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ABSTRACT

This paper examines the development of science content knowledge of elementary teachers (N=25) as a result of participating in a summer science Institute funded by the Massachusetts Department of Education and the National Science Foundation. The institute was designed to integrate the physical, life, and earth sciences by addressing the National Science Education Standards (NSES) K-4 and 5-8 content standards related to light. The goals of this research were to discover what teachers with little or no formal science education know about light and vision, explore if and how teachers' understanding of these topics changed during the course of the institute as a result of the pedagogy employed, and probe teachers' understanding of light and vision 2 months after the completion of the institute. Questions raised by this research pertain to whether or not elementary science should be handled by science specialists rather than poorly trained teachers, and whether the focus of elementary science education should be on helping students to become wonderers and explorers of science rather than emphasizing specific content. Contains 14 references. (DDR)

Examining Elementary Teachers' Explanations of their Science Content Knowledge

Paper presented at the Annual Meeting of the National Association for Research in Science Teaching

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Examining elementary teachers' explanations of their science content knowledge

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Science education nationally and at the state level is undergoing a period of dramatic reform. The National Science Education Standards (NSES) (1996) and numerous state standards, provide guidance for the science content knowledge to be attained by elementary, middle, and high school students as well as emphasizing the need for students to develop the process skills necessary for inquiry. By implication then, the standards also "provide a vision of what teachers need to understand and do to provide learning experiences for students that are aligned with content standards" (Yager, Lutz & Craven, 1996). Yet, we know that nationwide, elementary (and many middle school) teachers have little preparation in science. Generally, elementary majors take a minimum number of science credits in their undergraduate preparation and may or may not take a science methods course. This situation raises the question: Can elementary teachers teach science concepts specified in NSES if they neither know nor understand them?

It seems ironic that we should even be asking this question. We would no more expect an adult to teach a child to read if that adult could not read him/herself; neither do we ask a teacher to teach a second language to a student when the teacher speaks only English. Yet we ask teachers to teach science without having first developed their knowledge base. Science has its own syntax, its own processes, and a large body of consensually accepted information. Clearly, there is a desperate need to teach science content to preservice and inservice teachers and to move away from courses and workshops which merely emphasize activities devoid of conceptual understanding. Indeed, the professional development standards of the NSES document call for teachers to learn science content as inquiring learners themselves, committed to lifelong learning.

This paper examines the development of elementary teachers' science content knowledge as a result of participating in a summer science institute funded by the Massachusetts Department of Education through a National Science Foundation grant. The institute was specifically designed to integrate the physical, life, and earth sciences by addressing the NSES K-4 and 5-8 content standards related to light:

- Light travels in a straight line until it strikes an object. Light can be reflected by a mirror, refracted by a lens, or absorbed by an object (p. 127). Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection). To see an object, light from that object - emitted by or scattered from it - must enter the eye. (p. 155)

- For ecosystems, the major source of energy is sunlight. Energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis. That energy then passes from organism to organism in food webs. (p. 158)
- The sun provides the light and heat necessary to maintain the temperature of the earth (p.134). The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

Light is commonly studied in elementary schools and science activity books abound with suggestions for teaching shadows, color, reflection and refraction. Yet, students in middle schools often fail to link shadows to the idea of light traveling in a straight path (Driver, Gusene & Tiberghien, 1985); they believe that our eyes adapt in the absence of light so that objects can be seen (Harvard-Smithsonian, Private Universe Project, 1995) and that reflection in a mirror is akin to reproducing or duplicating an object (Bendall, Goldberg & Galili, (1993). These 'understandings' come from everyday knowledge which is not challenged and exchanged during the course of instruction (Driver, 1983). Knowing that teachers would in most likelihood enter the institute with similar beliefs about light as those documented in the literature, we embarked upon planning experiences that would challenge teachers' thinking in an open and accepting learning environment. Our goal was to develop an institute that would improve teachers' understanding of light by teaching them in ways consistent with our belief in conceptual change theory (Posner, Strike, Hewson & Gertzog, 1982). Consequently, this paper focuses on the science content knowledge of twenty- five elementary teachers who attended the institute. In particular, we sought to discover:

- what teachers with little or no formal science education knew about light and vision
- if and how teachers' understanding of these topics changed during the course of the institute as a result of the pedagogy employed; and
- teachers' understanding of light and vision two months after the completion of the institute.

