Educational Applets for Active Learning in Properties of Electronic Materials

Jessica Masters, Tara M. Madhyastha, *Member, IEEE*, and Ali Shakouri, *Member, IEEE*

***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. The authors created several Java applets (http://www.collage.soe.ucsc.edu) that present concepts related to properties of materials in both active and passive styles. The authors evaluated the use of the applets in a classroom setting, considering student learning preferences, background profiles, and applet preferences.**

***Index Terms*—Educational applets, electronic materials, learning preferences, online course content.**

I. INTRODUCTION

WITH simulations and online materials, students are able to take a more active role in learning. Having several forms of information presentation allows the student to choose the instructional media that best meets his or her learning needs. To understand student preferences for course materials, the authors created and evaluated applets of different styles in a large class at San Jose State University (SJSU), San Jose, CA, and a smaller class at the University of California at Santa Cruz (UCSC).

The remainder of this paper is organized as follows. Section II describes related work. Some of the material covered in properties of materials classes is described in Section III. Section IV describes the applets created. The evaluation of the applets and the results obtained through the evaluation are described in Section V. Conclusions and directions for future work are in Section VI.

II. RELATED WORK AND MOTIVATION

There is a rich theory on the activities that students must accomplish in the learning process [1], [2]. For example, students must understand the structure of discourse, relate knowledge to experience, and use feedback. Content designers can use web-based technology such as Java applets as a means to promote active critical thinking, in other words, to "amplify" student learning [3] and to engage learners in more steps of the learning process [2]. Visual self-guided simulations are useful for representing concepts with complex spatial and temporal relationships. They have the added benefit of being active and engaging, allowing students to change parameters and view the effects [4].

Several online applets and much educational course content have been created in the area of semiconductor devices. The Department of Electrical Engineering at the State University of New York (SUNY) at Buffalo has created a wealth of online Java applets in areas that include crystal structure, metal oxide semiconductors, digital circuits, and semiconductor devices [5]. In addition, Kansas State University, Manhattan, [6] and the University of Maryland, College Park [7], have developed active materials in quantum physics. In contrast to the applets at SUNY Buffalo, the authors' applets emphasize more fundamental concepts relating to electron transport in the material and the effects of temperature changes, an applied bias, and impurities. The authors chose to concentrate on these areas because they represent the higher order rules [4], [8] that are required for future problem solving in many areas of electrical engineering.

There have been several models developed to categorize the way students take in and process information, including the Myers–Briggs Type Indicator [9], Kolb's Learning Style Model [10], the Herrmann Brain Dominance Instrument [11], and the Felder–Silverman Learning Style Model [12]. The authors chose to use the Felder–Silverman Learning Style Model because it is simple, it can be easily implemented using a web-based quiz [13], and it has been used to classify the learning styles of engineering students [14]–[16]. This model classifies students along four axes: sensing/intuitive, visual/verbal, active/reflexive, and sequential/global [17]. Sensing learners retain information obtained through their senses, while intuitive individuals are more likely to retain information obtained through their own memory. Visual learners prefer pictures, 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 [17]. A study of over 800 students at the University of Western Ontario (UWO), London, ON, Canada, found that engineering students have strong sensing, visual, active, and sequential preferences [15], [16]. Regardless, Felder has found that instruction in engineering courses is biased toward learners with intuitive, verbal, and reflective preferences [18]. Traditional lectures alone may miss a majority of students in the engineering discipline. The authors created applets designed to appeal to the learning preferences of these students.

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III. PROPERTIES OF MATERIALS

Electrical Engineering 145 at UCSC [19] and Material Engineering 153 at SJSU [20] are two courses in properties of materials that deal with the fundamental electrical, optical, and magnetic properties of metals and semiconductors [19]. Courses in properties of materials often contain content that can be difficult for students to visualize yet is important for students to intuitively understand.

A. 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 have random motion at any finite temperature. If an electric field is applied, electrons accelerate in the direction opposite to the field. Metals also consist of atoms, which form a latticelike 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 their motion. 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.

