the Development of Physics

ing conversations in small student groups. Second, we discuss how special computer simulators make it easier for groups of students to construct the research setting, and methodology for our research. In Part II, we focus on how students use computer documents as shared spaces for represen-

In Part III, we discuss how students use ture of its natural physical environment to reduce the amount of actual pumping it must perform: it orients itself so as to make use of ambient currents to aid its feeding. The trick is an obvious one, yet not until quite recently did biologists recognize it. The reason for this

is revealing: Biologists have tended to focus solely on the individual organism as the locus of adaptive structure. They have treated the organism as if it could be understood independent of its physical no textbook for the course, instead, students construct their own "textbook" from print-outs of the computer activities they engage in in a majority of class time. The main role of the CPU instructor is to guide whole class discussions that either bring out students' initial particle model, waves and sound, and light and color. A unit consists of several cycles and each cycle begins with an Elicitation Phase, which is designed to elicit students' initial ideas about a particular concept through predictions, demonstrations, and discussions. This is followed by a

fully sequenced activities presented to them on the computer screen. The group uses these activities as a workbook by editing diagrams and pictures, constructing new diagrams and pictures, and adding text to the documents. The activities are based on physics education research and are designed to model-like predictions by drawing their own light ray diagrams and compare them with those that they construct using the simulator. A second type of representation is of the form of a simple model that is general enough to be consistent with several different

[redacted]

the computer document is similar to other types of representational media such as a whiteboard, a sheet of paper, or a chalkboard to which all mem-

[redacted]

upon within the group. Second, they provide contexts within which groups can modify and enhance their explanatory models.

A shared representational space supports collaboration As students work on a computer document in their groups, they are expected to have discussions about their ideas and are encouraged to type a single response to each question. We have found that each group member often contributes to a common group response. To illustrate this process we provide an example taken from an analysis of the interactions within a particular

Student	Spoken	Typed by Donna
Donna	We decided there would be no reaction	
Marge	to an un	
Anne	with an unrubbed straw	
Marge	unrubbed straw would have no reaction.	
Anne	Because of our observations in [the previous activity] that its because of our previous observation	We predicted that there would be no reaction with (pauses)
Donna	With, with	
Anne	an unrubbed straw	

important features. One feature was that each member of the

that "the N and S charges separate to opposite ends of the nail," without

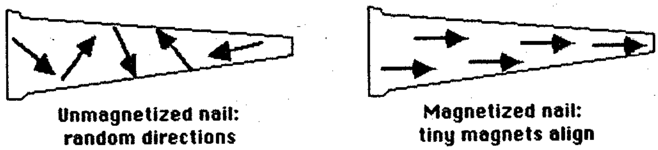


Figure 4. A formal model of magnetism. Arrows represent microscopic magnetic domains within the nail.

tendency to align itself in the presence of a magnetic field such as that of the Earth (see Figure 4).

The group's model did eventually evolve into a magnetic alignment they typically have little science or mathematical experience

[illegible]

The computer is not necessary for the introduction and use of this type of analogical model in the classroom. Students can make concept predictions using white boards, chalkboards, or paper and pencil. The difference is that with the computer simulator, relevant formal information is

not "in the back of the book" and is not revealed as the "right answer." Instead, it is revealed in the form of model-like evidence from a computer experiment that the students perform themselves. Our data analysis sugequal number of evenly distributed positive and negative charges. When the negatively (blue) charged insulator is brought near the soda can, the freely moving, negative charges within the conducting can are repelled as far away from the negatively charged straw as possible, since like charges repel each other. As these charges move away from the end of the soda can nearest the straw, positive charges (which are not mobile) remain in place. Therefore this end of the soda can is left with a deficit of negative charge (or excess of

positive charge) and is thus, positively charged. The far end of the soda can simulator. This example is representative of all of the groups that we studied. In this example, a group of three students, Janet, Abby, and Max were working on the Soda Can Electroscope activity at their computer. During the first part of the activity the students brought a wool-rubbed straw (charged straw) near the end of the conducting soda can. The first question of the activity asked them to describe their observations and to construct an explanation in words and enter it into computer document. The students answered with little discussion and no apparent disagreements. A reproduction of a portion of their computer document is shown in Figure 7. Students' answers are shown in bold.

Despite the apparent agreement that the group members had while formulating these statements, our analyses of preceding and successive activities, homework, journals, and interviews suggested that the group's answers

The analysis of students' homework, interviews, and video data sug-

[redacted]

how or why the tinsel moved out away from the end of the soda can. We concluded that Janet assumed that the tinsel was repelling directly from the blue-charged straw. Since the straw was assumed to be charged blue, she thought that the tinsel must also be blue since like-charged objects

[redacted]

Janet had argued for a coloring scheme that assigned blue to the tinsel and straw. Max had argued for a coloring scheme that assigned blue to the soda can and straw. The students were faced with the problem of accounting for the red *and* blue that appeared on either end of the soda can on the computer screen. The discussion that followed led to the convergence of the three students' ideas and to the development of a group explanatory model that helped them make sense of the phenomenological results.