Additionally, we were interested in the effect of modeling teaching for conceptual change on teachers' perceptions of how to approach science in their own classrooms.

The Institute

Twenty-five elementary teachers (grades 1-7) from nine different school districts enrolled in the eight day long summer institute developed and taught by the authors. The institute was one of about thirty offered by the State of Massachusetts as part of the PALMS

(Partnerships Advancing Learning in Mathematics and Science) initiative to improve the teaching and integration of math and science. The instructional team consisted of two university science educators both with at least twelve years of successful experience in conducting science inservice courses; a doctoral student in science education who was also a Museum of Science educator; a high school physics teacher with a Ph.D. in engineering; and a science curriculum coordinator from a local school district who was also a PALMS teacher leader. Detailed planning for the institute began three months before its commencement, with the instructional team meeting on a bi-weekly basis and corresponding via e-mail. In planning for the institute we recognized that many of the experiences would evolve throughout the two weeks based upon the questions that teachers generated, nevertheless we worked on developing 'spring-board' experiences which would trigger teachers' curiosity and help them to 'dive' into science. With this in mind, instruction was designed with three purposes:

Purpose 1 - To pose challenging questions and situations to be explored by the teachers:

For example, teachers were asked to create and explain their observations of overlapping shadows and colored shadows, to use their prior knowledge to predict the nature of their reflection in a mirror when standing close and far away, to reconcile their knowledge of light traveling in straight lines with the apparent 'curving' of light in a stream of water, to explain the action of light in the spinning of the vanes of a radiometer, and the cooking of a hot dog by light.
Teachers were provided with materials to explore the original question, but were required to generate more and more questions as they explored and recognized that they were intrigued and puzzled.

Purpose 2 - To collect and further explore questions generated by the teachers

Teachers' questions were written on poster paper and displayed on the walls for the duration of the institute. Some questions were taken as the focus for exploration on proceeding days. Each day there was also a 3-2-1 summary completed by each teacher which listed 3 things they had learned, 2 questions they had and 1 thing that they wished they had or had not done. These questions were added to the running list on poster paper. Some of the questions that were raised by teachers and addressed during the institute are documented in Figure 1. They proved to be invaluable for exposing the unanticipated connections that teachers made.

< INSERT FIGURE 1 HERE >

Purpose 3 - To assist teachers in developing a better understanding of concepts that could not be gained from their own explorations.

Instructors developed direct teaching experiences to address teacher-generated questions for which they themselves could not devise experiments. These direct teaching experiences involved demonstration tasks, small group tasks, and whole group discussion.

Clearly, the instructors were modeling inquiry as it might be practiced in a classroom, beginning with a question, leading to an investigation, leading to more questions. In some cases the investigation was a teacher developed experiment, in other cases it was instructor led sessions. The goal was for teachers to know and understand the concepts as described by the scientific community as well as recognizing the power of questions in promoting learning. Generation of questions is an important step in exploring one's own conceptions and integral to teaching for conceptual change.

Methodology

On the first day of the institute, the 25 participants were asked to respond to ten statements by indicating whether or not each statement "made sense to them" and then to explain why it did or did not make sense. Six of the statements related directly to light (the other related to temperature and heat) and are shown in Figure 2. The sense nonsense instrument was thought to be less threatening than the typical true/false response and had been used previously with high school children by one of the instructors. Each of the statements formed the basis of investigations that would be undertaken by the teachers during the course of the institute. The instrument was readministered twice, once at the end of the institute (twelve days later) and once at the beginning of the school year follow-up sessions (two months later).

