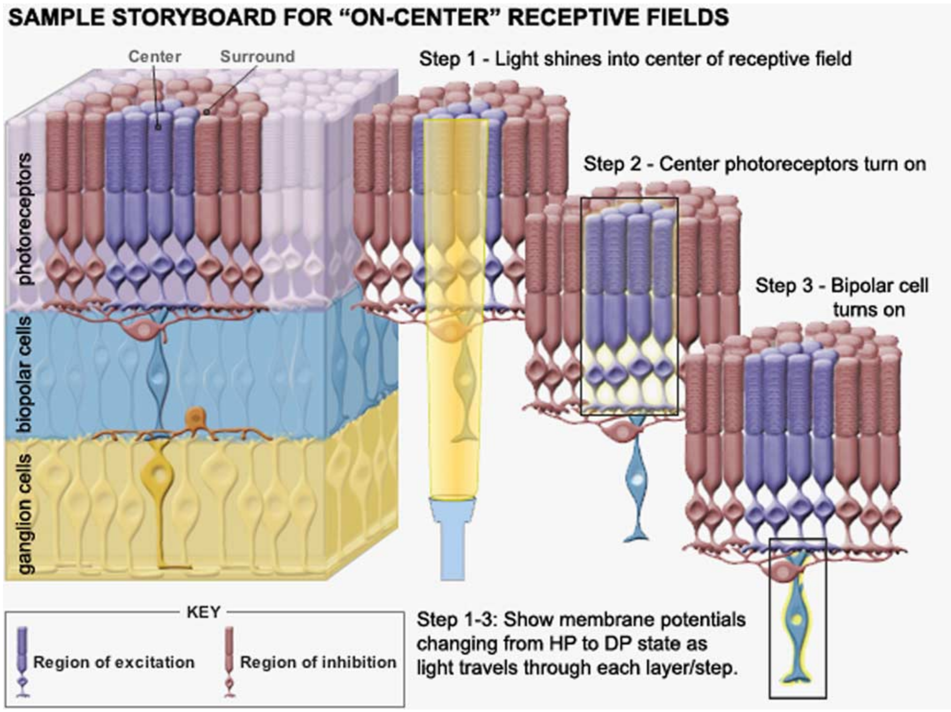


Fig. 5. *Storyboard*. A storyboard should include sketches (finished drawings are included here) to describe the details of the process in a step-wise manner. This storyboard has three key steps in time and the black box showed which areas are activated at which time. A corresponding graph showing membrane potentials would be shown next to this animation (not represented in this storyboard). A textbook may represent this animation almost as indicated below, but a dynamic animation of this principle shows the user a progression of the process over time. Animations can help decrease misconceptions since students often struggle to stitch steps together accurately.

### 6.6. Programmer/technical lead

The programmer provides technological experience and authors the interactive content for the multimedia. The programmer should be able to develop rapid digital prototypes.

### 6.7. Evaluation experts

Evaluators provide expertise on formative and summative assessments, measures for educational achievement, conduct field tests on users, design how to implement the module into the curriculum, and report to stakeholders on user feedback.

### 6.8. Users

A user is defined as any student today who will be using the learning module, usually one who is taking a class relating to the content in the module.

### 6.9. Storyboard ideas

A storyboard is the visual blueprint of the module; it describes the details of the module pages and choreographs the teamwork. It should describe how the content is laid out, list the media elements (images, animations, video, sound), and outline the user interactions (Fig. 5). A well-thought out and detailed storyboard is essential for the production team to translate your thoughts into a working module.

### 6.10. Develop assets

There are five main components that make up a multimedia module: content, media, interface layout, programming, and project administration.

— Content
  ○ Write material using world wide web style and content guidelines [15,16].

activity level when the spot is first off, then on. In this virtual lab, the user drags an recording electrode to the retina (not shown) and then explores the black screen with a spot of light to find the areas of high activity (indicated with a '+') or low activity (indicated with a '—'). The students can map the activity levels they discovered to see how this receptive field contains a center circle of high activity and an outer field of lower activity (indicating an On-centered cell). Then to test their understanding, students answer questions relating to their result. If the student moves the recording electrode to a new location, the activation zones, location on screen, size and shape of the receptive field change. After completing this virtual experiment, students learned about the different types of receptive fields as well as the dynamic nature of the research and exploration process. This learning process may not occur if the user memorizes the series of static figures.