Students must develop intuition about electrical conduction (drift, diffusion, resistivity, conductivity, and electron mobility) to grasp more complicated concepts, such as thermoelectric effects. Drift refers to electrons being drawn in the direction of an applied force, such as an electric field. Diffusion refers to the concept of electron concentration being nonuniform throughout the material. Resistivity is increased with temperature. Conductivity is the inverse of resistivity. Electron mobility determines how fast electrons move on the average in a given electric field.

B. Semiconductors

Students are expected to understand the same basic properties of electrical conduction as they apply to semiconductors. Semiconductors are separated into two categories: intrinsic and extrinsic.

An intrinsic or “pure” semiconductor also has a crystallike 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. In addition to free electrons, holes (empty places for electrons) also contribute to electrical conduction. When a given energy state is occupied by an electron, the Pauli Exclusion Principle states that a second electron of the same spin cannot occupy this state. However, when the first electron is released, some other bond electrons could come in and occupy the empty state.

An extrinsic or “doped” semiconductor contains impurities. In such a semiconductor, the number of electrons is also related to temperature; however, the effects of temperature can be divided into three regimes. In the lowest temperature range, the only electrons in the semiconductor are those given off by impurities, or dopant ions. At absolute zero, these electrons orbit around the dopant ions. As temperature increases in this range, the electrons from dopants 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 number of free electrons in the material is dominated by the ones released from other atoms, which have become ionized.

IV. EDUCATIONAL MATERIALS

The authors created simulations and tutorials to illustrate the principles discussed in Section III. The simulations are all hands-on interactive applets. The tutorial describes concepts in the form of a hands-off slide show. Each of the following applets can be viewed at the COLLAGE (COLLaborative Approach to Global Education) Project website [21].

A. Electrons in Metal Simulation

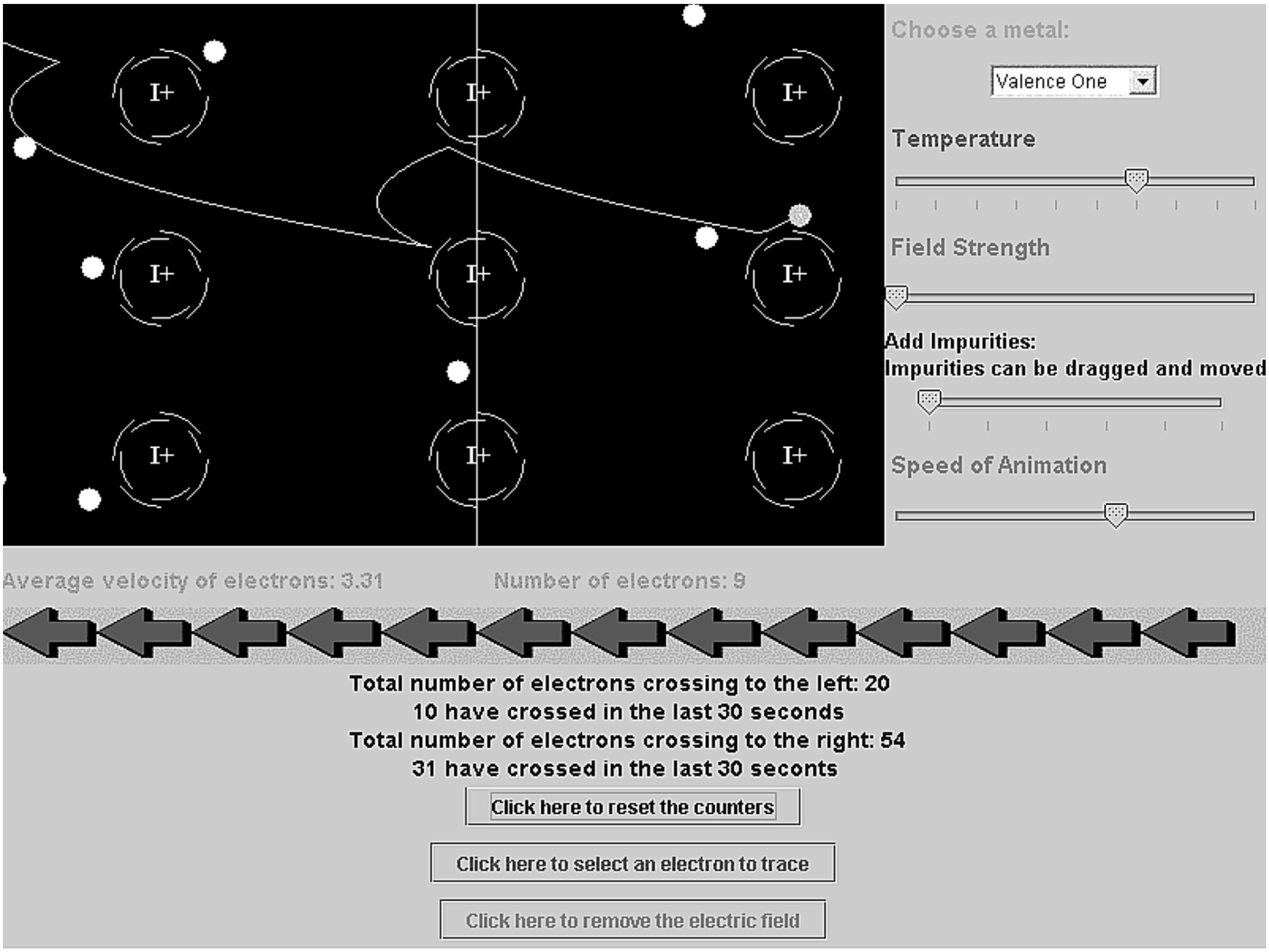
The goal of the Electrons in Metal Simulation is to visually illustrate electron motion in a metal. In this simulation, electrons appear as balls that move with random motion, bouncing off each other, and ions, represented as larger balls. Several simplifications have been made, as in all simulations. Most notably, electron collisions are represented as “hard ball” collisions; the simulations do not represent the true electron trajectory. (The students have been provided with a more rigorous treatment of the material based on the Boltzmann Transport Equation [22].) Despite the simplifications, the simulations illustrate the main effects of how resistance, drift, and diffusion of a metal and semiconductor are affected by changes in temperature and an applied bias.

