DOCUMENT RESUME

ED 391 680 SE 057 701

AUTHOR	Allen, Sue; And Others
TITLE	Teaching Scientific Concepts with Transparent Detector Models: An Example from Optics.
PUB DATE	Apr 95
NOTE	8p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, April 18-22, 1995).
PUB TYPE	Reports - Research/Technical (143) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Geometry; Instrumentation; *Models; *Optics; Physics; Science Instruction; *Scientific Concepts; Secondary Education

ABSTRACT

This paper describes an attempt to facilitate students' learning of scientific concepts by using detectors that take as input physical information and output an instantiation of the concept. The principle hypothesis was that students would have a better understanding of the concept of image if they were taught to use a simplified, runnable model of their own visual detectors, than if they were taught using a more traditional approach. To test this hypothesis, two almost identical versions of a curriculum in geometrical optics were created, one version used a mechanistic, interpretive eye model, while the other treated the eye as a passive receiver of light. Results indicate that students who were taught a runnable model of visual perception exhibited a better understanding of the difficult relationship between an observer and a virtual image, were better able to identify the location of an image in a range of real-world optical situations, and were less likely to think of it as located on the surface of a mirror or lens. It was concluded that significant gains are made by teaching students a transparent-detector model of image formation rather than a more traditional geometrical definition of image formation. (JRH)

Teaching Scientific Concepts with Transparent Detector Models: An Example from Optics

by

Sue Allen
Barbara Y. White
John R. Frederiksen

Teaching Scientific Concepts with Transparent Detector Models: An Example from Optics[1]

Sue Allen, Barbara Y. White, and John R. Frederiksen
University of California at Berkeley and Educational Testing Service
email: sueallen@research.com; phone: 415-353-0471

Objectives

This presentation describes an attempt to facilitate students' learning of scientific concepts by using detectors. By *detector* we mean a mechanistic device (such as a speedometer) which takes as input certain kinds of physical information (such as distance covered in a short period of time), and gives as output an instantiation of the concept (such as "speed is 58 m.p.h."). For example, a simple speedometer might work by recording the number of times in a clocked interval that a flag attached to a rotating wheel kicks a counter. The powerful and underused corollary is that speed may be defined as what an idealized speedometer reads. To be pedagogically powerful, detectors do not necessarily have to be physical entities in the world, although one might speculate that physical detectors are more readily understandable. Detectors might exist only in a representation such as a ray diagram. Building on the work of White (1993), we argue that what matters is that students be given a runnable mental model of an idealized detector, based preferably on simple mechanisms they already understand. We shall call this a transparent detector model.

Theoretical framework

During the last decade, many educational researchers have emphasized the importance of causal, model-based reasoning in science (e.g., Brown & Clement, 1989; White and Frederiksen, 1989). In this view, understanding science involves more than being able to do constraint-based reasoning; it requires the acquisition of runnable mental models that support chains of causal inferences. The work described in this presentation falls within this mental models paradigm, but explores a role for mental models that has been largely overlooked. What we wish to argue is that runnable mental models are a powerful and learnable means of understanding physical systems, not only the changing relationships between entities, but also the definitions of the entities themselves. We call "transparent detectors" those runnable models that can be used to define concepts procedurally. Ideally, such a detector has a mechanism grounded in p-prims, and is distinct from representations more generally in that it displays to the user an internal mechanism of measurement and/or calculation.

[1] Presented at the Annual Meeting of the American Educational Research Association, San Francisco, April 1995.

We believe that transparent detectors constitute a particularly powerful set of mental models, for the following reasons. Firstly, they provide a general, flexible definition of a concept. Secondly, to the extent that they are grounded in intuitive mechanisms, they are more likely to be remembered and applied correctly by students. Thirdly, because they are interpretive devices, detectors give students a way of putting themselves in the situation by taking the role of the detector. Finally, many concepts rely on the idea of limited interpretive power of a detector. For example, one can more easily learn the concept of *image* if one understands that certain visual systems cannot distinguish a real object from a mirror-reflection.

We chose to study geometrical optics because the central concept of *image* is notoriously difficult for students, in spite of the fact that their own eyes and brain constitute an excellent image-detector system. Our principle hypothesis was that students would have a better understanding of the concept of *image* if they were taught to use a simplified, runnable model of their own visual detectors, than if they were taught using a more traditional approach.