  - ○ Organize content into meaningful chunks of information. For example, bullet points can be used similar to PowerPoint.
  - ○ Write concisely and minimize jargon to ensure the message is clear [17].
- — Media
  - ○ Determine how you want to use visuals to communicate the content *(visual language and visual communication)* and set the mood of the page *(look and feel)*.
  - ○ Determine color palettes for the pages and modules to be created.
  - ○ Draw images to show a visual representation of the text content.
  - ○ Structure animations that capture the dynamics of complex processes.
- — Interface layout
  - ○ Determine what you want your users to experience while going through the module *(user experience)*:
    - ■ Determine the technological features to enhance the content: graphics, visualizations, animations, simulations, virtual labs, virtual patients, patient cases, games, etc.
    - ■ Determine what kinds of interactions you want the user to perform on each page, e.g., what the buttons are to click on, how the user will navigate.
    - ■ Assure that the users are on track with what you originally intended and that you are on track in terms of what your users wanted (*Usability* [26]).
  - ○ Establish the design of the layout using guidelines, best practices, usability compliances [15,16]
  - ○ Consider how to present the different kinds of information you plan to have on each page and how each kind of information works as a unified whole (information design [18])
    - ■ Visualization strategies
- — Code the module. Assign the task of writing source code to a programmer The programmer will take the storyboards and make the module interactive.
- — Perform project administration. Each phase should be documented and archived after they have been completed. Each phase will have files containing content, reference material, images in raw format, source codes, administrative, and management files.

### *6.11. Prototyping*

A rapid prototype is a very rough model (paper or digital) that can be quickly constructed and tested on the users. This testing occurs early in the instructional design process (method described in Rettig [9]). The module design is continually revised until there is confidence in the design. Once a prototype is established, subsequent modules can be developed with assurance in the design.

## 7. Phase 4: test and evaluate—test modules on your target audience

Phase 4 defines the general areas addressed during a user test. Instruments for measure include focus groups, surveys, interviews, log data, pre-/post-tests, and exam scores. Each area has standard evaluation metrics [5,7, 8,27]. We triangulated data from many instruments to assess higher order learning, since that is often more difficult to quantitatively measure.

### *7.1. User tests*

- Usability and interface:
  - ○ Is the module usable?
  - ○ Are there any technical problems that interfere with the learning outcome?
- Content:
  - ○ Is the content easy to understand?
  - ○ Does it convey the complexity of the information?
- Learning effectiveness and attitudes:
  - ○ How did the module help the student learn?

Perform surveys in the following areas: user satisfaction, usage, assessment, and instructor feedback data. Use a five point Liekert rating scale for the indicated areas to measure attitudinal responses: strongly disagree, disagree, undecided, agree, strongly agree.

- User satisfaction data: How well did the students like the module?

This information can be gathered with self-report surveys or by interviews. The following list areas to ask your students about, followed by examples:

- — Demographics of your user:
  - ○ What is your knowledge of topic X?
  - ○ How often do you use a computer?
  - ○ What do you use a computer for?
- — Technical and usability (Liekert scale)
  - ○ I had no technical difficulties with the module.
  - ○ Navigation through the module was clear.
  - ○ I was able to find the information that I was looking for.
- — Usefulness of the module (Liekert scale)
  - ○ The content was laid out in a clear and concise fashion.
  - ○ Feature ‘A’ in the module was useful in helping me understand ‘X’ concept.
  - ○ List features as separate questions: graphics, text, animation, simulation, virtual lab, quizzes, games.
- — Usefulness in learning. (Liekert scale)
  - ○ The module helped me with conceptual understanding.

    ○ The level of content was appropriate.
    ○ I liked the way the module was integrated with the class.
— Attitudinal affect (Liekert scale)
    ○ I enjoyed learning 'X' with the module.
    ○ Using module 'X' motivated me to learn.
— Open ended questions
    ○ Please list 3 difficult concepts in the course.
    ○ What was the most memorable item from the module?
    ○ Suggestions for improvement?

- Usage data: How much did the students use the module?

If the module is distributed over the Internet, you can collect useful information about how much the user used the module. In compliance with the Institutional Review Board's human subjects protocols, a consent form is required to collect data from your users. A backend tracking system can invisibly collect log file data from the user. This data contains information on which page, what items the user clicked on, and amount of time the user spent on that page. The following is a list of suggested data to collect for each user:

○ User ID
○ IP address of user
○ Last session
○ Number of sessions
○ Time spent on entire module
○ By individual pages: page visited, time spent on each page, items clicked

- Assessment data: How well did the students learn?

This information is collected using testing measures. Design questions that specifically test conceptual understanding and applications of the concepts rather than factual questions.

- Instructor feedback: How well did the students perform with the module?

This information can be gathered with self-report surveys or by interviews (Textbox 1).

○ How do you feel your students learned the concept with the module?
○ What would you improve for the next module?

## 8. Phase 5: improve—iterative redesign

Phase 4 will show what needs to be improved in the module. In an iterative design cycle [6], redesigns after user testing are common (back to Phase 3) and decisions for specific redesign areas are based on time, resources, impact, and importance.

