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ABSTRACT

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PROMOTING LOUD THINKING ABOUT LIGHT IN ELEMENTARY SCHOOL SCIENCE

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In studying young children learning in inclusive environments, we designed ways to enable children to explore scientific knowledge that is usually believed to require later, didactic teaching. Aspects of this design under scrutiny here are, first, the capacity of natural learning to lead to effective scientific ideas, and second. further clarification of the role of context. We found that in conversational modes, children were able to generate ideas and theories, to test them (by extended discussion in which they examined the logical consequences of holding those ideas, and by subjecting them to critical tests), and then to generate further theories. In doing so, the role of analogical analysis was especially productive; the simile of moving objects bouncing from a surface helped the idea of light travelling to emerge naturally (a contrary finding to the belief that understanding the propagation of light should precede the study of reflection). In this environment children studied keenly and co-operatively, kept records and critiqued the topic. As a result of this learning our view on the ages at which children might begin to deal with scientific ideas have been revised downwards.

INTRODUCTION

In seeking answers to the question, "Why is science hard to learn?" we (and many others) have noted that children are not inhibited in explaining happenings in their world; they use their rich, personally developed theories to understand and talk about phenomena and events that interest them. School science ought to recognize these capabilities, by nurturing and encouraging children's theorizing and to help them to develop coherent and (for some) scientific understandings of everyday phenomena.

From an epistemological point of view scientific knowledge is plastic; it is continuously invigilated, and its ideas are to be modified where they are shown to be restricted, so that they come to be more fruitful. While this scrutiny is not unique to science, it is essential to science. Intuitive knowledge, on the other hand, is the set of rules of thumb that people generate in order to be able to deal with the events of the world. Once they have been formulated, those rules are rarely scrutinized. Usually they conflict with the ideas of scientists, and because of their primacy and frequency of use, learning difficulties arise (Ausubel, 1968, p. 336).

Children's intuitive ideas are explanatory and helpful in the settings from which they emerge. Their ideas and the thinking which generated them can be used to guide deeper understanding and use in similar settings. That their ideas differ from scientists' does little to change their every-day currency. For example, children predict (correctly) that a large source of light, such as the sun, gives out more light than a smaller one, such as a flashlight[1]; they also predict (incorrectly) that light from the smaller source does not travel as far as the light from the large source (Stead & Osborne, 1980). Their common sense is useful if they need to decide which kind of flashlight is best suited to certain conditions, for the incorrect prediction does not change the everyday utility of the knowledge that it will be dark a few metres away from a source of light on a dark night.

The problems which science education need to resolve are whether all children should be initiated into the world of scientific common sense, and if so, when this process should begin and how it is best accomplished.

[1] For this North American audience, the word 'flashlight' will be substituted throughout this paper for 'torch', the word used by Australians.

PURPOSE OF STUDY

We are seeking ways of assisting students to articulate their intuitive ideas so that they too may be kept plastic. We have tried to do this here by introducing children to a study of light at a relatively early age and by encouraging them to explore phenomena in explicitly designed contexts from which some of the big ideas in light can emerge. We seek further understanding of the notion of context in both bringing about children's examination of their intuitive ideas (here, about light) and allowing children to generate further ideas.

We are interested in designing (co-operatively, with teachers and children) a variety of inclusive learning environments in which ideas about light might be explored and even appropriated by young children by tapping into the innate curiosity and inquiry children display before they went to school. The basis for our design is in blending ideas gleaned from educational research and from an emerging neuroscientific view of knowledge, with teachers' pedagogical practices and children's ways of finding out.

THEORETICAL UNDERPINNINGS

This study is based in several recently researched fields. One (already mentioned) recognizes the challenge of intuitive knowledge for formal learning; a second considers learning and teaching to be natural, while the third is from the more general field of learning environments which pay particular attention to inclusion.