< INSERT FIGURE 2 HERE >

Data Analysis and Findings

The first stage of the analysis was to tabulate the pre and posttest sense nonsense responses which were in agreement with the science idea (see Table 1). While it appears from Table 1 that some gains were made in the science content knowledge of the teachers in the study, analysis of the explanations reveals a different picture. The explanations were carefully read for correspondence with a view which could be described as consistent with dominant science thinking. The explanations were then categorized as either: (i) illustrating little or no understanding of the science idea or (ii) as having an understanding of the science idea at a level that could help the teacher to explore the phenomenon with elementary children (see Table 2). Clearly, at the end of the institute and two months later, more teachers appeared to be able to state the science ideas, but there were only small gains made in being able to explain them in a way that might help children to understand. There was minimal evidence of conceptual change which would have required teachers to have accommodated the new science ideas.

The explanations were then further examined to provide the institute instructors with insight into any small changes in thinking that might have occurred from pre to posttests.

If full conceptual change had not occurred, we wanted to know if teachers had found ideas from the institute intelligible and plausible. If this were the case we would expect to see their learning progress through phases (Shuell,1990). In the initial phase, teachers would be memorizing facts either retaining them as isolated pieces of information or attempting to link them to preexisting schemata. Gradually, teachers would begin to see relationships between the pieces of information they are accumulating and a network of ideas would start to form. However, these networks are rudimentary and do not allow the individual to operate fully autonomously. When conceptual change occurs the teacher has developed a deeper understanding of the material and can apply it flexibly in many contexts. Analysis of the teachers' responses allowed us to identify initial and intermediate phases of learning prior to conceptual change.

Statement 1: Light travels in straight lines

Pretest

Detailed analysis of the pretest responses to this statement showed that explanations were in one of four categories. (i) Explanations that illustrated that teachers had an understanding of the science idea were often drawn from observations of everyday life, such as:

- *If you look at sunlight on a clear day you can see straight rays*
- *I need a periscope to see around corners*
- *Shadows show that light doesn't bend around objects*

(ii) Deficient explanations contained terms which were used inappropriately. For instance, several teachers did not recognize the meaning of the verb "to bend" when used to explain refraction, thinking of it as synonymous with curvature, for example:

- *Light travels in straight lines although refraction appears to bend it*
- *It can be bent as it travels through prisms and water otherwise it is straight*
- *I've seen it bend in rainbows*

(iii) Even more problematic were explanations which were little more than a collection of science sounding words:

- *Because of the light ray waves*
- *The shortest distance between two points is a straight line, but atmospheric conditions affect the light's diffusion and different colors get through*

(iv) Finally there were explanations based on a belief and not understanding:

- *Because I learned this at school*

Posttest

Although in the posttest analysis there was no increase in the number of explanations that fully demonstrated that the teachers understood the science idea, the quality of the responses was very different. Only two categories of response existed: (i) responses based on observations of shadows and other relevant experiences from the institute:

- *You can see this when you shine a flashlight in dust particles, this is also how shadows are created when an object blocks the path of light*

and (ii) responses drawn from workshop experiences which partially provided evidence, but did not fully explain the statement:

* *I can see evidence for this in the way it reflects off a mirror.*
* *Light can be refracted in angles but it travels in straight lines*
* *Our summer experiment appeared to contradict this, but the appearance of light curving in a stream of water is due to reflection*
* *In the solar cooker - light was captured on a straight line and reflected onto the hot dog because of the angle*

These statements illustrate that the teachers were attempting to bring to the fore their experiences with mirrors. They also recognized that when light bends it is still taking a straight path. Thus there was some clarification of terms, less 'random' use of science terms, but the incomplete explanations for light traveling in straight lines suggested that this was not a fruitful idea. They could still operate in the world with mirrors and shadows without thinking about the path of light. Bendall et al. (1993) found that college students believed that "the eyes just looked at the mirror and the image would be seen" (p. 1183). The teachers in this study might hold similar conceptions and are using terms rotely learned rather than connected to any particular model of light and vision. Thus the 60+% who did not fully explain their understanding of this statement were attempting to link the new terms, but had yet to form a rudimentary network of ideas.

