Adventures on the Multimedia Teaching Frontier: A Narrative

John C. Russ
Materials Science and Engineering Department
North Carolina State University, Raleigh, NC 27695

The Challenge

Materials (MAT) 201 at N. C. State University is a sophomore-level introductory course in materials science. It is also both a problem and an opportunity, as I shall try to relate in this narrative. For many students it is the first course they take in engineering, after freshman courses in basic sciences, math and humanities. At one time all engineering students were required to take MAT 201; most still do (only Electrical Engineering has formally dropped it as a requirement). It represented (and represents still) the basic link between those science courses and the more practical and applied problems of engineering. It can also be argued (and I do argue it, when required) that a good understanding of materials is an essential introduction to any engineering discipline, since all engineers must select, design or produce materials of some kind in their work.

For the Materials Science and Engineering Department at N. C. State, MAT 201 is important in several less theoretical ways. First, since the number of students who take the course is quite large (currently about 800 per year), teaching this service course is a vital source of FTEs - the number of faculty-student contact hours that figure into the funding of professorial positions on the faculty. For a department with less than 150 undergraduate students of its own who will take upper division courses within the department, the FTEs generated by service courses like MAT 201 are essential to supporting the otherwise disproportionate number of faculty. Secondly, few students come to college expecting to major in Materials Science, and in fact few have ever heard of it. The department does try to promote its message to high school teachers and students, but the majority of its recruits come from MAT 201. Students who find the subject interesting often decide to enter Materials as a field, and represent a vital source of new undergraduates.

The problem with MAT 201, which I feel qualified to discuss having taught it to thousands of students during the 16 years I have been at N. C. State, is that it can be a terribly difficult, and hence for some students boring course. There is a huge amount of new vocabulary to learn as the course tries to cover a very wide view of materials science. Courses like this (which are taught at most engineering schools) typically start with atomic bonds, rush through crystallography and phase diagrams, try to distinguish between metals, ceramics, and polymers, encounter mechanical properties and perhaps electrical and optical behavior, corrosion, and so on. Even faculty members who have not taught the course recently and are periodically called upon to teach one section complain of being rushed to “get through” it all and keep up with the syllabus. For the student, it can feel like trying to jump aboard a rapidly moving freight train, and it is no wonder that some students fall off.

Furthermore, remember that most of these students are sophomores. For many, the development of study skills that can expertly abstract the important ideas in a lecture or chapter, organize the information into a coherent whole, and then access that knowledge as required on tests, is not very complete. It is difficult to convince a struggling student that the overview of materials science being presented in a course like MAT 201 is actually an introduction to all of the material that they will encounter again for the rest of their education, just in more detail. Instead a student who finds the pace and compass of MAT 201 too great is likely to conclude that all of engineering is like this and elect to pursue some entirely different course of study (or even to leave the university entirely).

The tradition of an early “washout” course that magically separates the sheep from the goats is certainly not new in engineering education (or other fields as well), but it is not comfortable to play that role and most teachers I have spoken with do not want to have their course be the fatal hurdle. We would all like to succeed in motivating students to learn and, even more, to like the subject matter.

Computer Graphics

Beginning in about 1990, I began trying to revitalize MAT 201 by addressing some of the specific problems that I could identify. One was a clear mismatch between the way that the material was taught (by conventional chalkboard lectures to large sections - typically 50-150 students) and the way the textbooks presented the information (lots of pages of detail that really challenged the students to figure out what was important), and the way that the students were actually prepared to learn. Most engineering students, and probably a large fraction of all students, are most comfortable as visual and active learners. Words, either spoken or written, do not communicate ideas as well as images.

Static listening to lectures or reading the textbook requires the students to build these images in their mind, and only the best few can really do this for themselves. The most successful courses involve hands-on laboratories in which students can explore and experience things for themselves, and take an active part in the learning process. But there was simply no practical way to make MAT 201 into a lab course. The resources (lab space, equipment, personnel) and the time (credit hours in the curriculum, already under downwards pressure from an administration fixated on increasing the graduation rate within four years) were just not available.