Natural learning and teaching

There is now much evidence to suggest that styles of discourse are crucially important (e.g. Biddulph & Osborne, 1984; Cosgrove & Osborne, 1985). Because we have high respect for the natural learning by which young children teach themselves to walk (Thelen & Ulrich, 1991) and by which they generate their intuitive knowledge, we want to see if children learn science in this way, too. So we set out to promote learning in a way that would encourage the kind of sustained intellectual searching that Tizard and Hughes (1984) described in young children's talking and thinking at home and which these researchers pointedly contrasted with those same children, subdued and passive at school: in short learning through dialogue and conversation (Cosgrove & Schaverien, in press).

Natural learning has other features. Because it is largely learner-driven, it might appear to be messy and unfocussed (to some adult minds!). Holt (1972) helps us to understand how children's learning can seem to be messy yet yield much that is fruitful as they think about their experiences; Papert (1980, 1991) points out the place of tinkering and of bricolage in his constructionist view of learning. He describes the intensity of his very early relationship with learning about gears where both love of learning and cognitive development were woven into the relationship. As well, Papert recognizes the potency of hand-brain collusion, as have others (e.g. Bronowski, 1972). Here, natural learning goes where the children take it.

How does natural learning occur? Recent views from biology (Edelman, 1992; Plotkin, 1994) propose that the mechanism by which all living things (gene-pools, brains, immune systems and cultures) learn follows a generative heuristic. For brain learning, ideas are generated and tested; successful ideas are selected. This heuristic was proposed by Minsky (1985), and the notion that the mind is a generator by Wittrock (1974). The neuroscientific view of the brain is that it is not a computer following pre-existing instructions, but a Darwin machine, learning by selection of successfully tested ideas.

Studies of young babies' reaching behaviour, attempts to walk, learning to bounce regularly in a bouncing device have shown that "skilled action does not just passively mature, but involves a process of exploration and discovery in which perception and action are integrably linked" (Lockman & Thelen, 1993, p. 957). Thelen calls this learning repertoire-refinement (Millson &

'Sington 1994). Here the child's repertoire of ideas and her or his own capacity to refine them is the essential ingredient.

We posit two implications from this for early learning of science at school: first, that some neuronal pathways are strongly formed already through natural learning; second, that certain early school science learning experiences can help to select and strengthen those connections which promote natural learning by stimulating children to pursue learning along paths and through styles which interest them. If the early learning of physical science is successful, then many of the problems of later learning may be offset (Freyberg & Osborne, 1985).

Traditional science teaching is mainly instructionist; knowledge, regarded as a commodity, is transferred from teacher to student. The process is not very successful, and it results in frustration and alienation. We have set out to forestall this failure by down-playing the role of transmitting teachers' ideas alone in favor of children generating ideas as well. We recognise the dilemma that this poses, in that we may seem to be neglecting the need to guide children into the consensually agreed world of the scientists' science. For that reason, the topic was carefully organised so that not only would important conceptual ideas about light be raised, but also so that children could develop their understandings of those ideas through discussion.

Learning environments

Instructionist teaching has been criticized on many grounds: for its presentation of science subject matter as ready-made and here-and-now with little sense of history, for its problematic nature, its failure to engage students in deep learning, its failure to connect with students' everyday lives, its neglect of aesthetics, its positioning of students in powerless situations, its alienation of girls from physical science (e.g. Fensham, 1988; Kelly, 1987). To offset these trenchant criticisms we have added to natural learning a view of a learning environment in which we do not make assumptions about genetic and developmental limitations of learners. Nor do we contrive the outcome; we do not have an agenda that children will discover what we have in mind. Rather we wish to promote interactions amongst children's ideas, the materials of a concept (e.g. mirrors, lenses, lights etc) and teachers' ideas. The essential criterion is development, helping children to develop their ideas, thus keeping their intuitive knowledge plastic.

Choice of topic

As we state elsewhere, (Segal & Cosgrove, 1993), a major reason for choosing Light as a topic of study is that it can lead to understanding a sense. Children should be assisted to learn about how they gain information about the world. In addition, the topic is gender inclusive, (Smail, 1987) and is of importance for later science discipline learning.