Fig. 1 is a screen shot of the simulation with several parameters enabled. The simulation always displays the current number of electrons and their average velocity. An electric field can be added and its strength adjusted. When there is a field, indicated by the arrows in Fig. 1, electrons are drawn in the direction opposite to the field.

Fig. 1 shows the simulation with the counters activated. The counters keep a running tab of the number of electrons that have crossed an arbitrary plane in both directions. The counters also keep a rolling count of the number of electrons that have crossed the plane in the last 30 s. Fig. 1 shows an unbalanced number of electrons: many more have crossed from left to right both in total and over the last 30 s. This difference results from the electric field being enabled, and the electrons being drawn in the direction opposite to the field.

Students may trace an electron’s path by stopping the simulation and selecting an electron, which then highlights its own path. Fig. 1 has one electron selected; its trace shows collisions with atoms and other electrons. If there were no applied bias, or electric field, this path would trace the random motion. Because the electrons in Fig. 1 are being drawn in the direction of the bias, however, there is a curvature to their motion.

Students can change the temperature of the metal. With increases in temperature, the vibration of atoms increases. This increase is represented by the circles around the atoms getting larger at high temperatures and smaller at low temperatures. Students should notice that changes in the area encompassed by the



Choose a metal: Valence One

Average velocity of electrons: 3.31

Number of electrons: 9

Total number of electrons crossing to the left: 20
10 have crossed in the last 30 seconds
Total number of electrons crossing to the right: 54
31 have crossed in the last 30 seconts

Fig. 1. Electrons in Metal Simulation: smaller disks represent electrons that bounce off atoms, represented as larger circles; counter is enabled; an electric field is being applied; and an electron's path is being traced.

atoms allow fewer electrons to cross the arbitrary plane. This reduction of area illustrates the concept of resistivity.

Students can add and move foreign objects or defects (interstitial impurities) to the metal and change the valence number of the metal to see how these parameters affect the simulation. Fig. 1 has no impurities added and is at the lowest valence.