Statement 2: There are only seven colors in a rainbow

Pretest responses which drew upon everyday experiences were again apparent, but this time the experiences that were connected related to pigments rather than light and this did not help the teachers in providing an explanation in agreement with science idea:

* *Because the color of water is green and blue and heat rays are colored yellow, red and purple*
* *There are a number of primary colors, but a greater number of blendings, when colors meet they blend*

Explanations which included the use of science words with no explanation were also given :

* *Rainbows are the separation of light into various frequencies*
* *This is the visible portion of the electromagnetic spectrum*

Finally, belief based statements were provided as explanations:

* *This is what is explained to children in textbooks*
* *I learned ROYGBIV in Junior High*

The posttest responses to this statement showed that teachers had much difficulty in understanding that color is a matter of perception. Although the institute had introduced the idea of the effect of different wavelengths of visible light on the cones of the eyes,, teachers had a difficult time accepting the idea that it is our eyes and brain that determine color. Many now recognized that more than seven 'colors' exist in a rainbow, but several generated unanticipated explanations which used other newly introduced institute ideas. Hence there were more inappropriately used science related ideas in the posttest responses:

- *There are seven visible colors but there is light that humans can't see like infrared and ultraviolet*
- *I think there is only one color - white- it is the other colors that make white*
- *This is the visible light, although I remember there are only three colors/cones?*

Once again teachers were clearly attempting to draw on workshop experiences, but had been unable to fully accommodate these new ideas about color and vision. They were attempting to use the new terms such as infrared and ultraviolet but were unable to link new learning to the statement in any meaningful way.

Statement 3: When the burner of an electric stove is turned to high and glows red it is giving off light energy

Pretest responses to this statement included remarks from two teachers that they have never observed this and therefore couldn't agree with the statement. However, several teachers used common sense reasoning to illustrate their understanding showing that they recognized that light is involved if an object can be seen:

- *Anything that changes to visible is producing light*
- *This would be visible in a pitch black room so it must be making light*
- *Because it is glowing it is giving off light*

However, the majority of the responses showed the presence of a common alternative conception that heat contains light or vice versa, or that heat is light :

- *One form of energy becomes another, hot also is light and light is hot*
- *It probably is because light and heat are closely related*
- *A red glow is heat*
  The glow is heat waves

The posttest responses showed a small decrease in understanding the phenomenon as once again teachers attempted to integrate new science ideas with previously constructed everyday reasoning. That light was responsible for the red glow was still a prevalent idea, but now several teachers attempted to explain where the light came from rather than being satisfied with saying light is given off. Their attempts showed that they failed to consider the burner as emitting light:

- *Because you can see it glowing red there are some light waves being reflected off the burner*
- *Red light is being reflected off and other colors are being absorbed*
- *The burner is causing wavelengths at the red end of the light spectrum to be reflected*

A second institute idea, energy conversion, led to a statement that *heat energy is transferred to light energy*. Several teachers retained the idea of the red color being due to heat rays.

Statement 4: If I were down a mine shaft with no light getting in, I would be able to see my hands in front of my face

Surprisingly, less than half the teachers in the pretest were able to explain that light was needed for vision. Of the 52% that stated that they would be able to see their hands, most used everyday explanations which included statements that are commonly heard:

- *Light is needed to see color*
- *I have taken children on night hikes and they have been able to see*
- *Normally your eyes adjust to the dark, but too dark might be a factor*
- *I can't imagine a situation so absent of light that my eyes would not adjust*

There were two pseudo-scientific explanations: *Your body gives off energy and energy creates light; Because you would be able to feel the energy from the body.*

The posttest responses indicate that 84% of teachers understood the need for light for vision. 16% of teachers failed to provide an explanation, the rest responded appropriately in terms such as:

- *Light is needed to cause reflection and nothing will be reflected back into your vision*
- *There must be a source of light to see something*

In this case at least, common, everyday conceptions of vision and dark adaptation had almost completely been exchanged for the science idea.