Our choice of topic is also governed by the paucity of Australian classroom research in physical science education. Little is known about how young Australian children develop their ideas about light in classroom studies. Neither are findings reported about how children continue to develop and test their ideas in group conversational interviews that are derivative from classroom studies. Lack of detailed knowledge about how American children develop their ideas and theories in classroom about phenomena that are not directly observable is also reported by Brickhouse (1994). Our study is one of a preliminary set of studies of young children learning about light (Segal, in progress; Segal, 1994, March; Segal & Cosgrove, 1993; Segal & Cosgrove, 1994) that describes such learning.

RESEARCH DESIGN

This research took place in an elementary school (with which our University was linked in a number of programs) in a middle class area of a large city. As part of one program, three qualified student-teachers (interns) taught classes, thus allowing the class teachers to collaborate in research into classroom learning about light (first in collaboratively writing a unit on Light with us, secondly in permitting study of the learning in their classrooms while the unit was in progress). Classes involved were Year 1/2; Year 3/4 and Year 4. Part of the design involved visiting teachers' classrooms at least once a week, from the beginning of the school year to become acquainted with the children and with classroom procedures. While the unit was in progress, there were about 11 sessions for each teacher, with each session lasting from one to two hours.

Alongside this development we had provided a year-long whole school inservice program, to introduce teachers to a view of learning which encouraged children to generate and seek answers to their own questions about events that interested them (Biddulph & Osborne, 1984; Faire & Cosgrove, 1988). The value of this approach is that it allows children to create their own questions, to share publicly expressed questions, to articulate ideas and then to follow their interests in exploring and inquiring into answers to questions selected from those they and others asked.

Just as our view of learning is naturalistic, so too is our research paradigm after Lincoln and Guba (1985) and Erickson (1986). Our data came from:

1 Observations, conversations with children and descriptions of children's activities in the classroom prior to the research (audio recordings and field notes).
2 Descriptions of the processes of the collaborative curriculum design and unit writing (audio recordings and field notes).
3 Descriptions of teachers' interactions with the whole class; of participant observer interactions with small groups before, during and after unit; of class teacher interactions with small groups; of a parent helper's interaction with small groups, of small groups' interactions without adults present, of children interviewing each other and their teacher (audio and video recordings and field notes).
4 Children's written records of ideas, conveyed in prose and drawings.
5 Conversations with class teachers and school principal (audio recordings and field notes).
6 Conversations with other researchers after viewing videos and listening to audio tapes during and after the research period (audio recordings and field notes).

Due to our university teaching commitments, the intervention of school holidays and the university inter-semester break, we requested that teachers teach the Unit in two parts, as otherwise we would be unable to be present in their classrooms. Teachers readily agreed. During this enforced gap, they presented a unit on electrical circuits - one of the areas discussed in the whole school inservice program. Therefore, between sessions 4 and 5 (see Table 1), there was a gap of two months.

This paper describes some of the learning in the Year 3/4 class (ages 8 - 10 years). Some findings relate to descriptions of general reactions of the class, others focus on individuals or groups. The story of children's understanding of reflection is told through a narrative theme using the process described by Erickson (1992). In this process, lessons are first broken into self-contained segments which are then reconstructed to make a coherent theme or story. By reviewing all videoed lessons and audio-taped conversations, we chose segments that together made up an investigatory theme about reflection.