B. Electrons in Semiconductor Simulations

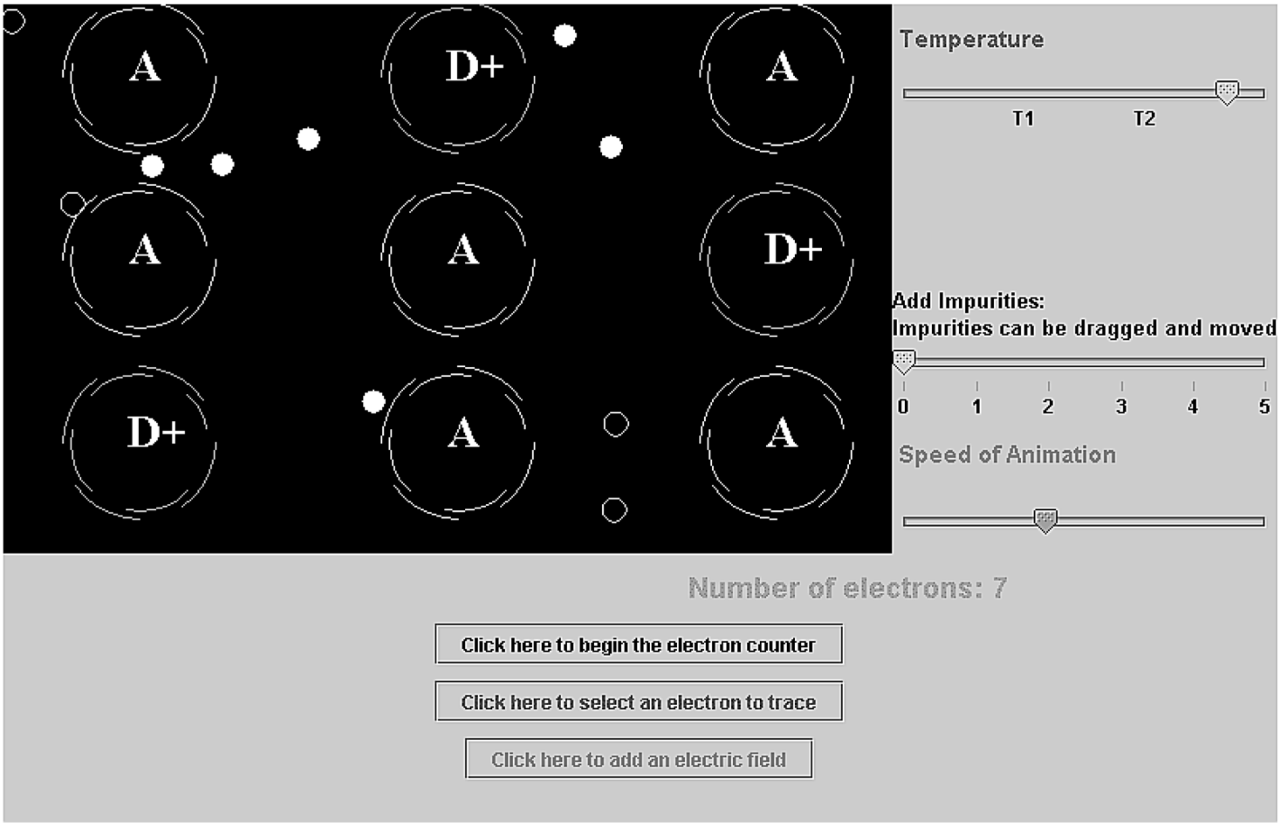
The Electrons in Intrinsic Semiconductor Simulation and the Electrons in Extrinsic Semiconductor Simulation have many of the same features as the Electrons in Metal Simulation. The main difference is the representation of changes in temperature.

In an intrinsic semiconductor, more atoms become ionized and release free electrons as temperatures increase. Students can note the effects of the temperature changes visually and by monitoring the "Number of Electrons" counter. The Electrons in Extrinsic Semiconductor Simulation, when in the lowest temperature range, shows electrons orbiting the dopant ions (indicated with a "D+" for *donor*). These electrons show no random movement. As temperature increases to the middle range, all of these electrons are released and show random movement. In the highest temperature range, semiconductor atoms become ionized and release electrons as well (Fig. 2).

