Title
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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 10(0)

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Publication Date
1988

Peer reviewed

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INTUITIVE NOTIONS OF LIGHT AND LEARNING ABOUT LIGHT

INTRODUCTION

A great deal of research effort has been invested in the identification of naive concepts held by students in different areas of science, and on the impact of science lessons on naive beliefs. According to Posner et al. (1982), the identification of concepts held by students is important since: "...a person's central concepts are the vehicles whereby a given range of phenomena become intelligible. Such concepts can be linked to prior experience, images, or models which make them appear intuitively obvious.."

Disessa (1981) claims that "intuitive physics is a rather well developed and exceedingly robust system that can potentially interfere with 'proper' physics." This implies that intuitive beliefs held by students before learning play a major role in formulating new concepts. Students approach new topics with a framework of related ideas which are derived from past experience. When faced with teachers' statements or notebooks, or with the results of their own investigations which are not in keeping with the conceptual framework they hold, students either modify their own views, or according to Keneth Lovell (1980), maintain two separate ideas about the same concept and apply them to different situations. Lovell claims that one of the two ideas is used for passing exams in schools, and the other, based on intuition, is used for explaining every-day phenomena. A model used by some cognitive scientists fits well with the hypothesis of interaction between the child's different ideas and the manner in which these ideas evolve with teaching. This model is based on the hypothesis that information is stored in the memory in various forms - schemas - and everything we say and do depends on the elements or group of elements of this stored information.

There is considerable research evidence to suggest that the context or the phenomenal setting of a task or problem influences an individual's performance. Driver and Bell (1986), suggest that the learner's interpretation of the task will depend on preexisting notions which arise from experience based intuition as well as on more formally acquired concepts. Studies which have documented children's conceptions have acknowledged the base concepts underlying learning, but have not critically addressed the question of the mechanism by which former knowledge controls the newly acquired knowledge. Piaget investigated the development of children's ideas about natural and mechanical phenomena. He concluded that young children do not explain phenomena on the basis of causal linking but instead attribute intention and desire to the objects themselves. As they mature they gradually outgrow this kind of belief in favour of more causally oriented thinking. Resnick and Chi (NSTA) note that there are two fundamental elements in this theory: constructivism and logical determinism. The latter term refers to the theory that children, while growing up, develop a set of general logical structures necessary to scientific thinking. In this view, misconceptions are a result of not having the logical structures needed for scientific reasoning.

Constructivism, the notion on which this work is based, refers to the idea that people build their knowledge for themselves. Personal knowledge is a complex, incompletely-understood outcome of an ongoing process of construction and interpretation. Thus the meaning of a concept develops as a result of interaction between meaning existing in the learner's mind and reality.

Kelly's notion of "Constructive Alternativism" in personal development is very much in line with constructivism (Pope and Gilbert, 1983). According to his position people understand themselves, and their surroundings, and predict future events, by constructing tentative models and evaluating them according to their personal models. The criteria used to evaluate new models are based on knowledge gained in the past. This knowledge is organized in personal representational models of the world which make sense of events and which are used to describe personal experience, to predict future events and to assess previous predictions. According to Kelly, any event is open to as many reconstructions as our imagination will allow. There is no absolute truth, but just "nuggets of truth", which are tested by their power of explanation and prediction, and replaced by what Disessa calls a more powerful "piece of knowledge". Thus the former knowledge has a crucial role in the mechanism of acquiring new knowledge.

Piaget suggested that two principal mechanisms govern the learning of new concepts: Assimilation - by which a new concept is interpreted in terms of knowledge that has been acquired in the past; and Accomodation - by which existing knowledge is adjusted according to the newly acquired concept. Resnick and Chi (NSTA) suggest that "children's failure to think scientifically comes not from logical disabilities, but from not having acquired key organizing principles for some domain of knowledge".

There is, however, a lack of information about the actual processes which take place when new concepts are learned. Do all former beliefs influence the acquisition of a new concept in the same way? If not, what are the factors related to past knowledge which will influence the meaning of a given concept more than others? Which of the established concepts and relations in the existing schemata are more dominant than others? In what way do they govern the acquisition of new knowledge?

THE FOCUS OF THIS STUDY

The research reported here deals with the identification of naive concepts of light held by students who have never formally learned about light, and with relations between intuitive knowledge acquired by past experience and new knowledge students are required to learn. We focus on knowledge about light for a number of reasons:

1) Light phenomena are all-pervasive. Children experience light as something which hits the eye, even causing physical pain if it is too bright.

2) Common expressions like "seeing the light", "throwing light upon", and the psalmist's "valley of the shadow of death", all raise questions concerning widely held concepts of light.