So I decided to try some other approaches. If the students couldn’t have a real hands-on laboratory experience, maybe the use of computer and multimedia technology would be an acceptable second best. Another factor in this decision was the observation that students have changed since the current faculty were students themselves. No, really, they have. My generation of engineering and science majors tended to have experience with real physical gadgets. We built (or dismantled) clocks, engines, and mechanisms of all kinds. We wired up elaborate electric trains or ham radios. The act of building conferred a particular kind of knowledge of how these things worked. Few of today’s students have that experience, even at a land-grant state-supported institution like ours that draws significant percentages of rural students. Instead, the experiences are “virtual” ones. Computer games and video are familiar. A radio or a clock is one chip, and the inner workings are hidden. So these students do not really have the hands-on skills that might help them to succeed in the laboratory but they do have a willingness to accept video, computer simulations, and other graphics as a representation of reality.

I decided to test that idea by selecting a few of the topics from the MAT 201 syllabus that by general agreement among faculty and former students were among the most difficult for students to master. The initial subjects dealt with were crystallography and phase diagrams. In questionnaires that asked students to name the most difficult or most confusing topics in the course, these two subjects always received 75-85% of the votes.

I had assumed (and in conversation most of the other faculty agreed) that the best way to learn about the sometimes complicated geometry of crystal structures was to build the physical models using sticks and balls. This seemed to combine visual and tactile learning in a way that made sense to us. But since we couldn't imagine any way to have a lecture class of 150 students each build all of the different models that would be needed, I decided instead to computer render models of the various unit cells, rotate them, and generate digital movies that could be used in class. I did this for all of the unit cells (metals, ceramics, and semiconductors - modeling the polymer molecules came later) that were covered in the course.

The advantages this seemed to offer over the static diagrams in the text were movement and color. And indeed, the students responded positively to these projected images and performed better on examinations that tested their understanding of the important concepts about the various structures. I learned a lot from those first animations, things that I have never found in any of the books that purport to give advice on making multimedia. First, the choice of colors is VERY important. About one in fourteen of our male students is color blind. The colors must be distinct not only in hue, but also in brightness. Second, fully saturated colors on a dark background may look snappy on the computer screen, but when projected in a dark room can be overwhelming. Softer colors work better for most observers. Third, and somewhat counterintuitively, it is best if there is not a consistent use of color to identify, for instance, the same element. By always changing the colors used for each atom or other visual structure, the student is not allowed to fall into the trap of memorizing the color instead of the information.

So I learned to use colors more effectively, and also made another discovery. To someone who already knows something about crystal structure, the unit cell diagrams in textbooks that show lines and points contain enough information to visualize the entire structure. But these students do NOT have that prior knowledge, and the dots and lines can be very misleading. I found that by animating the atom size, starting with the full-size touching atoms and then shrinking them to points, the students were enabled to visualize the relationship between the atoms and the points in the book diagrams (Figure 1).

I also discovered the importance of cutting away the atoms to show the actual unit cell (containing fractions of atoms) as a way to help the students understand what the repeating structure was, and how to calculate densities from the number of atoms in the unit cell (Figure 2). The same thing was true of planes and directions in unit cells. The ability to make some atoms become transparent, to show planes and lines moving through the structure, and to build up structures one layer of atoms at a time, allowed the computer graphics to show things that even building a ball and stick model would not easily accomplish.

Similar findings came out of the phase diagram studies. I found that a side-by-side display of the phase diagram with an isopleth (vertical line at some chosen composition), a cooling curve showing the temperature vs. time (with a hold in temperature at triple points), and a drawing of the evolving microstructure during cooling, helped the students to connect those pieces of information

(Figure 3). They are all in the textbook, but the connection must be made in the student's mind. When a lecturer (even one with good drawing skills) presents the same information on the blackboard, it is difficult to convey the sense of simultaneity in the various drawings. Also, it requires a lot of drawing and erasing, which makes for clutter, and it keeps the instructor's back to the class which makes it difficult to get feedback from students as to whether they understand, and to encourage questions.

Many of the same observations about the use of color were found as for the unit cell models. The diagrams of microstructure were simplified and perhaps over-simplified to show ideal eutectics and precipitates. But some images of real microstructures were included next to the drawings as a reality check, and again the power of side-by-side presentation was manifest. This same approach was applied to many of the other topics eventually covered in the modules (Figure 4)

These computer graphics were generated using my own Macintosh computer, and while it took a fair amount of time to render all of the graphics and save them as Quicktime movies, it was clear that once a particular set of the movies was done and done "right" it could be used over and over, so the effort seemed well worthwhile. Presenting them in class raised some new difficulties, though.

