MULTIMEDIA FOR TEACHING STATISTICS: PROMISES AND PITFALLS

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1. INTRODUCTION

It seems that it is always the *next* generation of education technology that will revolutionize teaching. Television, which has had dramatic effects on many aspects of society, has only a small presence in education. Computing has had a larger impact—at least on the teaching of statistics—but has supplemented rather than replaced traditional classroom practice. The next generation is now multimedia. This paper examines the usefulness of multimedia technology for teaching statistics, with attention to both promises and pitfalls. We suggest some principles for design and use of multimedia, and we also offer opinions (informed, we hope) on the role of human teachers in a multimedia educational environment. The paper reflects what we have learned in the preparation and preliminary development of a multimedia system for beginning instruction in statistics, undertaken with support from the National Science Foundation. Ambron and Hooper (1990) and Grabinger et al. (1990) are general surveys of multimedia instruction. Haykin et al. (1993) survey multimedia technology and methods more generally.

Multimedia presentation combines text, sound, still images, full-motion video, animation, and computer graphics in a single computer-based system. In current versions, the learner interacts with the system via keyboard and mouse. She both influences the sequence and pace of the presentation and interacts with the presentation (think of video games). In the case of statistics instruction, she also has ready access to computing facilities for statistics calculation, graphics, and simulation.

The term "Multimedia," like other buzzwords, is often used vaguely. We have in mind an instructional system that attempts to make full use of the technology, guided by sound principles of teaching and learning. Such a system goes far beyond a "book on the screen" augmented with occasional animated illustrations and exercises — a form found in many early attempts at multimedia.

The promise of multimedia for teaching statistics rests on the major premise of the movement to reform instruction in the mathematical sciences: that students learn best by their own activity, rather than by passively receiving information. Multimedia offers a highly interactive and individualized environment in which the learner is constantly invited to manipulate animations, asked to respond to questions, and encouraged to work independently to exercise newly-learned concepts. The combination of media, each with its own strengths and weaknesses, allows a multimedia system to adapt to variability in student learning styles and level of preparation. Different individuals learn more readily from different forms of communication. The learner can, for example, control the pace of instruction, decide to review material just presented, advance to a new presentation, or view supplemental enrichment or background material.

Multimedia's promise is also supported by recent changes in the content of beginning instruction in statistics. Courses that emphasize working with data, visualizing relationships with graphics, and the practical application of computing, match the strengths of new technology. Multimedia can also help students understand and remember the concepts of probability and inference by providing a better vehicle for illustrating, visualizing, and reinforcing these abstract concepts.

Whether these promises will be fulfilled is of course an open question. In this paper we provide some of the background required to assess multimedia products for learning statistics, and try to point out the likely strengths and weaknesses of such products. Our focus is primarily on pedagogy rather than on the details of rapidly-changing technology. Section 2 summarizes current views about content and pedagogy for beginning instruction in statistics and notes matches and possible mismatches with multimedia capabilities. Section 3 surveys the pedagogical strengths and weaknesses of some of the individual media and draws conclusions about wise use. Section 4 addresses the important issue of how much freedom a multimedia design should allow learners of a structured and hierarchical subject like statistics. Section 5 concerns technology; it is quite brief because specific comments would rapidly become outdated. Section 6 asks about the role of human teachers in a multimedia-based course and concludes that the human contribution cannot be replaced, but that it can be made more efficient. It should be clear, particularly from Sections 4 and 6, that there is much yet to be learned about effective design and use of multimedia in teaching. The period of experimentation is already underway.

2. THE SETTING: CONTENT AND PEDAGOGY FOR BEGINNING STATISTICS

2.1 Content: what do we want students to learn?

The practice of statistics has always been closely tied to data and to the substantive problems of inductive inference. Lately, research in statistics has turned somewhat away from mathematics towards developing new methods for dealing with a wider range of problems drawn from practice. Beginning instruction in statistics has also begun to reemphasize data and the conceptual foundations of statistical reasoning.

As a result, there is now a widespread consensus among statisticians that a beginning course should emphasize practical understanding. The first two recommendations of the joint ASA/MAA Statistics Focus Group (Cobb, 1992) are "Emphasize statistical thinking" and "More data and concepts: Less theory, fewer recipes." Statistical thinking includes such principles as the strategy of exploratory data analysis and the design of randomized comparative experiments, along with the reasoning of formal inference. Under the second heading they urge "using the computer to automate calculations and graphics."