The Electrons in Intrinsic Semiconductor Simulation and the Electrons in Extrinsic Semiconductor Simulations depict the concept of holes. A hole is represented as the same size and color as an electron, but the circle is empty, instead of filled with color, as shown in Fig. 2. There is one hole for every electron in an intrinsic semiconductor. In an extrinsic semiconductor, there is one hole for every electron released from a "nondonor" atom; therefore, at low and medium temperatures, there are no holes. In both simulations, when an electron and hole collide, both disappear (representing the electron taking the place of the hole and becoming bound to the atom), and a new hole and electron appear in a random location.

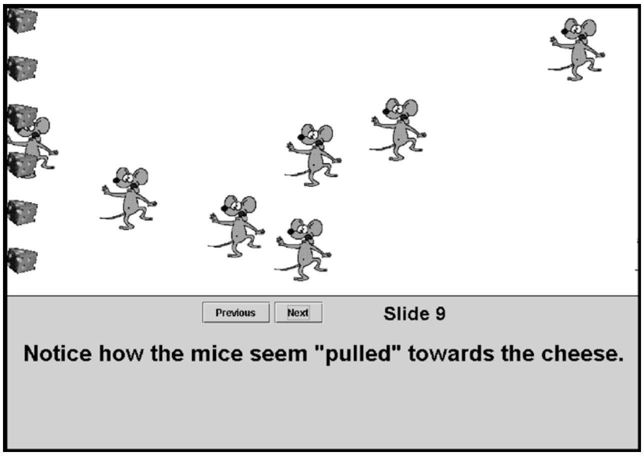
C. Electrons in Metal Tutorial

All of the simulations described thus far are animated representations of a metal or semiconductor. Another approach to teaching these concepts is to abstract them out one more level and explain the concepts with analogies. The authors developed the Electrons in Metal Tutorial to explain difficult concepts in this way. Useful analogies were identified from a homework assignment given in Properties of Materials, Electrical Engineering 145, at UCSC during Spring 2001.



Number of electrons: 7

Fig. 2. Electrons in Extrinsic Semiconductor Simulation: temperature is in the highest range, resulting in the existence of both electrons and holes (small disks and circles, respectively), as well as increased vibration of the atoms (larger circles).

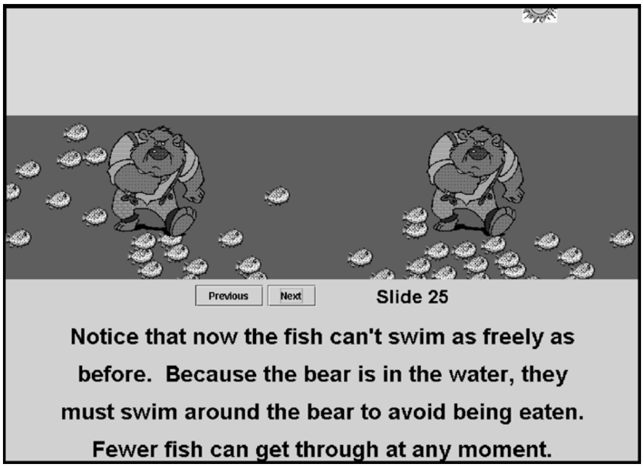


Slide 9

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

Fig. 3. Electrons in Metal Tutorial: this slide explains drift by representing electrons as mice. Electrons (mice) move randomly unless acted on by an outside force, such as an electric field (cheese).

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 analogy illustrates drift. When the cheese is removed, the mice return to their random movement and spread out. This analogy illustrates diffusion. Fig. 3 is a still screen shot of the Electrons in Metal Tutorial that features the mice analogy.