Classroom Delivery and Initial Results

First, the various sections of the MAT 201 course were often assigned to various large classrooms across campus. The large lecture hall in our own building was also used for other courses, some taught by other engineering departments and some for completely unrelated english, history, or economics courses. By insisting that we needed to use that lecture hall for 201 because we wanted to introduce multimedia (a little understood word, and thus having some magic properties), we managed to get most of the sections assigned to the one lecture hall. Then the department invested in blinds to cover the two large windows at the side of the room, which faced the afternoon sun and made the room too bright for any projection. The department (which has vigorously supported my efforts in this project throughout its duration) also invested in an LCD projection panel and a bright overhead projector, which I used with my own laptop computer.

The results were only fair. The LCD panel and projector were not really bright enough nor the image large enough for a lecture hall with more than 200 seats, even with the windows darkened by the new blinds. The students near the front and in the center could see the images clearly, but others could not and they complained about it. Our temporary solution was to encourage the students to come up after class and see them better, but this was clearly a stopgap measure. One thing that became clear immediately was that the use of the graphics changed the way the course was taught. It was possible to show the graphics for short times (30-60 seconds) so that the room was not darkened so long that student attention wandered, without having to turn to the blackboard, and to encourage students to discuss or ask questions about the images they were seeing. It felt more like teaching than the traditional chalkboard approach. But it required discipline for the instructor to keep to the already tight time schedule and not get sidetracked by the technology.

Comparing the test scores of the students in the sections using the graphics with those that did not (either because the professor did not feel comfortable with all the gadgetry and didn't want to use them, or because some sections were still being taught in other rooms) showed a definite and clear result. The averages on uniform tests given to all sections were about 1 full letter grade (10 points out of 100) higher for the sections that used the graphics. On other tests that covered topics in which the graphics were not involved, there was no statistically significant difference between sections.

This was exciting, and despite concerns about a Hawthorne effect in the results, we decided to keep on developing more modules, and trying to improve their delivery to the students. Switching around which section was exposed to the graphics, which professor used them, and continuing the same comparison testing over four semesters always showed the same results. The average grade differential was 9.6 points in tests involving a total of more than 1200 students (range 8.0-12.2 points), and persisted long enough that we believe the Hawthorne effect cannot provide an explanation. At present, all sections of the course have been moved to the same lecture hall, and the graphics are used for all students.

A Better Delivery Method using CD-ROM

Student comments were (and are) actively solicited on the graphics. Many of the specific modules developed have been produced to answer specific student questions or because they were suggested by students (more on that below). But one student comment the very first year the graphics modules were used caused me a good deal of thought. The student said "if these graphics are so important because you can't draw all that information on the blackboard at once, and make it move, then how am I supposed to take notes on it?"

Good point. It was clear that printing out static images of the graphics was not really different from what the figures in a textbook could deliver. In selecting the textbook to use for the course, we considered the quality of the graphics as one criterion, along with the organization of the topics and the quality of the example problems. But how could we let the students have the graphics to study at their own pace, as they would a textbook, while retaining the animated character that we believed to be important?

The first solution we tried was to make a CD-ROM with about 300 of the movies on it, in a hybrid format that would play on both Macintosh and Windows computers. By that time we had generated many more animations and simulations, included some digitized movie clips of laboratory experiments, and even some real-world examples. We also obtained some funding from the NSF-sponsored Succeed coalition, which made it possible to generate the additional modules and produce the CD. More about funding and the cost of all this work will appear below.

The additional topics that were added to the initial CD (called VIMS for Visualizations in Materials Science) were selected by the students themselves. We used questionnaires that asked the students to select the topics and the individual details within those topics that gave them the most difficulty in understanding. We also asked which topics in the course seemed to them most important for understanding future material (both in the MAT 201 course and in other courses taken afterwards). A frequently used feedback tool was to ask students in the last minute of class to write down and hand in an identification of the single topic in that day's lecture that was most confusing to them personally.

Finally, I made it a policy in my classes to allow any student to replace his or her worst pop quiz grade (usually a zero because they were absent) with a perfect 10 by writing up an outline that identified the topic that had given them personally a lot of trouble in understanding, and how they would now (that they did understand it) explain that topic to someone else, such as a peer, sibling or parent. Some students went beyond the bare essentials of that requirement to generate what amounted to storyboards for an animation to teach the material.