Modern introductions to statistics *begin* with the tools and strategies that are used to explore and understand data. We ask students to analyze real data as a means of both reinforcing and assessing the learning of new concepts and skills, and as a base for motivating the concerns of inference. To free students of their natural undue concern for recipes, we require that they become proficient with a statistics package. Statistical inference is put in the context of data analysis and often linked to the planned production of data to address specific questions. Formal probability-based inference, while still important, plays a smaller role, now motivated primarily by the need to assess the value of data analyses rather than as a mathematical argument emerging artificially from foundations constructed for the purpose.

Such a "reformed" beginning statistics course is ideal for multimedia instruction. A multimedia platform has computing constantly available, so the system itself can work with real data for presentation and students can analyze real data in exercises. As Wild (1994) notes in commenting on student deficiencies in data analysis, "One of the problems is simply that they have not seen enough examples. Some people require large numbers of examples before they begin to recognize patterns or structures." Human instructors tire of presenting examples (and students tire of passively listening to them). But a good multimedia system can be stocked with many data sets along with descriptions of their real-world settings. Moreover, students can be asked to follow through on their analyses, drawing conclusions about the real-world setting rather than stopping with the calculation of a numerical result. (After all, the computer will get the mean and standard deviation right; the student's challenge is to understand what they say about the world.)

Although data, graphics, and computing are the content emphases that most obviously suggest increasing the use of technology for instruction, many core statistics concepts can benefit from multimedia presentation. Any time an experienced teacher would choose simulation as a vehicle for demonstration, a multimedia system can be even more effective by placing control of the simulation in the hands of the learner and by providing animations that suggest the nature of the phenomenon simulated. For example, animated simulations are an ideal way to present the central notion of a sampling distribution and the reasoning of inference that follows from this notion.

Another goal of a first statistics course, often unstated but nonetheless important, is to motivate students; to change their attitude about statistics. Multimedia can use video and animation to draw on many real-world motivations for learning statistics. Typical (mis)uses of statistics from television and print can provide examples so that students gain practical experience in applying newly learned concepts to the kinds of informal situations they will encounter in everyday life.

Multimedia is probably more suitable for a "data-and-concepts" basic statistics course than for a course introducing statistics theory. Previous teaching technologies such as mastery learning and computer-assisted instruction were able to teach skills, but were less effective in helping students to learn concepts or solve complex, multi-step problems. Multimedia can certainly teach skills well, and has the potential to be equally effective for concepts, but this potential will not be realized until multimedia authors learn to use the special capabilities of multimedia to present, illustrate, and reinforce concepts in new ways. Until this is achieved, skeptics will be able to ask whether a multimedia course can convey an adequate conceptual understanding of statistics. We believe that the multimedia presentations that will become available in the next several years will prove as strong in teaching conceptual understanding as they are in teaching data analysis skills, but of course, this is yet to be proven.

2.2 Pedagogy: how do we help students learn?

Statistics challenges both teachers and students. Statistics courses introduce theoretical concepts and new ways of reasoning, but must also teach practical techniques for analyzing data. Sometimes students must learn to interpret displays intuitively; at others they must follow closely reasoned mathematical argument.

There is now a well-established movement to reform instruction in the mathematical sciences in general, and in statistics in particular. The central principle, which rests on research into teaching and learning, is that learning is inherently interactive and that instruction should therefore encourage students to be active participants in learning. Garfield (1995) gives a survey of the research basis of the reform movement as it applies to learning statistics. "Foster active learning" is the third main head in the recommendations of the joint ASA/MAA focus group on the statistics curriculum (Cobb, 1992). As the National Research Council report *Reshaping School Mathematics* puts it (Mathematical Sciences Education Board, 1990),

> What is needed is a variety of activities, including discussion among pupils, practical work, practice of important techniques, problem solving, application to everyday situations, investigational work, and exposition by the teacher.

"Activity" and "variety" are two of the watchwords in expositions of the reform position. Two other watchwords are "communicate" and "cooperate." Students learn in part by communicating their findings, both orally and in writing, both among themselves and to the instructor. They also learn by participating in group discussions and cooperative problem-solving. Discussion may be particularly important for "higher order learning," the stage at which students apply their knowledge to complex, multi-step and perhaps vaguely formulated (i.e., realistic) tasks. Teachers should encourage open discussion and group problem-solving, and insist that students express clear conclusions from their work. A number, a graph, or "reject H0" are not adequate solutions to a problem. Students should state a substantive conclusion in the setting of even the most routine problems, for example, "There is strong evidence (P=.0023) that attending language school improves the mean score of high school French teachers on the MLA listening test."