COLLABORATIVE WRITING OF UNIT

During collaborative planning sessions prior to the teaching (eight sessions: 22 hours), we worked with three teachers to clarify their understanding of some basic properties of light (propagation, formation of shadows and reflection), discussed ideas children may hold (Andersson & Karrqvist, 1983; Feher & Rice, 1988; Guesne, 1985) and devised learning sequences with an emphasis on inquiry in which these properties of light were embedded. Prominent among introductory activities were those that assisted children to clarify their ideas on whether and how far light travelled, on how shadows were formed, on what was meant by reflection, on the kinds of materials that reflected light, and to guide children towards the idea that light entered their eyes. These concepts embed the key concept about light (that light is an entity that travels in space) (Andersson & Karrqvist, 1983) usually overlooked in the curriculum as teachers start with its straight-line propagation. Understanding this fundamental concept about light is said to be a pre-requisite for understanding reflection, and understanding reflection is said to be a pre-requisite for understanding vision (Guesne, 1985). The information that most children do not understand how they see, even after studying light (e.g. Anderson & Smith, 1984) underpinned the decision to frame some activities to culminate in gaining understanding of vision.

During the planning, we developed activities that could reveal children's ideas about shadow formation and discussed general ideas such as making models of a room to show where children thought light was in the room, how it entered, and whether it ever left. Unfortunately, as later events were to reveal, we did not have time to develop strategies for ways of introducing and developing learning in all topic areas, and did not develop teachers' understanding about the eye. This was to affect the Year 3/4 teacher's decision not to introduce any discussion about the eye at the end of a sequence of activities designed to show that light enters our eyes. Hence our envisaged culminating activities did not eventuate.

We devised the Light Unit to be flexible, with wide-ranging topics nominated for inclusion (as it was being written for implementation in classes ranging from K-6) and made suggestions about how the science activities could be integrated with other subjects. This was an important feature of the Unit, as in Australian elementary schools, science has been regarded as an unimportant subject compared to mathematics and English and is either not taught, or is relegated to a small amount of teaching time in the afternoon (Cobbin, Bingle, Brown, Greenaway, Hughes, & Willis, 1989; Speedy, Annice, & Fensham, 1989). The teachers' strong desire to make the Unit an integrated one helped them to justify devoting large sections of time to it, as they perceived that children's language skills were developing through their science discussions and writing. We decided to present children with a special exercise book, a Light Log, for the Unit. This was to personalise their written record of learning.

Purposes of Light Logs

For children, constructing a personal chronicle of learning would enable them to keep a continuous record of their ideas. This would allow them to inspect how their thinking developed during their study. The Light Log could help them to tinker with their ideas, to realise that their ideas are fluid and that it is normal for peoples' ideas to change as more experience is taken into account. The Log would also serve to remind children that their ideas were valued per se and not, at this early stage, for their match with scientific thinking. Ideas could be represented in ways which were most convenient and enjoyable for the child, so that recording as drawings, paintings, flow charts, stories and feelings about all of these, were to be encouraged.

For teachers, the Logs would provide a record of children's ideas as they were being generated. Teachers could use this record to stimulate conversations with children about their ideas and about aspects of lessons the children found to be interesting, exciting or boring. Teachers could gauge children's understandings in this way and, as well, could be in tune with children's feelings. Provided teachers encouraged children to record their ideas, and especially any changes to their ideas, teachers would have a developing record which could be used for reviewing the learning and evaluating their own teaching.

We developed a proforma that was duplicated and attached to the inside cover of the Light Log. The proforma consisted of a number of sentence beginnings from which children could choose, if they wished, to begin their record of what happened. Completing sentences has been shown to stimulate thinking and evoke affective responses (Head & Sutton, 1985). Its contents included:

Today, I...
I think that...
I felt...
I would like to know...
Next time, I would do some things differently. I would...
I had problems with...
My drawing on this page shows...

LESSON DEVELOPMENT

The beginning

We began the unit with a display of lights in an activity room. Parents of one of the children owned a lighting shop and they brought in a large panelled board set up with electric lights of all descriptions and colours. We supplied an assortment of equipment, decorative materials, posters, coloured cellophane paper and laser paper. The room was filled with a variety of large and small pieces of equipment - many kinds of electric lights, large and small mirrors, mirrored balls, flashlights, kaleidoscopes, magnifying glasses, stroboscope, candles, sparklers, chemical lights, solar cells, Christmas tree lights, books about light and colour, etc. There was a dark booth in which we had placed some fibre optics torches and luminescent displays and a television showing a children's program about lights and vision. The children could play with any of these and examine whatever they liked. For children who wished to queue to enter the dark booth, we provided activities while waiting.

