EDUCATIONAL APPLETS FOR ACTIVE LEARNING IN PROPERTIES OF MATERIALS

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Abstract—*The traditional, lecturer-driven classroom is giving way to a new more active environment, where students have access to a variety of multimedia course materials. We created several Java applets for the electrical engineering course Properties of Materials. These applets help describe concepts related to electron motion in metals and semiconductors. They address ideas which are often difficult for students to visualize and yet important for students to intuitively understand. Simulation applets are "hands-on" and interactive while tutorial applets are "hands-off" and presented in slide show format. The applets can be viewed at http://www.collage.soe.ucsc.edu. We deployed these applets in a class of roughly 140 students. We recorded the students' learning preferences, background characteristics, and opinions about the applets. We then characterized population and usage trends of the students.*

Index Terms—Educational Applets, Learning Preferences, On-Line Course Content

Introduction

With simulations and on-line materials, it has become increasingly possible for students to take a more active role in learning. The more forms of information that exist, the better the chance that each student can find a form that will help him or her learn in the best possible manner.

Unfortunately, it is difficult for students to sift through course material without guidance. To this end, we created an infrastructure for delivering course content of different styles to a properties of materials class that records student learning preferences and other student information. Ultimately, we hope to be able to use a student's characteristics coupled with collaborative filtering to predict a preference for, and thus customize the selection of, a student's content. This will allow the presentation of course materials to be personalized for each student.

We deployed our applets in a large class at San Jose State University. We describe the applets, student characteristics, and their preferences for the different kinds of material.

Related Work

Several on-line applets and much educational course content have been created in the area of semiconductor devices. The State University of New York at Buffalo department of Electrical Engineering has created several on-line Java applets in areas that include crystal structure, metal-oxide semiconductors, digital circuits, and semiconductor devices[11]. A list of the applets created by SUNY Buffalo can be found at [11]. Our applets are different from these in both style and content. Our applets emphasize electron transport in the material and the effects of temperature changes, an applied bias, and impurities.

There have been several models developed to categorize the way students take in and process information. We chose to use the Felder-Silverman Learning Style Model[4] because it is simple. It is presented as an on-line multiple choice quiz, the Index of Learning Styles, created by Felder and Soloman [10]. We do not need a validated model because we are looking for correlations. Furthermore, this model has been used to classify the learning styles of other engineering students [1][7][8]. This model classifies students along four axes: sensing/intuitive, visual/verbal, active/reflexive, and sequential/global. Students will fall somewhere on the scale between the two extremes in each of these four categories[2]. Sensing learners retain information obtained through their senses and are oriented toward facts, while intuitive individuals are more likely to retain information obtained through their own memory and imagination and are oriented toward theories. Visual learners prefer pictures and diagrams while verbal learners prefer the written and spoken word. Active learners learn by experimenting while reflective learners learn by thinking about a concept. Sequential learners learn in small incremental steps while global learners need a strong understanding of the big picture [2].

A study at the University of Western Ontario found that 69% of engineering students surveyed had strong active preferences, 59% had strong sensing preferences, 80% had strong visual preferences, and 67% had strong sequential preferences. This data was collected from over 800 students [7][8]. Despite this, Felder has found that instruction in engineering courses is biased toward learners with intuitive, verbal, reflective, and sequential preferences [3]. Traditional lectures alone may miss a majority of students in the engineering discipline.

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Properties of Materials

Electrical Engineering 145 at the University of California at Santa Cruz and Material Engineering 153 at San Jose University are two courses in Properties of Materials. These courses deal with the "fundamental electrical, optical, and magnetic properties of materials, with emphasis on semiconductors: chemical bonds, crystal structures, energy bands, electrical and thermal conduction, optical and magnetic properties[9]." Courses in properties of materials often contain content that can be difficult for students to visualize. Many engineering students could benefit from a more interactive and visual presentation of information, as opposed to just lectures and textbook readings.

Metals

Electron movement in metals is a key concept that describes many physical properties such as electrical and thermal conduction. If not acted on by an external force, electrons in a metal will have random motion at any finite temperature. If an electric field is applied, electrons will be accelerated in the direction opposite to the field. Along with electrons, there are atoms, which form a lattice-like structure in the metal. If the temperature of a metal is increased, vibration of the atoms increases. Electrons may collide with the vibrating atoms, obstructing the motion of the electrons. At the temperature of absolute zero, where these is no atom vibration, electrons can flow without resistance inside a perfect metal. Impurities and imperfections in the metal can further increase the resistivity of the metal.