Employers share with education reformers an emphasis on the importance of communication skills and experience working in teams. Bailar (1988), for example, emphasizes that communication is an essential aspect of statistics practice that is neglected in traditional university instruction. When one of the authors visited Motorola, the strongest message he heard was, "We want employees who can work cooperatively in teams. Why do universities persist in sending us graduates whose only experience is in competitive individual work?"

Activity, variety, communication, and cooperation challenge teachers accustomed to the traditional emphasis on lecturing in university teaching. Exponents of multimedia point to its strengths in emphasizing student activity and offering variety in instruction. However, current technology does not necessarily promote discussing problems, working cooperatively, and communicating conclusions.

3 THE MEDIA IN MULTIMEDIA

Multimedia comprises a variety of communication channels. Each has distinctive strengths and weaknesses. A successful multimedia system must balance these channels, using each for what it does best but letting no one channel dominate.

3.1 Video

Both the strengths and the weaknesses of video in teaching are very pronounced. Moore (1993) discusses these and gives additional references, among which we recommend Howe (1983).

The most obvious strength of video as an aid to learning is that it takes students beyond the classroom by making distant or past events present. Video can concentrate our attention through editing, and can manipulate time and space through time-lapse, slow-motion, microscopic, or telescopic views. When these tools are used properly, a video presentation can be more compelling than direct observation.

Equally important is the less obvious fact that the strongest effects of video work subliminally rather than rationally, changing feelings and attitudes rather than conscious thought. Video is an ideal medium for demonstrating that statistics is widely applied and for changing attitudes toward statistics by showing real people making real use of statistical tools and ideas in diverse settings.

The weaknesses of video for instruction are as striking as its strengths. Video is a poor medium for exposition. Television shows rather than tells. Students who approach video segments as if they were text-style expositions become frustrated: they can't take notes because the presentation moves quickly and has several simultaneous levels, which they cannot satisfactorily reduce to a single linear track. Most important, video viewers are passive spectators, not actively engaged in their own learning. The passive nature of video viewing is no doubt closely connected with its effects on emotions and attitudes. Video may change attitudes, but without interaction it is unlikely to help students learn straightforward skills, and certainly not able to help them understand concepts, make judgments, and apply skills to complex problems.

Video is the most expensive multimedia channel in several ways. Shooting and editing good on-location video is very expensive in dollars, but there are few alternatives. Mediocre video noticeably degrades the quality of a multimedia presentation. Stock footage may be available, but presents issues of licensing, editing, and over-dubbing narration. Storing and displaying full-motion video, even with increasingly clever algorithms for compression and decompression, requires more disk space and faster data transfer than other aspects of multimedia systems. Nevertheless, the lay person's standard for judging the technical quality of multimedia is often video: how large a window, how smooth the motion, and for how long?

The expense of video sharpens the incentive to use it efficiently. Video clips of statistics applications are very effective for motivating learners and presenting problem settings. Moreover, keeping in mind video's strong subliminal effects, we should not insist that every excerpt directly support the topic being taught at the moment. Changing attitudes is an important instructional goal, and video is a proven means for achieving it. On the other hand, exposition by "talking heads" (even the heads of very distinguished people) is inefficient given video's weakness as an expository medium and the limited amount of video material that a digitally-stored product can offer.

3.2 Animation

Animation refers to making objects on the computer screen change or move in real time. Animation has the technical advantage that it is less expensive than video to produce, less expensive to store (taking up less space in digital form), and easier to display (requiring fewer computing resources). Multimedia game designers, following in the path of movie cartoon animators, have learned that a complex still drawing can be made to seem video-like by adding a small animation. Because motion on the screen is so important to holding the viewer's attention, animation plays a major role in multimedia design. Here are some ideas.

Animation can be used to maintain the viewer's interest and to provide a mnemonic image. For example, the "N" in the word Normal might change smoothly into a normal density curve and then back to an "N." Such smooth transitions between pictures are sometimes called *morphs*. The mnemonic image is often more vivid than a static illustration could be, and thus can make the concept easier to remember.