**Testimonial.** A faculty member used a Virtual Lab Module for their class on renal physiology and responded positively. The design rationale for the module follows. "Biology is a very visual subject and it deals with change through time. The new technologies provide powerful tools for dealing with these types of teaching challenges. My favorite example is teaching how urine is processed in the kidney which has always been a very difficult thing to teach and for students to grasp. Once we instituted a virtual laboratory on this subject where students could visualize the processes involved and manipulate them, the kidney was no longer the huge teaching challenge it had been for me in the past. I couldn't believe it when the teaching assistants reported to me that the students had no questions on the topic!"

## 9. Prospective in interactive media design for imaging informatics

Technology has opened the doorway in informatics to support databases that contain a wealth of information from many disciplines. However, these information systems often have complex interfaces and require training in order for the user to effectively and efficiently gain access to the information. In order to access any information on these databases, a user needs to learn how the interface works and query the correct search to access the material. One way to address this need is to create a training module on how to use these information systems. With the methodology described above, these information systems can be transformed into usable information and the training modules can be disseminated to any user. The training modules can be further enhanced to support the needs of different types of users on the system. For example, a clinician might want to search the organ systems and see how a particular drug may interact with a system physiologically. A researcher may want to search for the specific type of receptors that a particular drug may bind with across different physiologic systems. The design of the interface would be different since the needs of both users are different.

Other educational modules can be developed to train users in specific areas. These training modules can bridge knowledge and expertise and become the interdisciplinary learning material for tomorrow's student. One such module could be an interactive module on congenital hand anomalies to train clinicians how to analyze different radiographs for making diagnoses and treatments.

This module could also be modified to address questions that parents may have about their child's disease and offer coping mechanisms.

The medical and research knowledge bases found in informatics can be harnessed to create effective multimedia learning materials. Already enriched with high-quality graphics and dynamic simulations, only an interface with best practices in instructional design principles and human computer interaction are needed to transform this information from merely an information archive into a rich educational resource.

## 10. Discussion

Students entering college today comprise a more ethnically, culturally, and linguistically diverse population than at any time in the past 50 years. Yet among this heterogeneous population, a common thread exists: technology. As educators, we should exploit this commonality to improve our teaching, our students' experiences, and the quality of education.

Educational media is a way of harnessing technology and building the future of learning. Unlike PowerPoint or traditional textbooks, educational media incorporates high resolution animations and videos that bring dynamic processes to life. In addition, educational media can incorporate interactivity that stimulates and challenges the learner. As a result, students will find science learning fun and engaging. Educational media can train many students: biology, medicine, bioengineers, and medical informatics, with one common core learning module and then integrate knowledge from the different organ systems databases and relate them to medical conditions, symptoms, and treatment. With efficient and engaging learning tools, we can continue to attract and retain a talented and increasingly diverse pool of science majors.

This paper is an attempt to describe and document methods for building new and creative educational media content. It provides a framework for designing and implementing new content into classrooms. While the details of each project will be tailored to suit each team's needs, the basic phases of understand, design, build, test, and improve will remain relatively unchanged. This framework, far from being untested, was developed by the Virtual Labs project during the course of creating over 500 pages of material to teach physiology. It is from this experience that new designers will hopefully avoid pitfalls and produce quality educational media.

The importance of creating new teaching tools cannot be understated. Educational media is poised to help train new scientists, clinicians, information technologists, and health care providers by creating modules that teach relevant concepts and are sharable and distributable to any student, anywhere, anytime. In order to provide the diversity and depth of materials needed, we must empower teams around the world with the necessary skills to design new educational media. We hope that this paper will serve as an introduction to the methods behind creating new educational media resources and we are taking initiatives to train teams locally and abroad. Such cross-cultural exchanges are taking place with our community schools and our global partners in Sweden (Wallenberg Global Learning Network) and India (Apeejay Educational Society), with plans to collaborate with China.

Together, we can create the next generation of educational media tools which will train the next generation of scientists, clinicians, and health care workers.

## 11. Summary

The design of high-quality interactive multimedia for learning requires creators to incorporate best practices in education, instructional technology, and human computer interaction to create a useful and effective online learning environment for students. This paper describes how multimedia can enhance learning and offers best practice guidelines for building innovative multimedia materials. These development strategies were derived from six years of experience with the Virtual Labs Project at Stanford University. These strategies can be applied to new educational media development in imaging informatics and be disseminated with informatics databases. The development of a multimedia module consists of five phases: (1) Understand the learning problem and the users needs; (2) Design the content to harness the enabling technologies; (3) Build multimedia materials with web style standards and human factors principles; (4) User test; (5) Evaluate and improve design.