Statement 5: If a small candle was burning in the center of a 20 x 16 foot room, the light from the candle would reach the walls of the room

Bendall, Goldberg and Galili (1993) found that preservice teachers hold the conception that light spreads out with distance from the source, but that they do not always apply this conception meaningfully. This was found to be the case in the pretest responses of the teachers in this study. The majority of teachers agreed that light from the candle would reach the wall and once again applied everyday experience to explain their response:

- *I have observed this*
- *My room is this size and I always have a candle on the cocktail table and it reflects on the wall*
- *A match on a clear night can be seen for several miles*

Some teachers however, could not quite believe that a small candle could produce enough light to reach the walls (although afterwards they agreed that if they stood at the wall they would see the candle):

- *It might not appear visible, but it would change the room's light*
- *Might depend on the color of the walls*
- *But my eyes may not see it*

Several statements once again used science words incoherently : *Atmosphere carries the light; Because the light collects the heat.*

The posttest results did not display much change in understanding that light travels until it is blocked by an object. There was continued use of everyday experiences to make sense of the statement, no use of science words in a muddled way and one occurrence of a common misconception that there *is not enough light energy to reach the walls of the room.*

No sessions had specifically addressed the idea of light traveling out from a source in all directions until it is blocked, consequently there were no new terms applied in response to this statement. Clearly the teachers drew upon experiences of turning on a light and having a room bathed with light - they could not imagine a small candle illuminating a room adequately and therefore could not conceive that its light reached the walls.

Statement 6: A yellow sweater that you wear will look green if you stand under blue light

This statement was problematic for teachers in the pre and posttests because of the extensive prior knowledge of pigment mixing and little experience with colored light. Only two people did not invoke a pigment mixing model, but they did not have knowledge of the science idea of light absorption and reflection:

- *Yellow will appear white in yellow light but I don't think that will blend with blue*
- *I think this only works when mixing colors, there would be a change but it wouldn't look green*

The changes in the posttest were in the direction of realizing that light would behave differently from mixed paints, but the teachers were still unable to explain why:

- *Something about primary colors and rods and cones.....*
- *Oh help I forgot which colors are stronger and absorb other colors*
- *I wish I remembered, it's not the same as paint, probably black*
- *Only true for paint not light*

Discussion

The institute described in this paper was specifically intended to assist teachers in understanding science content as presently described by the scientific community, by teaching in a way which encouraged teachers to question and to be able to express their uncertainty. Thus the daily activities were centered around questions to be explored, with teachers being encouraged to find their own ways of experimentally investigating these questions. Roychoudhury (1994) described the need for just this type of inservice workshop when she cautioned that teachers must learn through exploration and searching for the unknown if their classroom practice is to be more than a series of hands-on activities. But if inquiry is to occur in elementary science lessons the teacher must recognize the unanticipated links that children make as they inquire and be able to guide the child in further investigation on the road to attaining the science idea. If the teacher him/herself is struggling to understand basic science concepts how can s/he assist. We cannot teach what we do not ourselves understand.

Did the institute fail to attain its goal? Clearly, the teachers did not emerge with a complete understanding of the science ideas, so in that respect we failed. However, by the end of the institute the teachers had begun the process of conceptual change by abandoning their private theories and attempting to draw upon their learning from their explorations. Teachers entered the institute with a conception of light similar to that of middle school children reported by Driver, Guesne and Tiberghien (1985). They did not explicitly accept that light travels, nor that seeing an object is due to the reflection of light unless that object itself is emitting light. Further, they did not recognize that light is conserved, but instead believed that it disappeared when its intensity was too low to be perceived. At the end of the institute, they had begun to accept the idea of reflected light, but applied it to all situations of seeing an object (e.g. the red glow of an electric burner is the reflection of red light from another light source). They began to use ideas of energy conservation, but not in ways consistent with the science idea, and they retained their conception of low intensity light "running out" before it reaches an object. This begs the question, was the institute approached in a way that was consistent with bringing about conceptual change? Like the students they teach, teachers were given events and objects to observe and then brought their prior knowledge into play in an attempt at interpretation. At this point their interpretations were challenged by the instructors and the teachers started to become inquirers generating questions out of the cognitive dissonance they were experiencing and exploring some of their ideas. The questions (see Figure 1) became more complex and more numerous as the institute progressed and teachers discussed each others' points of view. This indicated the teachers' growing confidence as they recognized that their questions were valued. By the end of the two weeks there were no activities that did not end in someone saying " I wonder what would happen if we now tried ....". Stopping at the point of creating dissonance would have left teachers at a stage of thinking that they just could not "do" science (Dykstra, 1992), but the opportunity to question and test questions is empowering. The institute thus succeeded in helping teachers to become "amateur scientists as they learn to pursue questions for which the answers are not known"(Roychoudhury, 1993, p. 95).