The three students began to work together to make sense of the simulator results as soon as the results appeared on the computer screen. In the face of this new evidence, the students shifted from tenaciously adhering to their initial ideas and began to consider alternative points of view. The model-like simulator results provided a context for the members of the group to evaluate their own ideas as well as the concept evidence in a shared representational space. By simultaneously interpreting these results and applying their ideas, each student was able to contribute sense-mak-

ing insights that led to the

Janet	So we're making blue charges
Abby	We're making blue charges [by rubbing the straw with wool].
Max	OK. this is blue just like the straw.
Abby	And this is red charges. And when we're doing this, all the red charges are coming up this way (see Figure 8b).
Abby	They [the red charges in the soda can] are coming to get this [the charged straw], because it's attracting the opposite.
Janet	Cause it's attracting the opposite
Abby	So all of those reds are coming here towards the blue—

the ways that the computer is used in the classroom. Thus far, we have only

the section that follows we provide a more detailed outline of the CPU course design and its dependence on research in physics education.

Part IV: The CPU Computer Simulator is Embedded in the Computer Documents

All of the CPU simulators include a phenomenological and a conceptual component. Some simulators, however, do not make use of an analogical model such as the one found in the static electricity simulator. Instead, the subject matter often lends itself to particular formal representations. For example, the Light and Color simulators use formal light ray diagrams to represent some of the conceptual aspects of the behavior of light. Using

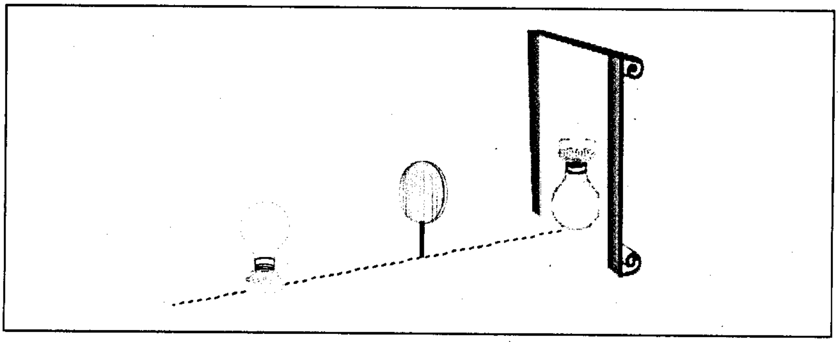
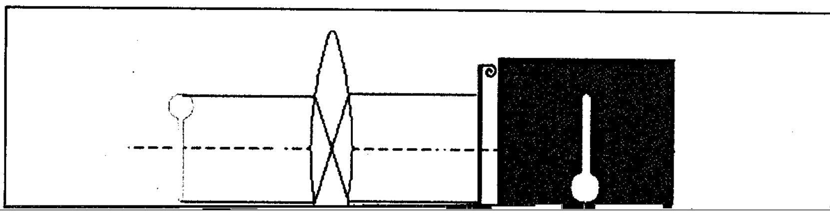


Figure 9. A set-up consisting of an extended light source, converging lens and screen. A sharp upside-down image of the source can be seen on the screen.



gested in the diagram in Figure 10. Second, the formal diagram uses two different points on the source (top and bottom) and is trying to represent what happens to the light that leaves each of these points. Any number of points on the source could have been chosen. Typically, two points are chosen both for convenience and to show how the image is formed upside-down. Implicit in this choice is the assumption that the entire source could be considered as a large number of closely spaced source points. Thinking of a source as composed of source points is quite different from thinking of the source as a single holistic entity. Finally, the diagram suggests that [illegible]

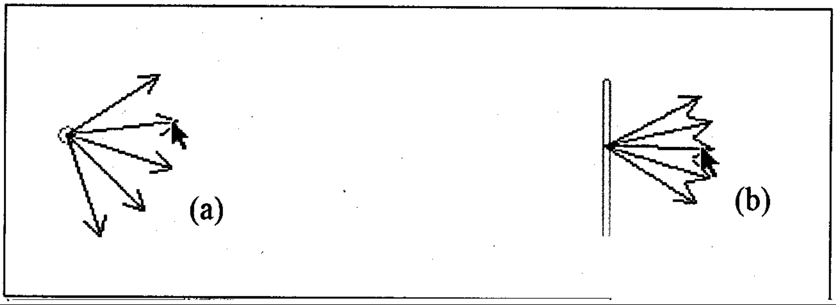


Figure 12. Screen snap shots from one of the light and color simulators. In (a) a light spray is being dragged out from a point source. In (b) a light spray is being dragged out

[redacted]

than with a converging lens. The relevant ideas, however, are similar to those mentioned above for lenses, except that in describing the *image idea* with curved mirrors one thinks of light reflecting from the mirror rather

[redacted]

than passing through the lens. If one actually performed the experiment

[redacted]

Previous research has shown that students who study optics in a conventional course typically have a great deal of difficulty with questions similar to the one posed above (Goldberg & McDermott, 1986; Goldberg & McDermott, 1987). The fact that 70 percent of the prospective elementary teachers were reasonably successful in answering this question sug-

gests that the CPU activities and software played a significant role

A third way the computer plays a role in fostering knowledge construction depends on the computer-based instructional design. Using the [illegible]

[illegible] ulators can be used within a pedagogical structure to accomplish specific [illegible]

Galili, I., Bendall, S., & Goldberg, F. (1993). The effects of prior knowledge and instruction on understanding image formation. *J. Research Sci. Teaching*, 30 (3), 271–301.

Goldberg, F. (1997). Constructing physics understanding in a computer-supported