Table 1: Lesson sequence for Year 3/4

Session	Main activities
1	Visit to Light Room display. After exploration, a class discussion on sources of light and how they might be classified. Children wrote about feelings and impressions in their Light Logs.
2	Revision of sources of light during class discussion, then conference with neighbour to share lists. Teacher asked the questions, "Where is there light in the room?" and "How does light get there?" Teacher turned off electric lights and asked same questions. After discussion, children recorded as a drawing their understanding of light in the room in Light Logs. Children independently and informally explored properties of light using flashlights and small mirrors. Teacher turned off electric lights and asked children to shine their flashlights up to ceiling one at a time, to land on the same spot. Teacher asked for children's observations and then asked them what they thought would happen to the light if the ceiling were not there.
3	Children continued to use flashlights and mirrors (small and large) to carry out more spontaneous investigations of their own. Teacher challenged children to send a light message using the flashlights. Individuals and groups were asked to tell class what they had been investigating and what they had found out. Children made entry in Light Logs. Part of homework was to plan an investigation to check any ideas raised in class.
4	Children reported findings from homework assignment to class - they were mainly about how far light travels and whether it reflects from substances other than mirrors. Children drew their ideas about sight in Light Log (an activity designed to investigate prior knowledge). Teacher challenged children to see if they could arrange mirror(s) to make the light turn through a right angle (a prelude to being asked to design a periscope). Children presented and explained their solutions to the class. Children drew what they had done in Light Log and teacher also asked them to write a sentence explaining their drawing. *School commitments prevented the next lesson from taking place until after the two month break.*
5	Children were asked to design, then build a periscope so that light from the outside could enter their eyes. The children were to kneel beneath the window to use their periscope.
6	Teacher told children they would have a short time to fix up their periscopes before demonstrating them to the class. Most children made major changes in design, so this took the whole lesson.
7	Children demonstrated periscopes to class.

8	*(Here teacher indicated she did not want to open up any activities that led to understanding vision (e.g. discussion of model of eye.)* Varied activities. Children wrote in Light Logs how they thought shadows were formed. Some children began investigating shadow formation outside. Two girls, built a disco (under a table, using large mirrors, fibre optics torches and large cloths) inside the room adjacent to the classroom, with everyone else instructed to stay out. Visitors were then allowed in two at a time, with a third girl monitoring the door, 'selling' tickets.
9	Class discussed shadow formation and examined shadows from spot lights in the school hall.
10	*Lesson cancelled as teacher involved in school swimming activities.*

FINDINGS

Children initiated and participated in many conversations and activities during class and in small group interviews during and after the unit. They discussed their views, capably planned and reported upon a range of questions suggested for their investigation, orally, in writing and by diagram. Conversations led them to generate and test ideas them by examining the implications of holding them, through experiments and discussion in true Galilean style (Medawar, 1969). They keenly recorded ideas and drawings in their Light Logs, critiqued the unit after its conclusion and gave us insight into some social interactions which can affect learning (for example, the problems of new entrants). In summary, we found that:

1 Children enthusiastically entered this learning environment; many sophisticated questions were generated and tentative explanations put forward without prior training in these so-called science skills.
2 Children solved problems of design (for example in designing and building periscopes). As there was no defined agenda there was plenty of time, thus enabling children to generate highly original solutions to traditional problems.
3 Children raised many subtle and penetrating questions, often about puzzling matters such as the nature of reflection from mirrors and other surfaces.
4 Children disputed evidence about what they had seen of objects, (other than mirrors) reflecting light and some children articulated fluently their beliefs in testing and retesting to check experience.
5 Children used the materials to create their own contexts. For example, some built simulated discos from large mirrors and fibre - optics flashlights and then suggested solutions to the puzzle of multiple reflections. Other groups modified contexts in ways that some might construe as gender specific. Some groups of girls painted and camouflaged their periscopes to incorporate them into narrative stories or otherwise just decorated the periscopes; no boys did this. Some boys used little toy soldiers to construct warfare stories; girls used these particular toys as objects for shadow formation and reflection.
6 During conversations about their views on the unit, some children informed us that allowing them to solve problems in any way they wished was not taking matters far enough - they wanted to solve problems that no other group in the class was tackling. We accept their point as an indication of their success.