Why then did the teachers fail to gain the science idea? Just like the middle school children in Driver's research (1985) many teachers held a conception of light as a source or an effect and were gradually coming to view it as an entity in space that propagates from a source and interacts with objects in its path. Also, just as we recognize that children need time and varied experiences to understand their own views, so do teachers who have little science in their formal education. The teachers in this study were perhaps for the first time realizing that their conceptions of light were inconsistent, with contradictory interpretations of various phenomena becoming apparent.

The teachers certainly felt that they were undergoing change in their thinking, as documented on an end of institute evaluation instrument. The institute was rated highly by the twenty-two teachers who completed the evaluation form, with eighteen participants stating that it was much better than previous science workshops they had attended and four saying that it was better. In particular the teachers valued the instructors' approach:

- *The instructors spoke to us as teachers and not as the fourth graders we teach. They did not expect us to do everything a fourth grader would do.*
- *The patience and knowledge of the presenters*
- *The enthusiasm of the presenters and the atmosphere of the class*
- *The way the presenters worked as a team*

The teachers recognized the attempts made to use their questions and to link concepts as a means to help them understand the science ideas, and they began to feel that science was not inaccessible to them:

- *I particularly liked how well integrated and connected all of the activities were. I could really feel the pieces coming together as my knowledge understanding was growing*
- *I feel I have grown tremendously through this course. I have never enjoyed science quite this much and I love science! I experienced my own personal quest for scientific knowledge (inquiry) for the first time!*
- *You made what always seemed like "off limits" information very palatable*
- *I particularly liked the way you based each day's lessons on the feedback from the day before... And your ability to help me to think more clearly - understand more deeply and to determine what I need to spend more time on to understand it better.*

One teacher summarized how effective teaching for conceptual change can be for adults when she stated, "*I have discovered how powerful learning is when you have time to explore and investigate things and how it aroused curiosity and 'I wonder' questions.*"

Implications

For all of us engaged in preservice and inservice science education there is much to be considered. At present we are asking classroom teachers, with little or no formal science education, to help children to understand science concepts which they themselves do not fully comprehend. Even if these teachers express willingness to 'learn with their students', for learning to occur there must be a more knowledgeable individual to help the child to recognize inconsistencies in his/her interpretations of phenomena and to provide challenging events for discussion as the child moves toward the science idea (Schoon, 1995). This idea is akin to Vygotsky's writings on the zone of proximal development (Vygotsky, 1978). A teacher who does not recognize inconsistencies in his/her own thinking cannot, with all the best will in the world, be that guide. This raises the issue of whether elementary science should become the domain of a science specialist. However, even without debating the pros and cons of using specialists to teach science, the likelihood that we shall be able to produce a cadre of elementary teachers who can serve in this capacity is low.

Much of the hope for the reform of K-12 science education has been pinned upon changing preservice teacher education (Yager et al., 1996). We share the view that the science preparation of preservice teachers is woefully lacking. Few elementary teachers enter the profession with science as a minor let alone as their major. We must therefore ask:

- Should K-4 science education concentrate its efforts on helping children to become wonderers and explorers of science rather than emphasizing specific content?

It is clear that science educators can help elementary teachers to understand what is meant by conceptual change teaching and to help them to contrast it with merely doing hands-on activities. In the institute described in this paper, two weeks was not long enough to change understanding of science concepts, but it was long enough to consistently model an approach that is needed in the classroom and to change attitudes to teaching science. The comments made by teachers at the end of the institute (see discussion section) illustrates the effectiveness of our modeling, This is further exemplified by the fact that eighteen teachers from original twenty-five have returned once /month for implementation workshops. Five Saturday workshops were scheduled and teachers have asked for three more and will be bringing a colleague. They bring examples of what they have tried in their classroom, together with work produced by their children. Their emphasis has been on assessing process skill development. In particular, observation has been effectively used to generate students' questions leading to the development of simple experiments.