One semester, in an honors section of the course, students carried out projects that resulted in videotapes of demonstration experiments that were also useful (Figure 5). From such feedback, one discovery was that demonstration experiments using familiar or everyday examples such as food provided a good vehicle to explain complicated concepts. We have since created quite a few such examples (Figures 6 and 7).

With the NSF funding, it was also possible to devote more of my time to the work and to hire students to help. I found out by a process of trial and error that hiring graduate students for this task was not very useful. They knew too much, and wanted to generate graphics and simulations that explained far too much, or were too detailed, or simply demonstrated their knowledge of the material. Instead, it turned out that undergraduate students, particularly ones who themselves had taken the course within the past few semesters, were by far the most productive. They remembered what they had struggled with, and how they had finally learned it, and many of them were able to design and produce excellent teaching aids to communicate that information to others. In most cases, the students with B and C grades were better at this than the A students, probably again because they had struggled a bit more to learn the topics themselves.

During this time, we also upgraded the projection facilities. With money from the Dean’s office of the College of Engineering, we installed a bright RGB ceiling mounted projector that produces a huge, bright display above the blackboard. This works with either Mac or PC monitor outputs. It can be seen from everywhere in the room, without completely darkening the lights. I still like to use the graphics for very short time intervals, never more than about 1 minute, so that the lights are not dimmed for long enough that the students can relax too much. And I like to put the lights back on and make eye contact with the students while we discuss what they have just seen. There are even brighter projectors (so-called light-valves) that can project images like these without turning the lights down at all, and that would be wonderful, but they are expensive and what we have now is a reasonable compromise.

We still use our own personal computers for the projection. Some instructors carry in a laptop, some a larger computer. Some copy the files for each lecture onto their hard disk and some use the CD. The department has a dedicated computer on a cart that can be wheeled in, which had been used with the overhead projector and panel (also on the cart), but that is not very convenient in the present setup. Eventually, a dedicated computer in the lecture hall would make it easier to use these modules in class, and reduce the setup and tear-down time. All it takes is the money.

Funding has been an odyssey in this project. For about 3.5 years, a portion of the support has come from NSF through Project Succeed. A combination of bureaucratic difficulties has plagued that funding, so that it has rarely been available on time, or the university matching money was delayed (or even omitted). At the moment, the funding is six months behind the work (that is, we have generated the budgets, have been told the money was awarded, but have not been given it to spend). Since nearly all of the funding is for personnel costs, and the largest fraction of that is used to pay students, this creates some real difficulties.

Hiring Students to do the Work

Students are most effectively hired during the summer. For the last 4 years, I have employed from 6 to 8 students full time during the summer and a lesser number for 5-10 hours per week during the school year to produce the various modules, which currently number more than 700, plus the associated text material and example problems that are described below. The summer is just ending as I write this, and the money that was supposed to be available on March 1 is not yet in hand. So we have borrowed money shamelessly from the Department and from other projects to pay the students and keep the work going. Sometimes, when the final money does arrive, we have even reimbursed the hujacked accounts. Thank goodness that the department has valued the results of these efforts enough to find creative ways to support it and allow it to continue.

The amount of time needed to generate a high-quality animation, simulation, graphic or digitized video is enormous. Designing the idea, working through a few false starts, and making the final product, takes an average of about one hour per second of final digital movie (a ratio of 3600:1). I have not found anyone what has not tried to produce digital multimedia who believes that. I have not found anyone who ***has*** tried who thinks it is not true, and perhaps even conservative (a report from Caltech on their video production described a team of students working for an entire summer to produce one short movie!).

It really pays in the long run to let the students try out their own ideas, and then gently channel their creative juices to produce a final product. The students' ideas are often innovative and witty, and they work much harder when they are encouraged to exercise their own ingenuity. Making sure that the final result is technically accurate and educationally on target is important, and may require re-doing or modifying a module, but it is important to not try to force the production into a straightjacket.