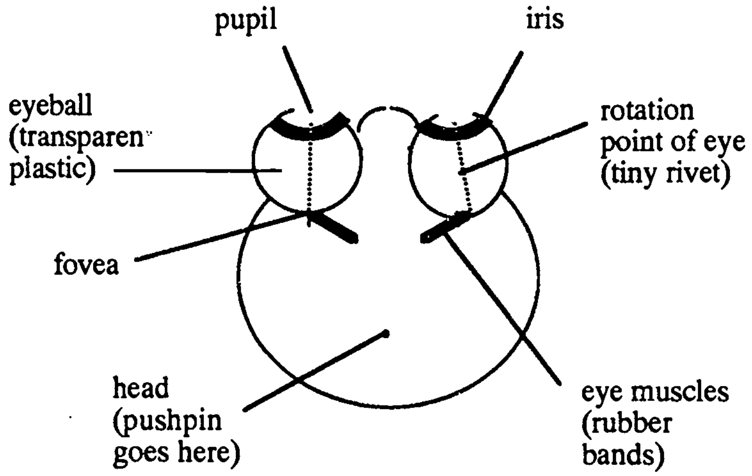
Methods

To test this hypothesis, we created two almost identical versions of a curriculum in geometrical optics. In one version ("Active Eye") a mechanistic, interpretive eye model is used throughout to define *image* and to reason about optical situations. In the other, the eye is modeled as a passive receiver of light, and the image formation is treated as independent of an observer's presence. This latter version ("Passive Eye") lacks a runnable mechanism for perception.

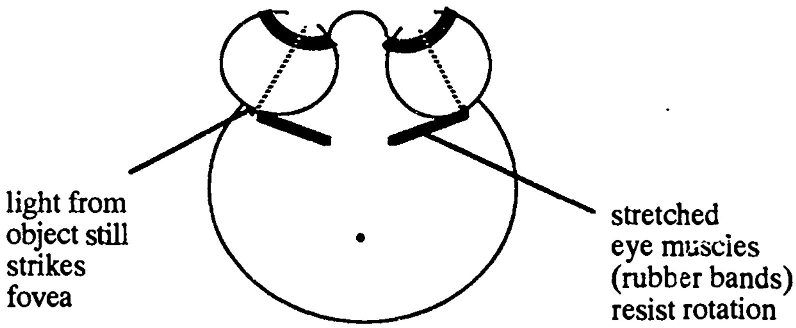
In creating the Active Eye model of perception, we looked for the simplest possible model that still accounts for the main features of an image: its location, orientation and size. We chose a model of vision in which eyeball convergence is the principle cue for identifying the location of an object or image. We embodied the model in a small plastic detector ("the Plastic Person") with rotating eyes and eye muscles made of rubber bands. In this model of vision, the Plastic Person has a runnable sequence of operations to carry out in order to see: 1) It must be positioned properly, facing roughly in the right direction. 2) Its eyes must be swiveled such that a light ray from the lens or mirror can enter the pupil of each eye, pass through the eyeball and strike the fovea at the center of the retina. 3) As a result of the swivel, its eye muscles (rubber bands) will be stretched to a greater or lesser extent. 4) The stretching of the eye muscles must be "interpreted" by its brain to determine the distance of the light source. The more the muscles are stretched, the closer it will think the light source is.

Overall, the sequence of steps helps clarify the eye's internal workings that enable the observer to make interpretations. It also provides students with a sequence of actions that can be completed in order to determine what an observer will see in any situation. The actions are all simple, and linked to one another in a mechanical sequence, which makes them easier to remember and envisage in the absence of the physical device.

<u>"Plastic Person" model of vision</u>



(a) Plastic Person looking at a distant object: eyeballs are almost parallel, so eye muscles are hardly stretched.



(b) Plastic Person looking at a nearby object: eyeballs are highly rotated, stretching eye muscles.

As a comparison treatment, students were given the same curriculum, but without the use of a transparent, mechanistic detector to define *image*. Instead, an image was defined geometrically as the crossing point of rays (extended if necessary) from the same object point. The observer's role was presented as subsequent to, and independent of, the process of image formation. Although this model lacks a runnable mechanism of depth perception, it still incorporates the idea that an image is seen if and only if light from the image travels in a straight line through space and penetrates the observer's eye.

With the exception of the different eye treatments just described, the Active Eye and Passive Eye conditions were made to be identical. Instruction common to both was designed to be as effective as possible, within the pragmatic constraints of a 6-hour curriculum (excluding individual assessments).

The subjects for the study were 28 students from an ethnically diverse public school in the San Francisco Bay Area. Aged 14-15, they had not yet received any significant formal optics instruction. Across the two treatments, groups were balanced for gender, mathematics class just completed, and self-reported grades in mathematics and science. Students worked in pairs for the instructional part of the study (lasting approximately 3 days x 2 hours per day), but were assessed individually. The study took place in a laboratory setting, with one pair of students working at a time.

The pre- and post-tests assessed students on their understanding and use of the concept *image*, both in the real world and in a diagrammatic context. All questions were open-ended performance assessments and required some interpretation in grading. In addition, many questions had multiple parts or required the students to do several different types of reasoning.

Results

Students' performances were scored based on 7 dimensions representing areas of traditional student difficulty, as reported in the literature. These were: (A) poor understanding of the role of light in vision; (B) difficulty understanding the concept of *virtual image*; (C) difficulty deciding where the eye of an observer must be to see an aerial image; (D) difficulty understanding the idea of point-to-point mapping and multiple rays; (Ei) reluctance to choose an orthographic representation when drawing an optical situation; (Eii) difficulty using an orthographic diagram to explain image formation; and (F) belief that the image is located on a mirror's surface. Every question was broken into one or more "items", each of which provided an opportunity for demonstrating competence in one of the seven areas of difficulty. In all, there were 48 such items. Care was taken to ensure that the different items in each question were independent of each other; that is, they involved responses to different parts of the question. Each item then had a scoring rubric designed for it, and a corresponding score of 0-2 was assigned to each subject's performance.