It is important for students to grasp the concept of electrical conduction intuitively to understand more complicated concepts such as thermoelectric effects. The key conduction concepts are drift, diffusion, resistivity, conductivity, and electron mobility. Drift refers to when electrons are drawn in the direction of an outside applied force, such as an electric field. Diffusion refers to the concept of electron concentration being non-uniform throughout the material. Resistivity is increased with temperature. Conductivity is the inverse of resistivity. Electron mobility determines how much electrons will move on the average in a given electric field.

Semiconductors

Students are expected to understand the same basic concepts of drift, diffusion, resistivity, conductivity, and electron mobility as they apply to semiconductors. Semiconductors are separated into two categories: intrinsic and extrinsic.

An intrinsic or "pure" semiconductor also has a crystal-like structure made up of atoms. However, in an intrinsic semiconductor, the number of electrons is related to the temperature. As temperature rises, atoms become ionized and release electrons. Thus the number of free electrons rises with temperature.

An extrinsic or "dopant" semiconductor contains impurities. The number of electrons is also related to temperature, however the effects of temperature can be divided into three ranges. At low temperatures, the only electrons in the semiconductor are those given off by the impurities, or dopant ions. At absolute zero, these electrons orbit around the dopant ions. As temperature increases in this range, the electrons are released and become free electrons. At medium temperatures, all electrons from the dopant ions have been released and these are the only free electrons. At high temperatures, the other atoms in the material can become ionized and release their electrons.

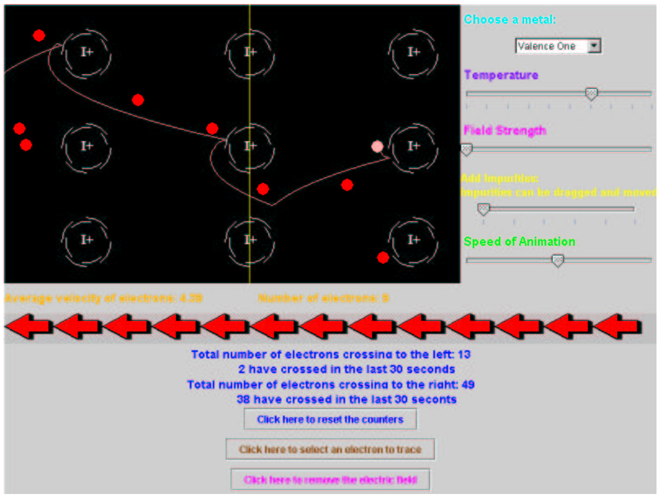
Educational Materials

We have created applets to illustrate the principles described in the previous section. Here, we describe each of the applets. The simulations are all hands-on, interactive applets. The idea is to allow students to understand concepts by manipulating an animated representation of the physical properties. The tutorial is hands-off, in the form of a slide show presentation. Each of the following applets can be viewed at the COLLAGE (COLLaborative Approach to Global Education) Project website [5].

Electrons in Metal Simulation

The "Electrons in Metal" Simulation was the first educational applet we developed. The goal was to illustrate electron motion by displaying electrons as red bouncing balls that move with random motion, bouncing off each other and ions, represented as larger white balls. The simulation displays the current number of electrons and their average velocity. The first feature of the simulation is the counters. The counters keep a running tab of the number of electrons that have crossed an arbitrary plane from left to right and from right to left. They also keep a rolling count of the number of electrons crossing the plane in the last thirty seconds. Electrons can be traced to keep track of their path. The simulation is temporarily stopped and students can select which electron to trace. This electron then leaves a pink path. The average velocity, number of electrons, electron trace, and electron counters are the benchmarks on which students can gage the effects of parameter changes.

An electric field can be added. When there is a field, electrons are drawn opposite the direction of the field, indicated by red arrows. Students should notice electrons being "pulled" in the direction of the field. They should also notice that the counters now reflect more electrons crossing toward the field than in the opposite direction. There is no change in the average electron velocity. Finally, students should note



Average velocity of electrons: 4.39 Number of electrons: 9

Total number of electrons crossing to the left: 13
2 have crossed in the last 30 seconds
Total number of electrons crossing to the right: 49
38 have crossed in the last 30 seconds

FIGURE 1: ELECTRONS IN METAL SIMULATION

that electrons traced now have a curvature to their motion, caused by the electric field.