It does take a lot of time. I estimate that I have spent at least half of my time actually working on this project for the last 5 years (and considerably more than that thinking about it). This is not something that is possible for a young faculty member seeking tenure and research grants, or that is possible without the strong financial and moral support of the department head. I have been lucky in that respect, and acknowledge the debt I owe to John Hren. Support from various members of the administration (both at the College of Engineering and the University level) has been sporadic, but welcome when it was present.

With much guidance and assistance from students (both the hired ones and those taking the course), we produced a second generation CD-ROM in December of 1994. This contains about 700 movie clips, comprising animations, simulations, graphics, and digitized video. It also has a Hypercard front end that covers the entire scope of the course. This provides the student with a concise digest of the important concepts in each chapter, effectively what a good student accomplishes by highlighting the textbook. Commercial distribution of the CD-ROM (both by itself bundled with a textbook) is planned by PWS Kent Publishing Company.

About 10% of the movies are digitized video of demonstrations or field trips that include sound tracks. It is not clear whether sound tracks are an advantage or not. For movies that are intended to be played frame by frame by students, they cannot be used. For some simulations and demonstrations, they offer a way to provide narration that directs student attention to the important details. For field visits to industrial sites, the inclusion of a sound track provides an ambiance that makes the experience more complete (Figure 8). However, the presence of the sound track as an essential part of the movie creates problems for playback on some platforms, as not all personal computers or workstations are equipped for it. In a setting such as our computer lab with 20 workstations in a room, earphones would be needed. We have considered using a subtitle track on the movies (which Quicktime supports) as a substitute for the sound track, but this does not provide quite the same degree of simultaneous and supplemental information as sound, and handles only text, not sounds that may be related to the experiments themselves. The optimum use of sound is still an open question.

There are also about 300 worked example problems, in the form of Theorist notebooks. Theorist is an interactive math package (from Waterloo). Unlike Maple, another of the products from Waterloo, Theorist is primarily intended to offer the student an environment in which they (not the computer program) can solve problems. Each problem is set up by entering the equations and assigning constants. Then it is solved by clicking on terms and dragging them from one side of the equals sign to the other, or clearing fractions, or expanding series, or whatever you would do to solve the problem with paper and pencil. But the program prevents silly errors, handles all of the arithmetic, allows easy substitution of other values to try “what if” calculations, and produces graphs that help students to visualize relationships between variables. Theorist also allows extensive comments, and the worked example problems (all taken from the Askeland textbook used in MAT 201 with the publisher’s permission) are heavily annotated with comments, drawings, explanations and hints.

There is very little else on the disk that is borrowed material. ASM International allowed us to reproduce some of the microstructure images from the Metals Handbook, and several local companies and artisans allowed us to videotape them (Figure 9). Everything else was done “from scratch” both to allow the maximum flexibility in designing the modules, and to avoid any copyright problems, which can plague projects like this.

Because we used Hypercard and Quicktime, both freely licensed Macintosh products, the second CD is playable only on Macs. We have nearly completed a Windows version by using Quicktime for Windows and translating the Hypercard to Allegiant Supercard, and expect this CD to be complete by the end of 1995. Theorist runs on both platforms.

Second Generation - an Interactive CD-ROM

The second generation CD, called VIMS2, is a highly interactive study guide to the entire course. Every topic is concisely explained in text, illustrated with appropriate graphics, and usually supplemented with movies of examples. There are also a series of “Easter Eggs” - icons we call the “pop-up professor” that can appear anywhere on the page, and are sprinkled throughout the cards. Each one produces a text box or graphic that contains relevant but not essential information to provide background interest.

The student can ignore these and miss nothing necessary to learning the material. But most students eagerly seek them out. They make the subject more interesting and more relevant to real life, and (like the teaching style of a good instructor that expands upon and comments on the material) they draw the student into the subject.

There is also an index on the CD. This allows the student to search by topic, look up ideas that have gotten fuzzy, or just follow interesting ideas. The essentially linear structure of a textbook has an important advantage for teaching: it assures that the student will visit all of the important ideas, in a reasonable order that provides necessary basic information before it is used. The rich linking and jumping possible with hypertext is more interesting and sometimes more useful, but can allow the student to become lost. We have tried to provide for both approaches, and expect most students to use a combination of the two strategies.