The Light Room and writing in Light Logs achieved their purposes and we describe children's reactions to these items first. Discussion of other findings are limited by space, to development of two themes: one, discussed briefly, children's understanding of light travelling; and the other, discussed more fully, children's understanding of reflection.

The Light Room

The class teacher, Ms. S., had not given children any hints that a special room had been prepared. On entry, children expressed wonder, with some gasps and wide eyes, as their teacher explained that they could examine anything that they liked. She then lit the candles and sparklers. Children smiled and exclaimed in recognition of present and past enjoyment, as they examined the fibre optics flashlights, and the sparklers. Many conversed in detail about prior experiences with each.

Boys immediately joined the queue for the booth - perhaps the mystery appealed, but girls spent more time playing with mirrors and flashlights, queuing later. Comments in Logs were enthusiastic, without exception.

> It was very fun and exiting (sic) to find out what was in the big box. I liked that the best and the lights in the glass that went on and off. I liked all of it relly (sic). (Katy, Year 3)

Eleven children chose either to pose questions in addition to their positive comments, or wrote a sentence stating what they would like to know.

> Everyone was excited about something they had never seen before. There were lots of things to do with light. There were flashlights, Disco lights, mirrors, dark little box. I liked the sparklers because they make a big spark for a minute. How does a mirror work? (Shane, Year 3)

In lesson 2, children now used the term 'light sources', in their conversation, recalling the varied sources they had observed in the Light Room. Through class discussion, they expanded their list, including sources ranging from light from a volcano, to the tiny red light on the video camera that signified the camera was recording. (The use of the term light source was deliberate, to try to help children, through natural use of language, to differentiate between light and its sources and effects.) Also in discussion, children justified their ideas when challenged by other children, with some disagreements about whether reflective surfaces such as a moon and mirrors could be called light sources.

Light Log

Children readily wrote and drew in their Logs. The careful drawings, personal Log comments, conversations with children during class and final interview conversations revealed that they enjoyed this activity. Ms. S. regularly read the Logs after school, and she wrote comments, or asked children questions about the drawings. Many children, in turn wrote answers to her questions in their Logs, so that the Light Log became yet another dialogic forum through which children could establish their ideas.

All children were keen to choose their favourite page when asked to talk about their Light Logs in final interview conversations, and revealed that they recalled in detail, the nature of the activities they had recorded. They had varied reasons for their positive reactions to keeping a Light Log. For example:

Gilda: How did you like writing in your Light log book?
Matt: It was fun actually. I like keeping the information somewhere safe. Like it's not only in my mind, I might not remember it.

Most children asked Gilda if they could take their Light Log home at the end of the year. We infer from this and from comments like that of Matt, that children placed high value on the activities and conversations in which they engaged during the unit. The intellectual nature of those activities and conversations will now be made clear.

How does the light get into the room?

The discussion on light sources at the beginning of lesson 2 set the scene for the introduction of what Guesne (1985) has called a pre-requisite for understanding optics, that light is something physical that travels in space, dissociated from its source and effects.

Children's ideas

Having established the meaning of source, Ms S. asked the children to tell her how they thought light "got into" their room. The class rapidly settled on the idea that light came from two sources - the sun and the electric lights that were on at the time. Ms. S. turned off the electric light and repeated the question.