Animated *cartoon characters* that have well-defined personal characteristics can emphasize key concepts, offer help when the student is stuck, and so on. It appears that even animated characters elicit from students a sense of identification and support (Oren, 1993).

Perhaps the most effective instructional use of animation is to construct objects that a student can manipulate to learn about a concept. We call these objects *toys*. Animated computer toys — like their physical counterparts — can simplify the world, focusing attention on a particular aspect. They are inherently participatory and private are designed to feel "safe" so that there is no fear of playing with them.

For example, a student might be offered a scatterplot with a superimposed line that she can grab and reposition with the mouse. Related displays might show the equation of the line and the current sum of squared residuals as a rising and falling thermometer bar. The student can quite easily (we have tried it) find the least-squares line by repositioning the line on the scatterplot. *Statistics Workshop* (Rubin and Bruce, 1991) contains a toy of this nature. More elaborate versions can illustrate the effects of outliers on the fitted line or compare the least squares and least absolute residual criteria.

A more subtle use of animation is to structure the presentation of material in a multimedia environment through an *exposition window*. The exposition window replaces the functions of a lecturer's blackboard, providing a basic "main track" structure for a lesson and recording key points visually. It also provides functions not possible on a physical board. Words written in the exposition window can move, flash, change color, and morph into mnemonic shapes. Similarly, illustrations and statistical graphics can move either in synchrony with narration or in response to student actions with the mouse or keyboard.

3.3 Narration

Developers of multimedia have tended to overlook the value of oral presentation of ideas. It is true that neither a disembodied voice nor a talking head is a particularly effective channel for exposition. But a spoken narrative can be very effective when illustrated with animations and perhaps accompanied by an outline of key points (built up point by point—more animation) in an exposition window.

Oral presentation combined with writing on a blackboard or transparency is the traditional means of classroom instruction (with the "animation" usually limited to a professorial wave of the arms or a disembodied pointer on the overhead screen). Video instruction often presents narrated animations, though without the exposition window and student interaction. In the Annenberg/Corporation for Public Broadcasting telecourse *Against All Odds: Inside Statistics*, for example, a narrator explains the construction of a stem-and-leaf display while the viewer sees the display being constructed.

3.4 Sound

The uses of sound go beyond narration. Properly used, sound enriches a multimedia environment. Haykin *et al.*(1993) note that

> "Sounds in the interface can alert users to problems or opportunities, mask transitions, acknowledge user actions, convey information, and divert attention from other processes." (p. 153)

Sounds provide an additional channel for toys; it is easier, for example, to minimize the sum of squared residuals in the regression line toy we described earlier if a sound accompanies the visual display, changing in pitch to reflect the residual sum of squares.

Sound effects can lend authenticity to animated objects, as when an opening door creaks or a cork pops. Sound effects can even lighten the mood of an exposition that has grown too serious. Sounds can make mnemonic morphs more memorable.

3.5 Statistics Software

A multimedia system for teaching statistics must include software for statistical graphics and calculations. Moreover, students should have some freedom in choosing when and how to use the software. There are strong arguments for incorporating a full-function statistics package, as opposed to limited functions that address only immediate instructional needs. Learning to use a full statistics package gives students a transportable skill that they can apply outside the course environment. It also allows students to explore alternative analyses and make graphics that are not specified by the lesson plan. However, the package must be easy to learn and use, lest students spend too much effort and attention on learning the package at the expense of learning statistics concepts and skills. Biehler (1993) provides extensive comments on desirable features of software for *teaching* statistics. He notes that the features may not be present in software primarily designed for *doing* statistics.

When a statistics package is integrated with a multimedia course, the authors can take advantage of the multimedia tools to teach students to use the package. The package, in effect, is the ultimate statistics "toy," and can be introduced in much the same way as the more limited and focused toys used in concept exposition.

Within the course, statistics software makes it practical for students to work with real data almost immediately. A statistics program can also be a "laboratory" for experiments in randomness and probability. Students can generate random samples from distributions with known parameters and see for themselves, for example, how means of many samples from the same population behave. By transforming the study of probability and inference from a dry presentation of mathematical results to an experimental science, multimedia attempts to provide students with alternative ways to understand and absorb these difficult concepts.