3) Links may be discerned between the historical development of concepts of light and concepts of light based upon everyday experience. (Pythagorean emission theory of particles bombarding the eye and experience of blinding light; Visual rays projected by the eye at infinite velocity and the simple observation that we see the stars at night immediately upon opening our eyes; the Platonist assumption that sight results from interaction among sunlight, particles emitted by objects seen and the eye, and the everyday experience that a light source, an object to be seen, and an open eye are all necessary for sight).

A PILOT STUDY

Interviews were conducted to examine non scientific beliefs about light held by persons with a good formal background knowledge of light. Amongst the interviewees were students majoring in physics and physics teachers. Questions asked related to everyday phenomena and to topics encountered in formal learning. This was done in an attempt to differentiate between the kinds of knowledge used in explaining phenomena as experienced and phenomena as learned in a classroom. For example, we asked: Why does TV or radio noise often accompany lightning? and, What causes the Crookes radiometer vanes to rotate?

The analysis of interview protocols showed that persons with good physics backgrounds often held beliefs incongruent with the formal science they had presumably learned. Responses suggested that although the questions called for knowledge in the same area, interviewees applied different sources of knowledge in dealing with everyday and with formal science problems. In addition the terminology used for dealing with questions on everyday phenomena often differed from that used in answering questions on formally learned phenomena. Thus in moving from everyday to formal science, terms like vibration, strength, colour, and mixing, gave way to terms like frequency, force, wave length, and superposition.

One concept, that of light particle, was found to be common to both knowledge sources, being seen as a small round material object rather than as the abstract notion encountered in formal learning about light. This suggests that the idea of light as an actual material substance was held by interviewees irrespective of the level of their formal achievement in physics.

In an attempt to identify possible sources of this naive and apparently intuitive conception, a study was initiated of a group of highly achieving 17 year olds who had never learned formally about light, and who planned careers in engineering or science.
Goals of the study were:

1) Identification of naive conceptual frameworks about light;
2) Identification of interrelations between established and newly acquired knowledge;
3) Development and evaluation of a method for restructuring knowledge about light.

THE IDENTIFICATION OF PRESCIENCE CONCEPTS OF LIGHT

Eleventh grade students majoring in the electrical engineering trend in a technological high school were interviewed in order to identify explanatory conceptual frameworks on the nature of light. In order to check for consistency of responses, each phenomenon was discussed in more than one way. Questions took the form:

1) What shines in each of these light sources? (Students were shown and were able to examine: incandescent, fluorescent and neon lamps; a TV screen; a candle;a burning match; and a gas flame).

2) Why do you see different colours when you put different materials in a flame?

3) Why does the light from an ordinary electric light make the Crookes radiometer rotate, but the lab laser light doesn't?

4) You land on an unknown planet lit by a sun radiating red light only. What are the colours visible on that planet?

5) What is a rainbow?

6) A lighted candle is placed on the floor of the room. Draw a line to show the furthest place reached by the light.

7) Is there any place in the room which the candle light doesn't reach? If there is, can you see the candle from such a place?

8) How is it that we have sunlight (twilight) after sunset?

9) A white shirt illuminated by red light appears red, and a red shirt illuminated by white light also appears red. Explain.

10)How does coloured glass change the colour of light passing through it?

It was found possible to classify students' conceptual frameworks with respect to five topics: light sources; propagation; the nature of light; light and sight; light and colours. Student beliefs were grouped for each topic.

The most popular beliefs concerning light sources were that they are all hot bodies, that any material can become a light source if heated to a sufficiently high temperature, and that denser materials require more heat to make them shine. Other popular beliefs were that light sources are created by chemical reactions such as the reaction of candle wax with oxygen, and that fire is a necessary precondition for illumination.

Beliefs concerning the propagation of light were revealed in discussion about a lighted candle placed on the floor at the center of a room. Some students claimed that the light intensity dropped slowly until at a certain distance it vanished. Students who marked a line to show the limit beyond which light did not pass explained that the candle could be seen from beyond this line since the flame was brighter than its surroundings. Others claimed that light was latent in the air, using this to explain the phenomenon of light after sunset. A third belief was that light intensity falls as a function of colour, so that blue light doesn't travel as far as yellow light. The rate of change of intensity was also seen to depend on the velocity of light, which in turn depends on the power of the source. This was used to explain why a stronger source is visible from a greater distance.

Light was seen as composed of particles, of waves, as a combination of rays and a sea of light, and as being associated with heat.

Sight, it was believed, depended upon the reflection of light from bodies or upon light filling the surrounding space. Few students related sight to light entering the eye.

Light is believed to have a particular colour either because its source, such as a heated filament, is coloured, or as a result of passing through coloured glass. This may explain a student prediction that a blue object illuminated by red light would appear violet, rather than black, just as a mixture of blue and red paint appears violet.