## References


[1] Alessi SM, Trollip SR. Multimedia for learning: methods and development.: Allyn and Bacon; 2001.

[2] Bransford J, Brown A, Cocking R, editors. How people learn: mind, brain, experience and school. Washington, DC: National Academy Press; 2000. p. 39–66.

[3] Kozma RB. Learning with media. Rev Edu Res 1991;61(2):179–211.

[4] Clark RC, Mayer RE. e-Learning and the science of instruction. New York: Wiley; 2003 p. 322.

[5] Creswell J. In: Laughton C, editor. Research design: qualitative, quantitative, and mixed methods approaches. Thousand Oaks: Sage Publications; 2003. p. 246.

[6] Dick W, Carey L. The systematic design of instruction. New York: Harper Collins Publishing; 1996.

[7] Harvey J, editor. Learning technology dissemination iniative 1998. Edinburg: Institute for Computer Based Learning, Heriot-Watt University. http://www.icbl.hw.ac.uk/ltdi/cookbook/cookbook.pdf

[8] Kellogg WK. Kellogg foundation evaluation handbook 1998. Battle Creek, MI: Author. http://www.wkkf.org/Pubs/Tools/Evaluation/Pub770.pdf

[9] Rettig M. Prototyping for tiny fingers. Commun ACM 1994;37(4): 21–7.

[10] Flashlight Tool Kit. American Association of Higher Education's Teaching.
[11] Cooper A. About face: the essentials of user interface design. Foster City: IDG Books Worldwide; 1995 p. 580.
[12] Nielsen J. Usability engineering. Indianapolis: Morgan Kaufmann Publishers; 1994.
[13] Nielsen J. Designing web usability: the practice of simplicity.: New Riders Publishing; 1999.
[14] Shneiderman B. Designing the user interface: strategies for effective human–computer interaction. Reading: Addison-Wesley; 1997.
[15] Research-based Web Design and Usability Guidelines.
[16] Lynch PJ, Horton S. Web style guide. New Haven and London: Yale University Press; 2001 p. 223.
[17] Strunk W, White EB. The elements of style.: Pearson PTR; 1995.
[18] Tufte E. The visual display of quantitative information. Cheshire: Graphics Press; 1983.
[19] Tufte E. Envisioning information. Cheshire: Graphics Press; 1990 p. 126.
[20] Tufte E. Visual explanations. Cheshire: Graphics Press; 1997 p. 156.
[21] Wickens CD, Holand JG. Engineering psychology and human performance: attention in perception and display space. 3rd ed. Upper addle River, NJ: Prentice Hall; 2000 p. 350.
[22] Fogg BJ. Persuasive technology: using computers to change what we think and do. San Francisco: Morgan Kaufmann; 2002.
[23] Lepper M, Malone T. Intrinsic motivation and instructional effectiveness in computer-based education. In: Snow R, Farr M, editors. Aptitude, learning and instruction. Cognitive and affective process analyses, vol. 3. Hillsdale, NJ: Lawrence Erlbaum Associates; 1987. p. 256–86.
[24] Huang C. Changing learning with new interactive and media-rich learning environments: virtual labs case study report. JCMIG 2003; 27(2–3):157–64 [Special Issue].
[25] Huang C, Huang H. Interactive instruction of cellular physiology for remote learning. Cell Mol Biol 2003;49(8):9.
[26] Research-based web design and usability guidelines. Volume 2004.
[27] Rogers G. Materials development and the ATE program.: Western Michigan University; 2001.
[28] Hubel DH, Wiesel TN. Receptive fields, binocular interaction, and functional architecture in the cat's visual cortex. J Physiol 1962;160: 106–54.

**Camillan Huang** is the Director of the Virtual Labs Project at Stanford University's Medical Media and Information Technologies (SUMMIT) in the School of Medicine and a lecturer in the department of Computer Science at Stanford University. Cammy received her degrees from the University of California, Berkeley: PhD in 1999 in the department of Molecular and Cell Biology and B.A. with majors in Molecular and Cell Biology (emphasis, neurobiology) and Classical Civilizations. Her training includes neuroscience research (neuroimaging and neuroanatomy), traditional and digital arts, animation, project management, educational media development, human–computer interaction, and instructional design. Her current research and teaching interests include use of educational technology for biology and instructional media design for students learning science. She has taught in undergraduate biology classrooms at Stanford University and University of California at Berkeley, and in interdisciplinary courses: Art and Vision at the Alliance for Lifelong Learning and Interactive Media Design for Kids Learning Biology at Stanford University. She is also currently an academic advisor and collaborates on many outreach projects including H.E.L.P. for Kids to design computer-based teaching media for kids (grades 4–12) learning health education.