3.6 Randomness and Simulation

We noted earlier that the computer can provide a laboratory for learning about randomness, probability, and inference. The great advantage of this approach is that each student can have full control over the properties of a population and see for herself how those properties are reflected in samples or in sample statistics. Moreover, an accompanying pictorial animation can try to convey the connection between the simulated sampling and its real-world analog.

One potential problem with all computer simulation is that students may not regard the computer's results as representing real-world random behavior. Students who have grown up with computers are sufficiently sophisticated to know that deterministic machines are not random. Another difficulty is that many repetitions are needed to demonstrate the long-term regularity described by the laws of probability. Short random sequences are often much less regular than our intuition suggests. Tversky and Kahneman (1971), for example, have shown that people believe that small random samples ought to be much more representative of the population from which they were drawn than they really are in practice.

Multimedia designers therefore face the dual challenges of first making clear to the student the nature of the phenomenon simulated and then performing enough repetitions to demonstrate the long-term regularity of random phenomena. In facing the first challenge, an appeal to traditional randomizing props is almost sure to fail. Animated dice or roulette wheels look faked (and, of course, they are). One possibility is to allow the student to draw the random sample herself, depending on the limitations of human reflexes to make the resulting sample undetermined. Thus, for example, the student may be asked to halt (e.g. with a mouse click or key press) a rapidly moving animated process such as the spinning of many wheels holding digits. Or the system might present a population of values and then rapidly nominate different random samples of the values (say, by changing their color or boldness). The student can draw one of these samples by stopping the animation with a mouse click or key press.

The second challenge may require explicit instruction about the number of repetitions, a real-time display of cumulative results during the simulation (slowed to allow the display to evolve effectively), and assignments that ask the student to contrast short-term and long-term outcomes. Clever simulation toys can help provide the guided experience with randomness needed to correct our faulty intuition.

3.7 Data Generation

Students who deal with real data as an integral part of learning statistics can gain still greater "ownership" of the data if they participate in generating it. Students can manipulate on-screen tools such as rulers, calipers, and stopwatches to produce data from a video or from an animation. They can experiment on themselves, recording reaction times or perception abilities; a computer screen can be an excellent tachistoscope.

Students can also enter data from other sources. They might participate in class projects away from the multimedia platform and return with data from surveys or experiments. They might find data on the Internet and "bring it to class". We discuss below some implications of such individual work for assessment and evaluation.

3.8 Exercises

Frequent drill exercises with immediate feedback (another element identified as helpful to effective learning) are a natural part of a multimedia course. One advantage of multimedia is that the computer never tires of repeating drills. A disadvantage is that computer is ill-equipped to evaluate student performance, and virtually incapable of recognizing the underlying misconceptions that may be the root of an incorrect answer. We suggest ways for teachers to deal with this challenge in Section 6.

4 CHOICE VERSUS STRUCTURE

4.1 Choice

A student playing with an animated toy or analyzing data with a statistics package controls the pace of that interaction. However, students may be offered different degrees of control over the global pace and sequence of a multimedia course.

Control over pace is quite simple, but is an effective way of meeting individual needs. Control over sequence can be offered through *hypermedia*. Rather than a single linear track as in a book or movie, hypermedia provides a web of interconnected paths that the learner may choose to follow. Hypermedia accommodates students with different levels of preparation and different learning styles. For example, a course can offer reviews of prerequisite concepts, such as the algebra and geometry of lines when students first meet simple linear regression. Students who do not need review will not choose this path, and those who do need it can review in private and without embarrassment. The learner may choose among enrichment material, such as a derivation of the least-squares formulas (either algebraically or with elementary calculus, at the student's discretion) or a comparison of least squares with resistant criteria.

Multiple pathways may, however, disorient learners. The reader of a textbook has no difficulty knowing where she is in the lesson and in the course. Questions such as "How far to the next natural stopping point?" and "What material comes before what I am now reading and what comes after it?" are easily answered by thumbing a few pages of a text. It is more difficult to convey this sense of place in a software environment. Students can feel disoriented simply because they have no sense of where they are, how they got there, and where (and how far) they must go.

A well-designed multimedia interface reduces this complexity, helps students see where they are, and allows them to navigate. Part of this simplification can result from restricting the choices offered to beginning students, focusing their progress along relatively few paths. More advanced students can be offered greater freedom with less risk of confusion.