The temperature of the metal can be changed. With increases in temperature, the vibration of the atoms increases. This is represented by the circles around the atoms getting larger at high temperatures, and smaller at low temperatures. Students should notice the change in area encompassed by the atoms and that fewer electrons can now cross the arbitrary plane. This illustrates the concept of resistivity.

Interstitial impurities can be added to the metal. These are foreign objects or defects. They can be dragged and moved to see how their placement affects electron motion. Impurities increase the resistivity of the metal.

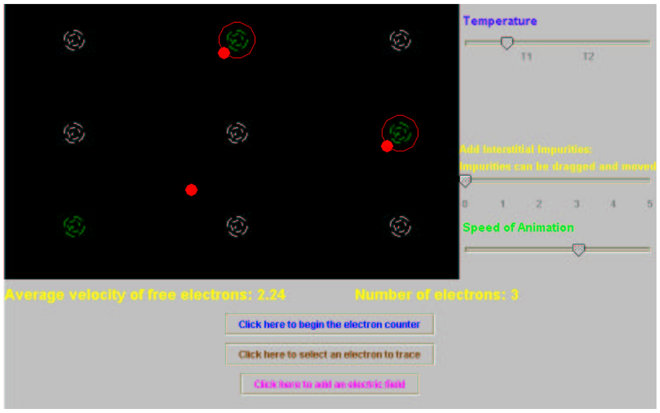
Finally, students can change the valence of the metal. By changing the valence, the number of electrons changes. This is the only parameter that affects the number of electrons in a metal.

Figure 1 is a screen shot of the simulation with the electric field enabled, counters enabled, and an electron trace in progress.

Electrons in Intrinsic Semiconductor Simulation

The Electrons in Intrinsic Semiconductor Simulation has many of the same features as the Electrons in Metal Simulation. Students can monitor the number of electrons and their average speed. Students can activate the counter, add an electric field, trace an electron's path, and add and move impurities.

The main difference between metals and intrinsic semiconductors is the effects of temperature. At low temperatures, there are fewer ionized atoms and fewer free electrons. As temperature increases, more atoms become ionized. When this occurs, their label changes from an "A" to "I+." At any temperature, the number of ions (labeled "I+") should match the number of free electrons.



Average velocity of free electrons: 2.24 Number of electrons: 3

FIGURE 2: ELECTRONS IN EXTRINSIC SEMICONDUCTOR SIMULATION

Electrons in Extrinsic Semiconductor Simulation

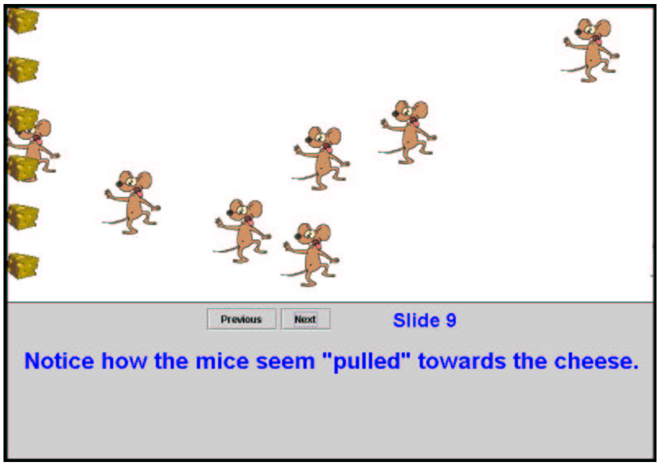
The Electron in Extrinsic Semiconductor Simulation is very similar to the Electrons in Intrinsic Semiconductor Simulation. The simulation displays the number of electrons and average speed. Students can add counters, an electric field, interstitial impurities, and an electron trace. The main difference is that some of the atoms are impurities, indicated with a "D+" for donor.

This simulation has three temperature ranges. In the lowest range, there are electrons orbiting the dopant ions. Figure 2 is a screen shot of the Electrons in Extrinsic Semiconductor Simulation in the lowest temperature range, where there are still electrons orbiting the dopant ions. As temperature increases to the middle range, all of these electrons are released. In the highest temperature range, semiconductor atoms become ionized and release electrons as well.