Finally, we know that science is relegated to a low position of importance by most elementary schools, which see reading and mathematics as their priority. If there are not to be science specialists at the elementary level (and once again, we are not suggesting that this is necessarily desirable), then science educators will need to prepare preservice and inservice teachers in a way that will help them to see the interconnections between science and the rest of the curriculum (Guillaume, 1995). Preservice preparation programs should consider abandoning methods courses in the separate disciplines, in favor of an integrated approach. This takes the type of scheduling and credit-bearing changes at the higher education level that have been required of our middle and high schools. We must also have realistic expectations for what elementary teachers can do during the course of a school year. This means that science educators must be fully conversant with the demands placed on elementary teachers and policy decisions should reflect this understanding. Standards documents specifying content for middle and high school levels are necessary if we are to help students to understand the body of knowledge that science uses, but at the elementary level it is inappropriate to expect that students can attain certain science concepts if teachers themselves are struggling with the same ideas.

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Figure 1

Examples of questions generated by teachers throughout the eight days of the institute

- Which matters most when making a shadow - the distance between light and object or the distance between object and screen?
- How did we get a yellow shadow with red, blue and green lights?
- If there is no light how can there be reflection?
- When you use one colored light you don't get a colored shadow, but why do you get a colored shadow with 2 colored lights?
- If we need dust in the air to see a light beam, why doesn't light bounce off water or air molecules?
- What is the difference between shadow and shade?
- Would a plant grow in green light if it's reflecting green light?
- Is your green the same as my green?
- Where did the energy in the sun originally come from?
- How does energy get to us in light waves?
- Is infrared light a different form of energy than heat?
- Why can I see many different colors and shades at the same time?
- Why do paint and light colors mix differently?
- Since ultra-violet rays contain more energy and therefore heat, why are infrared lamps and not UV bulbs called heat lamps?
- Why do snakes and bees see different light energy than humans do?
- The solar cookers did not cook the marshmallow as I expected, has it got anything to do with the marshmallow being white and not absorbing any light?
- On a hot day we can see heat rise from a hot asphalt road, are they heat waves?
- What type of energy causes my photosensitive eye glasses to change?

Figure 2

Pretest - Posttest Instrument used during and after the Institute

Six statements referring to light and vision

For each statement, check whether it makes sense to you or whether you think it is nonsense.
For each statement, explain why you think it is sense or nonsense.

1. Light travels in straight lines.
2. There are only 7 colors in a rainbow.
3. When a burner of an electric stove is turned to high and glows red it is giving off light.
4. If I were down a mine shaft with no light getting in, I would eventually be able to see my hands in front of my face.
5. If a small candle was burning in the center of a 20 x 16 foot room, the light from the candle would reach the walls of the room.
6. A yellow sweater that you are wearing will look green if you stand under a blue light.

Table 1
Percentage of Teachers' Responses in Agreement with the Science Idea

Statement	*Pretest* *N = 25*	*First Posttest (12 days later)* *N = 25*	*Second Posttest (2 months later)* *N = 19*
1. Light travels in straight lines	92	96	95
2. There are more than 7 'colors' in a rainbow	32	44	37
3. The red glow from an electric burner is due to the emission of light	64	64	84
4. When in a mine shaft with no light you cannot see.	56	84	89
5. Light from a small candle in the center of a room will reach the walls	80	76	89
6. A yellow sweater will look black under a blue light	12	40	47

Table 2
Percentage of responses which indicate understanding of the science idea

Statement	*Pretest* *N = 25*	*First Posttest (12 days later)* *N = 25*	*Second Posttest (2 months later)* *N = 19*
1. Light travels in straight lines	32	36	32
2. There are more than 7 'colors' in a rainbow	4	4	16
3. The red glow from an electric burner is due to the emission of light	40	44	32
4. When in a mine shaft with no light you cannot see.	48	68	84
5. Light from a small candle in the center of a room will reach the walls	16	36	32
6. A yellow sweater will look black under a blue light	0	4	4

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