4.2 Structure

The nature and extent of user choice describe a continuum of designs for multimedia teaching. At one end of the continuum are the many attractive multimedia products that invite their users to explore freely some area of knowledge. Dinosaurs, musical instruments (with effective use of sound), and an art gallery are the topics of currently popular "explore this world" multimedia products. Some of these products have impressive graphic design and elegant navigation controls that allow users to browse at will. Unfortunately, the "explore this world" design does not meet the requirements of systematic instruction in statistics. Browsing and exploring don't provide enough structure to guide a beginner through a subject in which some ideas and skills are prerequisites for others.

At the other end of the continuum is a book transferred (in the current jargon, "repurposed") to the computer screen. Students read the text on the screen and select from a variety of supplementary animations and exercises. This form of presentation controls the order of presentation while letting the student set the pace. Its major failing is that it relies on text on the screen for exposition. It is tiring to read text on a computer screen. Students cannot assimilate text on the screen as easily as text printed in a book, for it usually does not accommodate the artifices that most students employ to create a sense of participation in the assimilation such as highlighting, underlining, and writing in the margins. This form of "multimedia" instruction is quick to design and cheap to produce, and will therefore be the first form to be widely available. Unfortunately, it takes only minimal advantage of the capabilities of multimedia and does not move substantially closer to the reformers' ideals than the lectures and textbooks currently in use.

4.3 How much choice?

We believe that an effective multimedia design for teaching statistics will avoid both ends of this continuum. It must have an ordered core of lessons because of the hierarchical nature of beginning statistics, though the specific order is to some extent a matter of author choice. But to what extent should student (or instructor) options be allowed within the core order? Review material is presumably always available, but what about enrichment lessons and optional topics? Should the system require students to complete earlier lessons before moving on to later material? Should it require students to demonstrate a minimum level of competence in drills to mark a lesson as completed? Traditional computer-assisted instruction tends to the authoritarian side of these structural issues. There is certainly room for differences of taste. Multimedia authors may wish to permit teachers to set parameters within these ranges for their students.

However, multimedia authors must balance the need to impose a sequence on presentations against the students' desire for freedom. Even conscientious students who honestly think they understand a topic can become confused if they are allowed to skip it. A student who "knows about the mean," for example, may think he can skip that lesson. All might be well for several subsequent lessons until the introduction to regression notes that "like the mean, the regression line is a least squares statistic" and the student realizes with a sinking feeling that he missed that property of the mean and knows neither its definition nor its consequences. Of course, a hypermedia link should be available to return the student to the appropriate earlier lesson, but the student has gained little but frustration from skipping ahead in the sequence.

One way to disguise the ordering of material is to hide it within a story or game. Learners might, for example, be assigned the role of sleuths solving a mystery or characters in a fantasy "quest" story. Facts about the subject matter provide keys to solving the puzzle or accomplishing the quest and must be learned in a specific order to advance in the story. Such instructional games are used in some teaching programs for elementary or pre-school students. However, they are not suitable as the main vehicle for secondary and post-secondary instruction because a game or quest becomes trite over the course of the many lessons needed to cover a full term of college-level material.

Within each lesson, an effective multimedia design must use and sequence multiple media appropriately. It should present new material with a combination of narration, animation, text, and pictures. It should avoid a text-based presentation: at no time should a student have to read more than a brief paragraph of text on the screen. It should require that learners participate at frequent intervals, not just by pushing a button but by manipulating an animation or doing a calculation to answer a question. Students must move from the presentation of concepts to their use in data analyses on a statistics package smoothly and regularly. New concepts should generally be presented through at least two channels simultaneously and reinforced in at least two different ways.

For example, a student might see a video to motivate the problem, listen to a narration while watching a display or animation, manipulate the display or animation for herself, immediately employ the new concept by applying it to some real-world data (perhaps the data discussed in the initial video) using the statistics package, and finally write a brief paragraph relating what she found in the data to the questions posed in the video.

How much choice students should have remains a major issue. We believe that learners should have nearly total control of the pace of a lesson. Some segments of a lesson (e.g. a video) remove most of that control temporarily while they play. Such segments should not begin until triggered by the learner. Other segments (e.g., playing with an animated toy, analyzing data in the statistics package, experimenting with simulated data) should continue until the student chooses to stop.

But some issues of pace are open questions: Should the learner be permitted to choose to skip a course segment entirely? Should the system require that students do some minimum amount of exploration using manipulable animations, or simply invite that exploration? Is the student required to do at least some drill exercises, or allowed to merely view the multimedia exposition and move on?