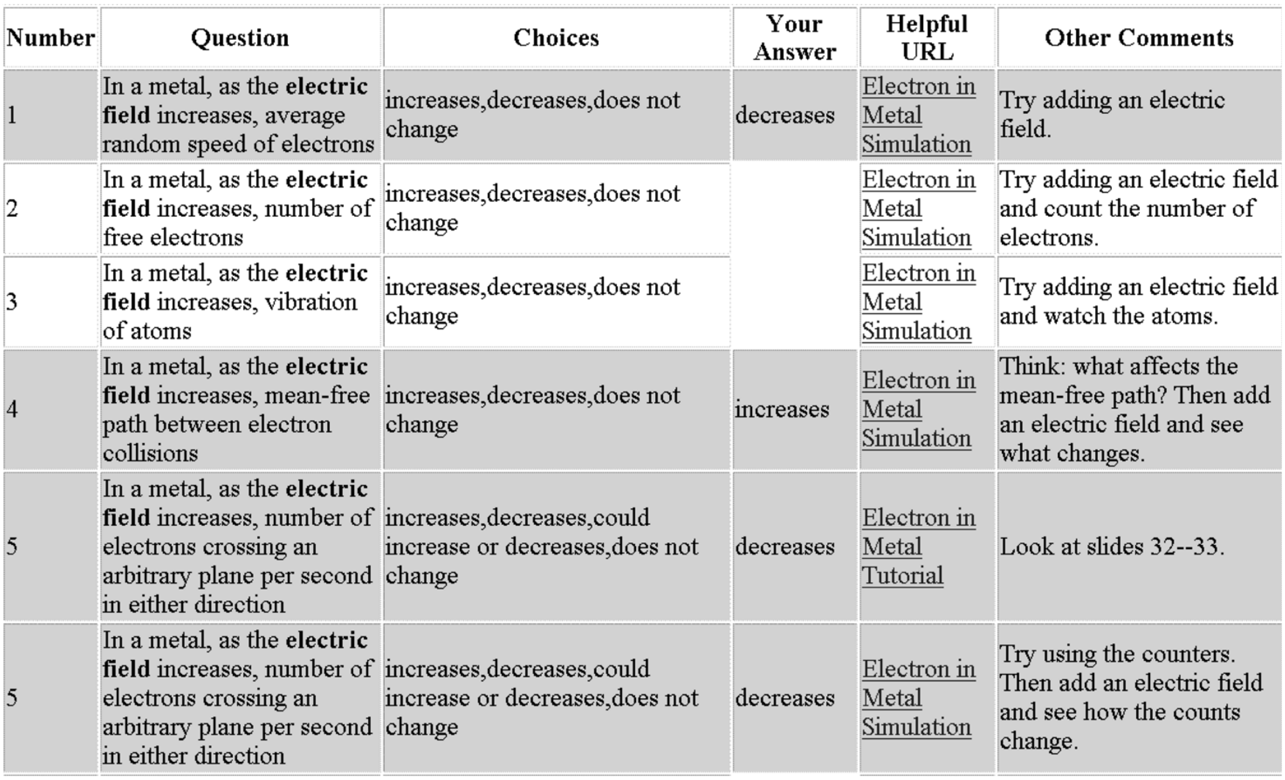


Slide 25

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.

Fig. 4. Electrons in Metal Tutorial: this slide explains resistivity by comparing electrons to fish. With increases of temperature, atoms occupy a greater area. This is represented by bears entering the water and leaving less room for fish to pass through the material.

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 analogy 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 analogy explains increased resistivity as a result of temperature changes. Fig. 4 is a still screen shot of the slide that features this analogy.



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 an 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.

Fig. 5. Question/suggestion table for the Electrons in Metal quiz.

V. EVALUATION

The applets relating to metals were deployed at SJSU in a class of 137 students in Fall 2001, as well as in a class of 19 students at UCSC in Spring 2002. The students at SJSU did not have enough time to use the semiconductor applets. The students at UCSC used the semiconductor applets; however, there was insufficient data for an evaluation of these applets. In evaluating student responses to the metal applets, various conclusions were drawn about the population and their usage patterns. A full description of all results obtained in the larger evaluation performed at SJSU can be found in [23].

A website was designed to present applets and quizzes to the students at SJSU and UCSC and record information about their progress. The framework can be viewed as a guest user through the COLLAGE Project website [21]. The framework was created out of a need for tracking and authentication; it is a collection of Perl CGI scripts [24] that log timing and other information into a MySQL [25] database. Students were instructed to experiment with the Java applets and then take quizzes designed to test the knowledge addressed in the applets.