At this stage of the study, having categorized some student beliefs about light, we identified three basic beliefs used in explaining light phenomena.

The first was the notion of a hot body radiating a flowing material or stream of tiny particles which can fill, and remain in, the air (light conservation as in the case of twilight). Light colours were seen to mix in the same way as do the colours of liquids. (22% of students).

The second was the notion of a hot body emitting variously sized particles, each size having a specific colour. 'White' particles easily change to particles of another colour, but the reverse process is more difficult since other colours are darker, and therefore more dominant, than white. In this view the colour of an object seen is a simple mixture of the colours of the object and of the illuminating light. A lab experience in which students saw that a red object viewed through a blue filter seemed black, did nothing to change this view of colour. (18% of students).

The third notion was that particles emitted by a chemical reaction are able to fill space but that their movement is retarded by the air, by some sort of friction. This would explain the belief that light from a source such as a candle flame propagates only to a limited distance. (22% of students).

These basic approaches to light all explain observed phenomena in materialistic terms in which the behaviour of light is reminiscent of the behaviour of a gas. This is the case not only for the 62% of students whose basic assumptions form the three clusters mentioned above, but for most of the other students too. We believe that students did not arrive at such a view of light as an outcome of formal learning, but that this view exemplifies a naive materialistic way of thinking about natural phenomena.

A NAIVE STANDPOINT AND FORMAL LEARNING

A series of laboratory learning situations was developed in which experimental phenomena examined by the student were accompanied by real time computer based analysis. The basic equipment included: an IBM PC; an A<->D converter; light and temperature sensors; a step motor controlled from the keyboard to move the sensors along a bench or to rotate them; a set of light sources; and a 3cm micro wave kit.

The lab-pc interface simultaneously provides empirical and analytical information. This two fold presentation increases what Posner et al. (1982) call the intelligibility of the physical concepts involved. On the basis of the simultaneous juxtaposition of both kinds of information the student is able to build, modify and rebuild explanatory hypotheses. In this resides the power of the system as an agent for change of students' conceptual frameworks since it provides for the immediate testing of ideas against experience. Unlike analysis in the traditional school laboratory experiment, here analysis becomes an integral part of the experiment.

The experiments covered: (1) the dependence of light intensity on the source, on distance, and on direction; (2) the notion of field; (3) the dependence of intensity on type, colour and thickness of an absorbing medium; (4) the relationship between absorbtion and temperature of a light transmitting medium; (5) polarization; (6) diffraction; (7)interference; and (8) the behaviour of 3cm electro magnetic waves.

Each experiment was planned to force students to draw inferences about relations among variables, and the process of learning from an experiment was seen as the process of learning to draw the inferences. The kinds of knowledge introduced by this teaching method were analysed and knowledge related to the experimental variables was identified.

We call knowledge on relationships among variables "relational knowledge" while "explanatory knowledge" refers to explanations as to why a particular relation holds rather than another. The first kind of knowledge was explicitly introduced in the experiments, while the students were encouraged to develop the second. For instance, in one experiment in which students examined the intensity of illumination from a light source, the relational knowledge found was I= K/R2. The related explanatory knowledge which students were expected to develop is that light propagates spherically. Both kinds of knowledge are significant, but our interest is mainly in the second.

Relational knowledge was examined by questionnaire, explanatory knowledge was examined by interviews during the experiments. Questions were designed to explore how students made sense of their experimental outcomes and how they defended their explanations.

In one experiment, for example, a light source heated two identical glass beakers, one containing strong black coffee, and the other weak coffee, during the same time period. The rise in temperature of the black coffee was found to be greater. Students explained that heat was created by friction between light particles and coffee particles and that since the black coffee was denser, friction was greater. One student argued for this explanation by saying that "You can't see the light so clearly in fog because it is much slower than usual". When asked about the heat that should be produced, he said that the fog is so much larger than the cup of coffee that you don't feel it.

UNDERLYING EXPLANATORY BELIEFS

We found that students' explanations of experimental results were governed, in the main, by the following ideas:

The light sensor differs from the eye in that it "sees" only if the light is directed toward the sensor. This indicates an assumpion that light does not have to enter the eye in order for us to see.

Light is absorbed by material and fills it. Just as gas fills a container, so light enters and takes the container's shape. A material is bright if the particles of light stay inside it.

Particles of light can heat a medium through which it passes as a result of friction with particles of the medium..

The naive material particle conception of light seems to govern the learning of new concepts. Though relational knowledge was learned very well, this was not the case for explanatory knowledge. We believe that the tenacity with which students hold on to non science beliefs despite formal learning of science, results at least in part from the stress teachers place upon relational rather than explanatory knowledge.

In continuing this study, we now plan to construct a taxonomy of materialistic beliefs commonly used in the development of explanatory knowledge.

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