Electrons in Metal Tutorial

We developed the Electrons in Metal Tutorial to explain difficult concepts with analogies. We identified useful analogies from a homework assignment given in Properties of Materials Electrical Engineering 145 at the University of Santa Cruz, Spring 2001. This demonstration is "hands-off" with each slide containing an animated pictorial analogy of a concept along with some textual explanation.

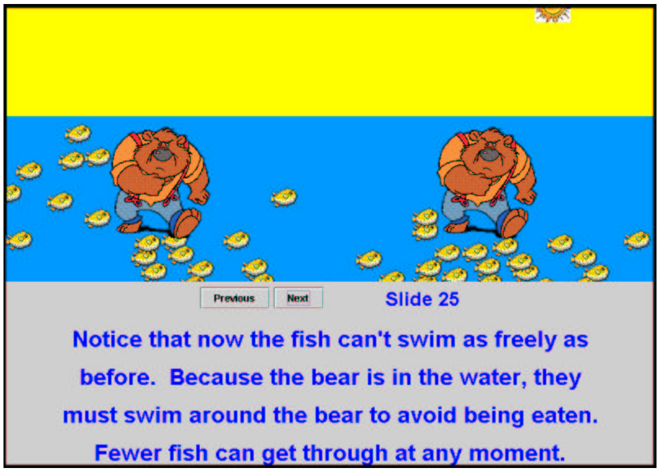
The first analogy compares mice to electrons. The analogy explains that with no outside forces, mice move randomly. However with a bias, cheese, mice are drawn to the cheese. This explains drift. When the cheese is removed, the mice return to their random movement and spread out. This explains



Slide 9

Notice how the mice seem "pulled" towards the cheese.

FIGURE 3: ELECTRONS IN METAL TUTORIAL: MICE ANALOGY



Slide 25

Notice that now the fish can't swim as freely as before. Because the bear is in the water, they must swim around the bear to avoid being eaten. Fewer fish can get through at any moment.

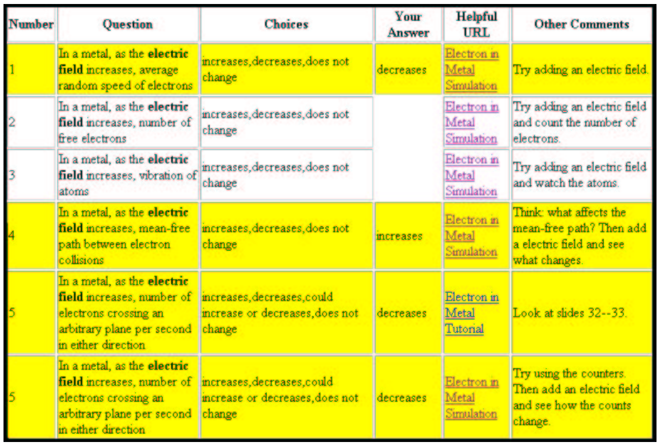
FIGURE 4: ELECTRONS IN METAL TUTORIAL: FISH ANALOGY

diffusion. Figure 3 is a still screen shot of the Electrons in Metal Tutorial that features the mice analogy.

The next set of analogies explains the effects of temperature changes in metals. Electrons are now compared to fish swimming in a stream. The fish move randomly. When temperature rises, however, a bear sleeping far away enters the stream to cool down. For the fish to avoid being eaten, they must swim around the bears. This represents the increased area occupied by atoms as their vibration increases with temperature. Because there is less room for fish to swim, fewer fish can pass through the water. This explains increased resistivity due to temperature changes. Figure 4 is a still screen shot of the slide that features this analogy.

Evaluation

We deployed the simulations and tutorials related to electron motion in metals at San Jose State University. Due to time constraints, we were not able to collect data relating to the semiconductor applets. In evaluating student responses to the applets dealing with metals, we were able to draw various conclusions about the population and their usage patterns. A full description of all results obtained in the experiment can be found at [6].