After a student submits a quiz, he or she is presented with a table of each question that appeared on the quiz. Fig. 5 is a screen shot of this table; it 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 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 suggestion referring to a different form of presentation, either simulation or tutorial. Students can retake the quiz with only

TABLE I
DESCRIPTION OF USAGE PATTERNS FOR THE STUDENTS AT SAN JOSE STATE UNIVERSITY AND THE UNIVERSITY OF CALIFORNIA AT SANTA CRUZ

	SJSU	**UCSC**
completed all assigned tasks	19.7%	84.2%
completed the student information poll	61.9%	100.0%
completed the learning style quiz	59.7%	100.0%
completed the opinion poll	46.0%	89.5%
completed the Electrons in Metal Quiz	84.7%	100.0%

TABLE II
DESCRIPTION OF THE PARTICIPATING STUDENTS AT SAN JOSE STATE UNIVERSITY AND THE UNIVERSITY OF CALIFORNIA AT SANTA CRUZ

	SJSU	**UCSC**
students who completed the information survey	86	19
students who were male	74.4%	94.7%
min, avg, and max physics classes	0, 3.4, 10	1, 3.9, 7
min, avg, and max computer science or computer engineering classes	0, 2.3, 11	0, 6.8, 12
min, avg, and max science classes	0, 5.6, 24	3, 15, 36
electrical engineering majors	94.0%	73.7%
min, avg, and max full time years of work	0, 3.4, 45	0, 0.68, 5
used the web “very often,”	59.0%	78.9%
used the web “sometimes,”	32.8%	21.1%
used the web “seldom” or “never”	8.2%	0.0%

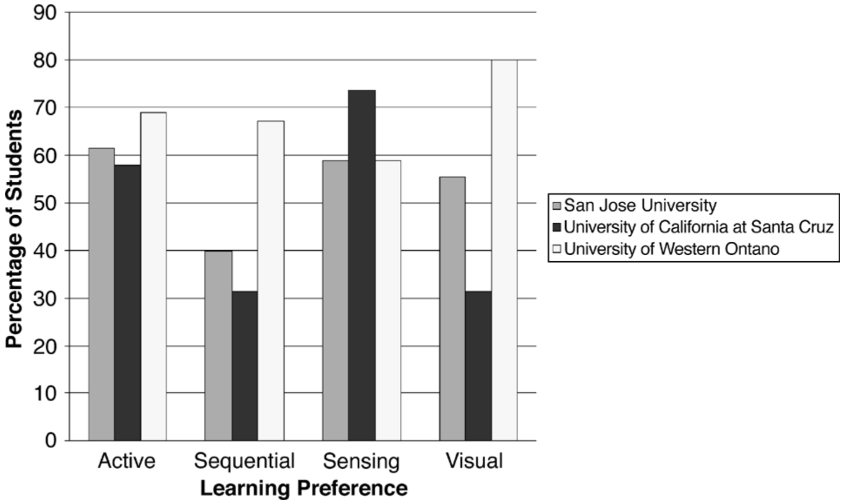


Fig. 6. Learning preferences.

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 [13], and a quiz consisting of Likert-type opinion questions designed to record their opinions about the applets.

A. Usage

There were 137 students in the class at SJSU. In this class, the applets were given as an extra-credit assignment. At UCSC, there were 19 students; and taking all the opinion polls and quizzes was part of a graded homework assignment. Table I describes the student participation at both SJSU and UCSC. The nonresponse bias at SJSU was large. Moreover, although 84.7% of students at SJSU completed the Electrons in Metal quiz, a majority of these students could not be characterized because they did not take the other quizzes; thus, this data could not be used.

Although online materials exist, students may not use them. The qualities of the students at SJSU who completed the entire assignment, and those who completed only parts of the assignment, were analyzed. The only differing factor was web usage. For those students who completed all parts of the assignment, 3.7% claimed to use the web "seldom" or "never." For those students who did not complete all parts of the assignment, 11.6% stated they used the web "seldom" or "never." Web usage could be used to predict the usage of web-based learning tools.