To assist the student in keeping track of the flow of the material, each card or screen has a reference to the corresponding page in the textbook where more detailed information can be found. In fact, we included references to the pages in all of the half-dozen or so textbooks that are commonly used for this type of introductory course. That emphasizes that this CD is not intended to replace the book (nor, for that matter, to replace the lectures) but rather to supplement the traditional tools of teaching with another that provides different benefits to the student.

Formative Evaluations

One concern that we addressed right from the start of the project was to determine how the students responded to the various graphics, whether the intended message and information were conveyed, and how various parameters of the graphics were related to student response. A series of comparison graphics were created for the crystallographic unit cells in which several parameters were systematically varied. These included colors, rendering quality, speed of motion, and the inclusion of shadows and reflections. We were unable to find any comprehensive literature on these topics beyond a general warning in some “How-To” texts on multimedia and screen graphics to “be careful” with the use of colors.

Because we presented the students with an opportunity to compare the graphics and express a preference (and indeed whether either, neither or both presentations made the geometric relationships clear to them), we were able to collect some quite interesting data. The students also self-identified themselves on the response forms according to expected grade in the course, sex, and whether they were a member of a minority group (primarily black students on our campus). This rather unexpectedly led to some puzzling observations.

Generally speaking, the minority students preferred a more “realistic” rendering while white students preferred a more “simplified” or abstracted graphic. For example (Figure 10), showing the atoms as polyhedra with flat shading is quite acceptable to the whites, while perfect spheres with Phong shading are preferred by the minority students ($p=0.0004$). Since the perfect spheres were also acceptable to the whites, this observation simply means that it is worthwhile to spend the extra time to make the more detailed computer rendering. This is a one-time operation since the images are then stored as an animation or movie, so there is no essential conflict presented.

However, this was not the case in some other situations. Male minority students preferred more saturated colors than the whites or the female minority students (p=0.001), generally commenting that the colors looked “pale.” However, the use of intense colors was rated as definitely objectionable to more than 50% of the whites, who generally commented that they made the details “harder to see.” Our compromise in this case was to use the less saturated colors, which were not preferred by but did not seem to raise significant objections for the male minorities.

Speed or smoothness of motion (e.g., the rotation of a unit cell) produced a significant (p=0.0003) difference between males and females, regardless of race. The use of a step size up to 15° between successive views was acceptable to the males, with a step size of 12° preferred. This was too large a step for the females, who equally preferred 9° or 6° steps. These were judged to be too slow by the majority of males. We have compromised on a step size of 9 or 10° as being the upper limit acceptable to the females and close to the lower limit preferred by the males.

The most confounding problem is the use of shadows and reflections (Figure 11). When given a choice of two identical renderings, one using shadows and reflections and the other not, 9% of the students prefer the presence of the shadows and reflections (the general comment is that this looks more “real”). However, the presence of the shadows and reflections is considered “distracting” by 77% of the students, who prefer the more abstract but less cluttered views produced without these additions. Normally when presented with such a difference, we would unhesitatingly opt for the rendering without the shadows and reflections, and in fact we finally did so in producing our final animations. However, 100% of the students who preferred the presence of the shadows and animations were black minority students. Since one of the goals of our program has been to specifically reach out to minority (and female) students entering engineering, this finding has caused some concern.

In the earliest round of evaluations of the animations and graphics for phase diagrams and crystallography, we found that the student response on questionnaires was favorable, but more favorable for whites than minorities (p=0.0001) and more favorable for males than females (p=0.003). Using an arbitrary scale of 0 to 5 (5=Essential, 4=Useful, 3=Nice, 2=Ho-hum, 1=Unnecessary, 0=Distracting) the overall student rating was 4.0, while for females it was 3.4 and for minorities it was 3.1. By soliciting specific suggestions for changes in the graphics and for additional graphics that should be added, and paying especial attention to suggestions from the females and minorities, we were able by the third year to raise the overall rating to 4.1 (Figure 12), and for females to 4.0 and minorities 4.0, with no statistically significant differences between groups. We found this ability to respond to the perceived differences gratifying.

Third-Generation Delivery via the Web

Another problem specific to the North Carolina State University campus remained. Few of our students have personal computers with CD players. Some institutions encourage or even require students to have their own computer. The campus computing strategy at NCSU has instead installed labs with workstations networked to servers. The workstations do not have CD players, and would not in any case easily run software designed for Mac and Windows machines (they do have emulators, but they are slow and tricky to use at best, and at worst they crash).