Number	Question	Choices	Your Answer	Helpful URL	Other Comments
1	In a metal, as the **electric field** increases, average random speed of electrons	increases,decreases,does not change	decreases	Electron in Metal Simulation	Try adding an electric field.
2	In a metal, as the **electric field** increases, number of free electrons	increases,decreases,does not change		Electron in Metal Simulation	Try adding an electric field and count the number of electrons.
3	In a metal, as the **electric field** increases, vibration of atoms	increases,decreases,does not change		Electron in Metal Simulation	Try adding an electric field and watch the atoms.
4	In a metal, as the **electric field** increases, mean-free path between electron collisions	increases,decreases,does not change	increases	Electron in Metal Simulation	Think: what affects the mean-free path? Then add a electric field and see what changes.
5	In a metal, as the **electric field** increases, number of electrons crossing an arbitrary plane per second in either direction	increases,decreases,could increase or decreases,does not change	decreases	Electron in Metal Tutorial	Look at slides 32--33.
5	In a metal, as the **electric field** increases, number of electrons crossing an arbitrary plane per second in either direction	increases,decreases,could increase or decreases,does not change	decreases	Electron in Metal Simulation	Try using the counters. Then add an electric field and see how the counts change.

FIGURE 5: QUESTION/SUGGESTION TABLE

The Experiment

We designed a website to present material to the students at San Jose State and record information about their progress. The website can be viewed as a guest user through the COLLAGE Project website [5]. Students were expected to experiment with the Java applets, and then take quizzes designed to test the knowledge addressed in the applets.

After each submission of a quiz, the student is presented with a table of each question that appeared on the quiz. Figure 5 is a screen shot of the suggestion table. The table contains the question, answer choices, and a suggestion of where to find information relevant to the question. The table contains links to the applets, and the suggestions are statements about which parameters to change, or which slides to visit. Questions that the student gets wrong are highlighted in yellow and also state the incorrect student response. Students can follow the links next to each question and, in theory, obtain all the knowledge needed to answer each question correctly. Several questions have multiple suggestions, with each suggestions referring to a different form of presentation. Students can then re-take the quiz with just the questions they answered incorrectly until they receive a perfect score.

Students were also given a personal information survey, the Felder-Soloman Index of Learning Styles [10], and a quiz consisting of Likert-type opinion questions designed to record their opinions about the applets.

Usage

We did not anticipate the extreme lack of participation we encountered with the students. There were a total of 137 students in the class. Of those students, only 27 (19.7%) followed directions and completed all the assigned tasks. The non-response bias was large. Only 86 (61.9%) students completed the student information poll, 83 students (59.7%) completed the learning styles quiz, and 64 students (46%) completed the opinion poll. Although 116 students (84.7%) completed the Electrons in Metal quiz, we could not characterize a majority of these students since they did not take the other quizzes, and thus we could not use this data.

Population Description

From the data recorded we can describe the population of the students who answered the information poll, the learning style quiz, and those who completed the entire assignment. From this data, we can get a general profile of the class as a whole, and a profile of those students who followed the precise directions.

Total Population

Of the 86 students who completed the information survey, 74.4% are male. The average number of physics classes taken by students was 3.4, with the maximum number being 10 and the minimum zero. The average number of computer science or computer engineering classes taken was 2.3, with the maximum being 11 and the minimum zero. The average number of science classes taken was 5.6, with a maximum of 24 and a minimum of zero. Ninety-four percent of these students are electrical engineering majors. The average number of full time years the students had ever worked is 3.4, with the maximum 45 and the minimum zero. Fifty-nine percent of the students stated that they use the web “very often,” while 32.8% use it “sometimes,” and only 8.2% use it “seldom” or “never.” From this information we can get a general idea of the composition of a typical engineering course.

We can categorize the learning preferences of the 83 students who took the learning style quiz. Each category is scored from 1 to 11. The average active/reflective rating was 7.13, biased toward active. The average visual/verbal rating was 6.75, biased toward visual. The average sequential/global rating was 6.25, biased toward sequential. Finally, the average sensing/intuitive rating was 7.55, biased toward sensing. In addition to this, 61.4% of the students were active, 55.4% of students were visual, and 59% of students were sensing. Only 39.8% of students were sequential learners, however an additional 20% of the students scored a 6, meaning they fell directly between sequential and global. This data is consistent with the data found at the University of Western Ontario about the general learning preferences of engineering students [7][8]. Engineering students typically have preferences toward active, visual, and sensing learning.

Subset Populations

It is possible that there are some qualities that can be determined ahead of time that could predict which students would take advantage of additional on-line materials and those that would not. We analyzed the qualities of those students who did complete the entire assignment to see if there were any population trends. Then, we separated the students who did not use the on-line demonstrations. These students either only looked at one of the available applets, or did not look at either applet. We characterized this population as well.