Ms. S.	So the lights are going off. Where's the other source of light? *(Many children called out their answers)*
Jean.	From the window.
Ms. S.	So if I covered the window, would there be any light? *(The children seemed to ignore the idea of the covered window and proceeded with the previous question, discussing how the light entered the room.)*
Jim:	The wind could blow the light here.
Ms. S.	If the wind blows the light here, where is it coming from?
Child:	Outside.
Matt:	It could be reflecting from that shed. *(A shed was adjacent to their classroom, and could be seen through the windows on one side.)*
Ms. S.	What does reflect mean?
Matt:	Bounces off.

This excerpt from class discussion is included here for two reasons: First, it marked the first public use of the term reflect, with Matt defining reflect in an active way, implying movement of light from the shed to the classroom window. Second, it indicates a possible source of many children's later tacit acceptance of the idea that light travels as it bounces off mirrors.

Most children's drawings showed light from the sun (shown by straight lines, jagged lines or a shaded beam) directed through the classroom windows. Their explanations were simply expressed, for example: "The sunlight goes in the class and goes everywhere" (Steve, Year 4); and "The sun comes down throw (sic) the window an (sic) lights the room" (Alex, Year 3). A few children did not indicate through their drawings the idea that light travels. These drawings showed the entire outside area and the classroom bathed in a sea of light.

Matt and four other students used his idea and drew diagrams showing rays from the sun bouncing off the shed and into the classroom. One student (not Jim) drew light coming part of the way from the sun, with the wind taking it the rest of the way to the classroom, while one child incorporated the sun, transmission wires and reflection in the drawing. Her written statement was: "The sun reflects onto the electric wiers (sic) and the wiers are conected (sic) to our lights" (Kathy, Yr 3).

The dialogue about how light might enter the room, used by Ms. S. in the lesson 2, was pre-planned, following suggestions by Andersson & Karrqvist (1983) that children seem to have no difficulty with the concept that light moves in some way from the earth to the sun. Responses from children in the class, both orally and through inspection of their Light Log diagrams, supports the suggestion that this is a useful way to introduce the notion that light travels. At this early stage of the unit, it was not clear whether children believed that light was travelling in the room. By the end of the unit, some were beginning to develop that idea and to consider the consequences of holding it.

A conversational context for developing the concept of light travelling

In many end of Unit conversations, children conversed freely, listening to each other and interrupting to explain a differing point of view. The conversation reported below with two boys was different, in that Matt and Simon did not interact with each other, only with Gilda. The conversation has been chosen to illustrate the role of a conversational style in developing children's ideas, in this case, about light travelling. As Gilda had not seen the children during the two months between the end of the unit and final small group conversations, she drew children into conversation gently by asking them to show her their favourite page in their Light Log and to tell her about it.

Matt:	This is my favourite. It shows the sun going into the room. Well the sun, it shines down from here, and reflects on the shed that's next to us and goes through into the window and shines. It keeps on going round the room, there is more sun staying there and blocking up the way to go out, and it sort of heats the room up as well.
Gilda:	Yes, so how do you - so you think the light is coming down from the sun, bounces off the shed.
Matt:	Yes, and then going through the window.

Gilda: Yes, and then what happens to the light?
Matt: It just circulates round and round.
Gilda: Oh, right, what, just in the middle of the room?
Matt: Well, all around the room.
Gilda: Yes. Does it hit anything?
Matt: No.
Gilda: No. That's interesting. And what ..
Matt: It might hit like mirrors and stuff.
Gilda: And do you think light is moving all the time then?
Matt: Yes, it could be.

In choosing that page of his Light Log, Matt readily interpreted his diagram, clearly recalling what his diagram meant to him at the time and expanding a little on his written version by explaining how the room might heat up. His diagram does not give any hint of his idea expressed here, that light circulates. When Gilda asked if the light hit anything, he was able to incorporate his ideas on sunlight being reflected from the shed, that light from the sun "might hit mirrors and stuff". Gilda's next question, with the qualifier "all the time" was a difficult one. Hitting mirrors may not stop light moving, as Matt already had expressed the idea that light bounces from objects, but what happened to light when it hit other objects could have interfered with his claim that light was circulating. Matt paused before answering that question and his answer was cautious, symptomatic of the weighing up of alternatives that were opened up by the question. Later in the conversation, (reported below in a later section) it appeared that he had carried out spontaneous investigations at home, to find out if objects other than mirrors reflected light and had made up his mind that they did not.