B. Population Description

Table II shows a description of the population in both classes. UCSC had a higher percentage of males. In addition, students had approximately three times more science classes in their backgrounds, specifically three times more computer science or computer engineering classes. There were many more computer engineering majors at UCSC (21.1%) than at SJSU (1.0%). The differences in full-time years worked indicates that there was a higher percentage of students who had matriculated after being employed for several years at SJSU. In addition, students from the class at UCSC used the web more often.

Fig. 6 shows a summary of the learning style quiz results from the authors' evaluation as well as the data found at UWO. As stated in Section II, the study at UWO surveyed 800 students and found that engineering students typically have preferences toward active, visual, and sensing learning [15], [16]. The most notable difference in the authors' data is that a much smaller percentage of the students at UCSC had visual learning preferences. Regardless of this discrepancy, the authors feel their decision to create simulations that describe the concepts of electron movement in an interactive visual environment is justified by the data from UWO and SJSU.

TABLE III
DESCRIPTION OF SAN JOSE STATE UNIVERSITY AND THE UNIVERSITY OF CALIFORNIA AT SANTA CRUZ STUDENT PREFERENCES FOR THE ELECTRONS IN METAL SIMULATION (EMS) AND THE ELECTRONS IN METAL TUTORIAL (EMT)

		SJSU	**UCSC**
	students who completed the opinion poll and viewed both applets	28	16
(a)	preferred the EMS	64.3%	87.5%
	preferred the hands-on simulation *type*	50.0%	81.3%
(b)	average score for the EMS	40.0 (liked)	41.6 (liked)
	average score for the EMT	40.5 (liked)	36.6 (uncertain)
(c)	EMS made concepts easier to understand	71.4%	68.4%
	EMT made concepts easier to understand	78.6%	47.4%
	EMS made me think outside of class	78.6%	68.0%
	EMT made me think outside of class	82.1%	52.6%

C. Preferences

Students completed a questionnaire designed to discover their opinions about the educational materials. Table III shows some of the important preferences stated on the opinion poll. Table III(a) shows that students were somewhat evenly divided both on which applet they preferred and which *type* of presentation they preferred (hands-on simulation or hands-off tutorial). One form of presentation is not enough, even for a small set of students. Moreover, the stronger preference by UCSC students for the simulation could be linked to their greater web usage.

In addition, the UCSC student preferences for the simulation, which provided a more rigorous treatment of the material, might also be linked to the UCSC students' more extensive science backgrounds. The two types of presentation can appeal to different learning preferences and to students at different stages of the learning process.

Most questions on the opinion poll were Likert-type questions that made a clearly negative or positive statement about the applets and allowed the students to strongly agree, agree, be uncertain, disagree, or strongly disagree. Scores for the applets were generated, based upon the student responses. The scores could fall between 11 (worst) and 55 (best) and were 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. Table III(b) shows the average scores for the applets.[1] While both groups of students had positive reactions to the simulation, the students at UCSC did not have quite as favorable a reaction to the tutorial. This conclusion can again perhaps be explained by the UCSC students preferring a more sophisticated treatment of the material because of their more extensive science background.

Table III(c) shows the responses to other important questions. These results show that a majority of students found that at least one of the applets helped clarify important concepts and encouraged them to think about concepts outside of class. The latter is a significant accomplishment that could lead students to seek answers and explanations on their own, even if they cannot find them by using the applets.

VI. CONCLUSION AND FUTURE WORK

The authors created several online materials for properties of electronic materials courses and deployed them in an evaluation designed to obtain student preferences about those materials. A majority of students at both UCSC and SJSU found at least one of the applets to be a worthwhile learning tool. Instructors can use the applets to explain concepts at varying levels of understanding and use information about a student's science background and web usage to help predict which applet will be the most appropriate. Even for a small group of students, differences in learning preferences and student profiles warrant the inclusion of several types of information presentation.

In the future, the authors hope to use the initial data as a basis for a framework that will create a personalized information system tailored to each student. This system will filter learning tools based on both style and content and deliver it to students based on their individual characteristics.

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[1] The average score for the Electrons in Metal Tutorial at UCSC was 36.3; while this score falls in the uncertain range, it is on the far end of this range (uncertain range: 29–37).

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