Finding the proper balance between strictly sequential presentation and free choice by the learner, while allowing for variation among learners, is one of the most difficult aspects of designing multimedia instruction in statistics. Specific efforts will inevitably reflect the ideas and tastes of the authors. We think this is good, because it may lead to a population of multimedia statistics courses with greater variance than we find in the current population of statistics textbooks. Large variance is desirable if evolution is to yield strong products.

5 TECHNOLOGY

It is clear that multimedia in our sense of the term requires that the learner use a workstation with a CD drive, sound and video capability, a monitor large enough to display several windows simultaneously, and sufficient CPU speed and memory to handle all this smoothly.

The technology required to *play* multimedia is already adequate and is advancing rapidly. For example, it is possible to store about 40 minutes of digitized, full-color, small-screen video on a CD-ROM with random access. Furthermore, multimedia capability is becoming standard on all but entry-level computers.

The software tools for *developing* multimedia applications have (despite several years of hype) only just begun to become practical. Even today, the best multimedia tools are relatively crude compared to what we can imagine doing "if only we had the power." The available multimedia authoring tools are best suited for developing short multimedia presentations, but are not adequate for building entire multimedia courses. The required custom programming adds to the time and expense needed to develop multimedia for instruction.

Several foundation technologies have emerged to support multimedia in both the Macintosh and Windows environments. These include Apple's Quicktime support for video, animation, and sound, Taligent's OpenDoc protocols for merging views from several programs into a single responsive document, and Microsoft's Object Linking and Embedding (OLE) protocols for cross-document communication. These and technologies like them may well provide the functionality and portability needed to build effective multimedia-based courses.

Technical tools are, of course, not the only barrier to designing effective multimedia instruction. We have already mentioned a number of unanswered pedagogical questions. Moreover, writing a multimedia course combines elements of script writing, textbook writing, graphic design, and electronic game design. Few people combine expertise in all these genres. Development teams are a natural — and expensive — way to gather sufficient talent.

One consequence of these constraints is that it is not yet inexpensive — in money, resources, or time — to develop a full multimedia course. We anticipate that early forays into multimedia-based teaching will either be designed to support, rather than replace, traditional teaching, or that they will rely heavily on repurposed texts. A full multimedia course is likely to require ten person-years of effort and a budget of several hundred thousand dollars to develop. As support software improves, we hope to see some of these costs decline.

6 THE HUMAN FACTOR

6.1 Communication

One weakness of having students work at individual workstations is that the benefits of student-to-student communication and group work are lost. Technological optimists believe that it may be possible to rebuild communication by providing electronic forums in which students interact with each other by email or use a course bulletin board to ask and answer questions. A large class could have study groups of six to ten students who "meet" electronically to discuss concepts and homework. Email is now sufficiently widespread and popular that these hopes may see at least some fulfillment. Similarly, instructors could be contacted by electronic mail to answer questions and can either reply to an individual or broadcast information to an entire class. Assignments might be submitted and returned electronically. A full multimedia course package should include user-friendly means for electronic communication.

Another aspect of electronic communication is harvesting material from the Internet. One example is the *Chance* project developed by Laurie Snell at Dartmouth College (Snell and Finn, 1992). Chance makes available on-line resources concerning current events that can be used to motivate discussions of statistics. One of us (Velleman 1995) is developing an on-line library of real-world data sets suitable for teaching. The Data Archive and Story Library (DASL) will be made available for preliminary trials and public comment on the World Wide Web through StatLib. It permits teachers and students to search a library of data sets according to their subject matter base and according to the statistics methods that they illustrate. Stories associated with each data set describe an aspect of the analysis of the data and the way in which the data illustrates the statistics method. A multimedia course could easily incorporate access to the

WWW with Mosaic or a similar program. Students might be assigned reading (and short essays) based on topics from the Chance archive or assigned projects in which they select and analyze a data set that interests them from DASL.