Of the 27 students who successfully completed the assignment, there was no significant difference in their make-up in terms of gender, major, average number of science classes taken, or number of full-time years worked. The average learning preferences were also similar to the class as a whole. The notable difference was that only one student claimed to use the web “never,” and thus 96% of the students use the web “very often” or “sometimes.”

There were 50 students who completed the learning style quiz but did not properly use the applets. The learning preferences of these students did not differ significantly from those of the total population. There were 52 students who completed the student information survey but did not use the applets. For these students, there also was no significant difference in the gender, major, number of science classes taken, or full time years worked. The major difference was that 11.6% of these students stated that they use the web “seldom” or “never,” as opposed to “very often” or “sometimes.” Thus, the only way in which the subset of students who did not utilize the additional materials differs from both the total population and the subset of students who completed the assignment successfully is that on average they had less regular web usage.

Preferences

Twenty-eight students completed the opinion poll and visited both applets. One of the questions on the poll asked students which applet they preferred: the Electrons in Metal Simulation or the Electrons in Metal Tutorial. Of the 28 students, 35.7% preferred the simulation while the other 64.3% preferred the tutorial. Another question in the opinion poll asked students which *form* of presentation they would prefer: hands-on simulation or hands-off tutorials. Of the 28 students, exactly half stated they preferred the simulation type of presentation and the others preferred the tutorial. We can conclude from this that one form of presentation is not enough, even for a small set of students. In addition, a student’s score on a learning style quiz is not sufficient to directly predict what type of materials they will prefer. An active learner might prefer the tutorial, for example.

The other questions on the opinion poll were Likert-type questions that made a clearly negative or positive statement about the applets and gave the student five answer choices: strongly agree, agree, uncertain, disagree, and strongly disagree. Once the 28 quizzes were scored, the scores could fall within the range of 11-55, with 11 being the most negative score possible, and 55 being the best score an applet could receive. The scores can be divided into five ranges: greatly disliked the applet, disliked the applet, uncertain in preference for the applet, liked the applet, and greatly liked the applet.

The average score for the Electrons in Metal Simulation was 40, which falls in the range of liking the applet. The average score for the Electrons in Metal Tutorial was 40.5, also in this range. Only 7% of the students fell in the dislike range for the simulation with zero strongly disliking it. 3.6% of the students disliked the tutorial and zero fell in the range of greatly disliking it. Clearly, the students who used the applets in the way they were intended had favorable reactions to the materials.

One question asked if the applets made concepts easier to understand. 71.4% of students either agreed or strongly agreed with this statement as it referred to the simulation. There were 78.6% of the students that either agreed or agreed strongly with this statement in terms of the tutorial. Seventy-five percent of the students thought the simulation was fun and 71.4% found the tutorial fun.

One important goal of the applets is to get students to think more about the important concepts outside of class. 78.6% said that the simulation made them think about concepts outside of class, and 82.1% said that the tutorial made them think about concepts outside of class. This data would indicate that students who used the material as intended found it useful for understanding difficult concepts.

Anecdotal Usage

There are several interesting usage patterns that, while they may not indicate any noteworthy trends, they deserve mention. Twenty-three students answered the opinion poll without ever having visited the applets that they were stating their opinions about. One student took the quiz 19 times, without ever once looking at any of the available applets. After every attempt, the student was presented with a table of suggestions, as shown in Figure 5, which was never used. A single link was never followed. This piece of anecdotal data tells us that for some students, no matter how much supplemental material we try to provide, and how easily accessible that material is, some students just will not take the time to go beyond the traditional lecture and learn the concepts on their own.

Conclusions and Future Work

We created several on-line materials for Properties of Materials and deployed them in an experiment designed to obtain student preferences about those materials. The applets took two forms: active simulation and passive tutorial. We found that overall students liked the materials and were approximately split on their preferences for one or the other. One form of presentation alone did not appeal to all of the students. Students found that the materials helped them to understand difficult concepts and think about those concepts outside of class. Of all the information gathered about the students, web experience seemed to be the greatest predictor of their successful use of the course materials.

In the future, we hope to use our initial data as a basis for a framework that will create a personalized information system tailored to each student. This system will filter information based on both style and content, and this filtering will be determined from student characteristics.

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