ANOVA's carried out on students' scores revealed that both groups of students showed significant learning following instruction, and that this effect was broadly distributed across the dimensions of difficulty.

The Active Eye students significantly outperformed the Passive Eye students in two dimensions of their performance.

Firstly, over a range of optical situations, Active Eye students outperformed Passive Eye students in identifying the critical relationship between where an observer stands and what she sees, $F(1,27) = 5.02$, $p = .04$. Specifically, the situations where this difference appeared are "virtual image" situations, in which an image is not located at an obvious crossing point of rays. These include cases where (i) the image is virtual and no such crossing point exists; (ii) the rays are hidden from view in a mysterious box, or (iii) the rays form an ill-defined crossing region, where image location depends on precisely where the observer stands. It is interesting that Case i situations are those that are notoriously difficult for students to understand, and that Cases ii and iii are so difficult as to be omitted from all but the most ambitious high school curricula. It seems that the detector-based model of image formation gave students a robust method of interpreting diagrams of this type.

Secondly, Active Eye students were significantly better at identifying the location of an image[2] by viewing it directly, $F(1,27) = 5.86$, $p = 0.03$. At least two aspects of instruction may have been responsible for the Active Eye students' success. First, the explicit detector model may have given them a deeper understanding of how local information determines what interpretations can be made. Second, Active Eye students may have gained a heightened awareness of their own eyeball convergence from learning the model in the familiar context of a flat mirror. Either of these possibilities -- and they may well be interlinked -- suggests an advantage to using a detector to model perception.

Conclusion

This study has demonstrated the gains to be made by teaching students a transparent-detector model of image formation rather than a more traditional geometrical definition of image formation. In particular, students who were taught a runnable model of visual perception exhibited a better understanding of the notoriously difficult relationship between an observer and a virtual image. They were also better able to identify the location of an image in a range of real-world optical situations, and were less likely to think of it as located on the surface of a mirror or lens.

The model of a visual detector taught to the Active Eye students had almost all of the properties listed by White (1993) as being important for a runnable mental model in a physical domain. However, the results of this study suggest that the two properties most responsible for its success were specific to detectors rather than causal models in general. These properties are (i) the incorporation of the principle of proximal stimulus, and (ii) the use of an interpretive mechanism that plausibly applies to students' own eyes. In a sense, both of these involve creating a detector model that is true to the properties of a real-world detector.

---

[2] While physicists distinguish between images located on, in front of, or behind a mirror or lens, researchers have reported that many students believe that an image must always be located on the surface of a mirror or lens (e.g., Goldberg & McDermott, 1987). Such a belief serves as a major barrier to understanding much of geometrical optics.

Overall, our hypothesis was borne out by the results; the Active Eye students exhibited greater learning than the Passive Eye students in two central aspects of performance.

Educational significance

Transparent detector models may be used in other domains of physical science. For example, many students have difficulty distinguishing the extensive concept of internal energy (sometimes called "heat") from the intensive concept of temperature (e.g., Linn & Songer, 1991; Wiser & Kipman, 1988). These concepts might be easier to discriminate if students had a runnable mental model of a thermometer as a local measurement device that could not "know" what is happening in the rest of a large body. Many other concepts in physical science also have the property that they describe only a local interpretation of a global situation. Examples are speed, phase velocity, acceleration, simultaneity, and electric field. The results of this study suggest that transparent detector models might help students to understand such concepts, using simple local mechanisms so that the students can imagine themselves as the detector and ask "What would I think is happening?"

In addition to gaining a better understanding of important concepts, students who are taught to use idealized detectors gain practice in running mental models and viewing a physical situations from different observer perspectives, skills which are critical to many domains of scientific reasoning.

References

Brown, D. & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: abstract transfer versus explanatory model construction. *Instructional Science, 18,* 237-261.

Goldberg, F. & McDermott, L.C. (1987). An investigation of student understanding of the real image formed by a converging lens or concave mirror. *American Journal of Physics, 55,* 108-119.

Linn, M.C. & Songer, N.B. (1991). Teaching thermodynamics to middle school students. *J.ournal of Research in Scinence Teaching, 28(10),* 885.

White, B.Y. (1993) Intermediate causal models: a missing link for successful science education? In Glaser, R. (Ed.) *Advances in instructional psychology. Volume 4.* LEA, Hillsdale, N.J.

White, B.Y., & Frederiksen, J.R. (1989). Causal models as intelligent learning environments for science and engineering education. *Journal of Applied Artificial Intelligence, 3,* No. 2-3.

Wiser, M. & Kipman, D. (1988). The differentiation of head and temperature: an evaluation of the effect of microcomputer models on students' misconceptions. *E.T.C. Report TR88-20.* Cambridge: Harvard School of Education.