6.2 The place of the teacher

Proponents of multimedia often seem to suggest that the new technology is capable of largely replacing human teachers. This may in fact be true when the learner is strongly motivated, mature, and disciplined. It is most unlikely to be true for beginning instruction in statistics for a broad group of college undergraduates. The experience of televised distant learning (see Moore 1993) suggests that standalone multimedia may well succeed with mature learners who seek some valuable educational credential, such as the post-graduate engineers served by the National Technological University. In general, however, we believe that human teachers are an essential part of multimedia instruction. We ought to analyze their strengths and weaknesses just as we analyze those of video or sound. The proper goal of teaching technology is not to eliminate the teacher, but to preserve expensive human time for the tasks that humans do best.

Chief among the strengths of human teachers is *motivating students*. Humans are social animals who profit from direct interaction with other humans. A skillful teacher does much more than transmit information. She encourages, prods, rewards, and in general increases student effort and accomplishment by personal interaction. Motivating learners borders on a second human strength, which might be called *high-level interaction*. The teacher deals with individual difficulties—any difficulty, not just those anticipated by the authors of a technological system. She makes exceptions for individual circumstances (sometimes grandmothers really do die). She injects well-chosen questions and comments into a group problem-solving session.

These "soft skills" are not the only dimensions in which human teachers outperform technological systems. *Assessment* of learning has received as much attention from reformers as teaching itself, and their verdict on traditional assessment is more negative than their opinions about traditional teaching. As Joan Garfield (1994) says, "Traditional forms of assessment of statistical knowledge provide a method for assigning numerical scores to determine letter grades but rarely reveal information about how students actually understand

and can reason with statistical ideas or apply their knowledge to solving statistical problems." Multimedia systems, like traditional computer-assisted instruction, are good at routine drill to develop and assess discrete skills in settings where the computer can judge a response to be right or wrong. Drill has its uses, but eventually a human teacher must assess the student's ability to solve problems, present multistep analyses, and draw sensible substantive conclusions from data.

Toward this end, a multimedia environment offers the advantage that each student is working regularly on a computer and with a statistics package. Lessons should regularly apply methods or principles to be explained and show how the application of these methods can lead to new understanding of the data. Against this background, assignments can ask the student to examine a dataset (in particular, using the methods just presented) and then draw conclusions about the data and report them in a prose paragraph or two.

Such assignments have the multiple advantages of reinforcing new concepts in the context of practical application, of motivating students by demonstrating that what they are learning has practical value, and of providing students with a loosely structured challenge to their understanding that can effectively reveal the weak points in that understanding. However, assignments that require conclusions drawn from analyses clearly must be evaluated by a human teacher.

6.3 Keeping the human factor in multimedia

The ideal instructor may well be an always-present, infinitely patient human being. Multimedia systems need not, however, compete with an ideal so rarely realized. Classes of 50 students challenge the skills of the best teachers in motivating and interacting with individuals, and lectures of several hundred students defeat us. In principle, multimedia should be superior to large classes for helping students learn basic concepts and skills because of its individualized pacing, graphic presentation, and constant demand for interaction. In practice, the challenge is to organize instruction so that the human teacher, freed from tasks a machine can do as well or better, can concentrate on motivation, interaction, and assessment.

It is possible, for example, to combine individual learning of basic skills and concepts guided by a multimedia system with group sessions moderated by an experienced teacher. The group can devote itself to problem-solving, project work, discussions of real-world applications of concepts, or simply remedial work on common difficulties. Encouraging groups to comment on and criticize the multimedia system applies a standard tool of quality improvement and forces the learners to reflect on their experience. Small groups encourage discussion among students and the formation of ties with the teacher that allow him to motivate and to deal with the specific difficulties of individuals.

Some forms of assessment, such as project reports by individuals or groups, also fit the small-group setting. In larger classes, teachers may choose to devote more effort to assisting students who need extra help — perhaps with special discussion sessions or individual tutoring — or to challenging students who find the course easy —perhaps by proposing special projects or other enrichments.

7 CONCLUSIONS

Multimedia offers remarkable opportunities and equally remarkable challenges for teaching statistics. Some may point to the deficiencies of multimedia presentations relative to human teachers, while others may note their effectiveness at many instructional tasks and their efficiency relative to expensive (and perhaps inattentive) humans. Our task as teachers is to use the new technology wisely, taking advantage of its substantial strengths while not overlooking the importance of the human factor in education. Our task is also to improve the pedagogy built into the technological platform itself. No one yet knows how best to use multimedia to help students learn statistics. First efforts will surely not be optimal. The suggestions and ideas of many experienced teachers will lead to continuous improvement and perhaps to a real change in teaching.

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