Our response to this has been to create a world-wide-web site (http://vims.ncsu.edu) with all of the same material as the CD. The various Hypercard pages have been translated to html (HyperText Markup Language) documents, accessible by Netscape (or any other browser that supports level 3 html tags and formatting). The Quicktime movies can be played by Xanim on X-windows machines, and the Theorist problems can be read by saving them as Adobe Acrobat pdf (portable document format) files. This makes the web site accessible to Mac, PC or workstation users. The size of the movies, which range upwards to 5-15 megabytes, makes casual access to the site by a modem or other low bandwidth connection rather impractical, but for our on-campus users it works fine.

The site was announced just before the start of classes for the fall 1995 semester, and had more than 8000 accesses the first week (a maximum of 14 simultaneously, but the program is configured to handle up to 25 connections at one time). Within the first month, we had delivered more than a Terabyte of documents. The server (an old Mac IIci belonging to the author) has so far been able to keep up with the demands nicely, and we are gradually fixing the various typos and other minor errors in the documents.

Since the students are now encouraged to use the campus computer network for access to the study materials for their own self-paced review of the graphics presented in class, it also made sense to utilize it in other ways. All of the homework problems are available on-line with fully worked and commented solutions. Instead of crowding around the bulletin board in the hallway, or trying to get a copy in the library (which always seems to disappear just before exams), the students can now read (and optionally print) them as they wish.

There is also a listserver to which the students are invited to subscribe, where they can voice their questions, complaints, insights and gripes. The faculty and some upper class students read the list and respond when they need to, but it is also possible for students to help each other over this list. And the faculty get a further insight into what ideas cause the most difficulty.

Juniors and seniors (and even graduate students) in our department also report that access to the on-line web site material helps them. It provides a concise review of topics that they studied once upon a time, but about which they may have forgotten some details. This is a comforting thing to have available when starting a new course whose professor assumes that each student is freshly up to date on all of the prerequisite material, and jumps immediately into the advanced details and vocabulary.

Beyond the horizon

Certainly, there is much more to be done. There must be many other questions in students minds that we haven’t yet discovered nor prepared answers for, and in some cases it may be necessary to produce better graphics or acquire more real-world examples to optimally support the learning process. But we think the mechanism for accomplishing that is in place (assuming that funding can continue at a reasonable level).

It would also seem natural to bring in materials that may exist at other sites, such as other universities, national laboratories, corporate labs, etc., that could be adapted to become part of this collection. Perhaps a professional society might be the best vehicle for that process of discovery and solicitation. The need to adapt and modify (usually to simplify) the kinds of graphics, movies and technical materials that are available from such sources is substantial.

Extending the materials also seems worthwhile. Some students have wanted to extend the simulations upward to become more detailed and realistic, but that seems to me to be the lowest priority. The more advanced students should have the necessary skills to handle this themselves, either with mental visualizations or their own computer routines. Extension laterally to other disciplines, including tying in freshman science courses more closely to engineering problems is certainly worthwhile, but is more a matter of example than content.

Extending the multimedia approach downwards to the secondary and primary grades may offer the most exciting challenge and greatest opportunity to fundamentally alter the education of engineers and scientists. We hope to find funding and collaborations that will pursue that goal.

Acknowledgements

The following students have contributed to the development of the multimedia modules (alphabetically): Wade Babcock, R. J. French, Rhett Guthrie, Jake Huffman, David Knott, Todd Miles, Brent Neal, Dan Poulton, Mark Schaffer, Tim Smith, Don Wigent, Abbey Van Rood. Brent Neal wrote the bulk of the Hypercard scripts and Rhett Guthrie created the web site.

A portion of the funding for this program has been provided by the National Science Foundation through Project Succeed. Other funding has been provided by the N. C. S. U. College of Engineering and by the Materials Science and Engineering Department.

Permission to use copyrighted information has been given by PWS Kent Publishing Corp (problem sets from D. R. Askeland “The Science and Engineering of Materials - Third Edition”) and ASM International (micrographs from “The Metals Handbook - Volume 7”).

The major programming tools used include Quicktime and Quicktime for Windows (Apple Computer), Hypercard (Apple Computer), Supercard (Allegiant), Theorist (Prescience Corp.), and Webstar (Starnine).