What happened in the conversation with Matt was illustrative of many final conversations. Children not only recalled exactly what they had done or said in class, but articulated understandings during the course of the conversations that were either new or previously tacit. They readily participated in discussion about abstract ideas, seemed interested in the intellectual nature of the ideas, and gave them due consideration before answering.

Some tales

A story of reflection from mirrors

In lesson 3, children had access to flashlights and mirrors of varying sizes (many were small and hand held but some were nearly as tall as the children) and were free to carry out any activities they wished. Gilda moved around the room talking to children about their explorations and ideas. Many children excitedly showed her how light shone at a mirror "reflected" or "bounced off" (terms used spontaneously by the children) onto their faces or onto other surfaces in the room. Some indicated that they were surprised when this happened the first time. They enthusiastically took up their teacher's suggestion, later in that lesson, to send a light message around the room.

Comments in Light Logs were varied. Some children reported what they had done using text and labelled drawings; some used the sentence beginnings to indicate how they felt or what they would like to know. Children who included comments about reflection, used the term reflect, rebound or bounce. Examples include: "When you shine the flashlight on the mirror it rebounds back." (Catherine, Year 4) "Steve and I made the sun reflect off the mirrors and we used the flashlights to reflect as well. There were three flashlights. The sources of light we used was (*sic*) the sun and flashlights." (Andy, Year 4)

In lesson 4, children accepted a challenge from their teacher to try to make the light turn through a right-angle. These activities were based upon tasks that Piaget (1974/1978) and later, Osborne, Black, Smith, & Meadows (1990) devised. Some groups found the task difficult, but everyone succeeded in changing the direction of the beam of light. Some used elaborate combinations of mirrors to direct their beam into predefined places. It seemed that in moving their mirrors and angling the flashlights, many children were tacitly acting and building upon knowledge, empirically constructed from free exploration in the preceding lesson, that light bounces from mirror surfaces, and hence, light travels.

The children then sat in a circle, watching as each successive group indicated to the class how they had successfully manipulated the flashlights and mirrors, both large and small to make light turn a right-angled corner. When the final group arose, they offered a different solution to any previously demonstrated. They brought two large mirrors to the centre of the room and directed the light from the flashlight towards the carpet, between the mirrors. They explained to the class that the light from the flashlight could now be seen in the mirror and hence, it had turned a corner. Their teacher recognised the opportunity to extend their thinking.

A story of reflection from carpet

During our collaboration prior to teaching, teachers had been made aware that educators and researchers for example, Eaton, Anderson, & Smith (1983), strongly recommended making explicit the role of light reflecting from all objects as a preliminary to children's understanding of vision. At the same time, through the year-long inservice program, teachers had developed understanding that merely telling the children these abstract ideas had been shown to be a relatively fruitless procedure. The value of elementary teachers having an understanding of these research findings, and thus being able to readily; but subtly act upon ideas introduced into the class by the children is illustrated below by the question Ms. S. asked the children after they had demonstrated their successful solution to the problem.

Ms. S.	So how come if you're not even shining the torch in the mirror, it's being reflected in the mirror?
	Rachel attempted to answer, but many children were eager to answer too.
John:	Because it's hitting, it's bouncing off the mirrors.
Ms. S.	Even though you're not shining the torch directly in the mirror?
Janey:	It's bouncing off the mirror.
Ms. S.	*(to class)* Can you answer this question? John isn't shining the torch directly on the mirror. He's shining it in between. How come it's going on the mirror?
Jim:	Cos it bounces.
Ms. S.	From where? He's not shining it on - Where's it coming from? Emily?
Emily:	*(inaudible)* It bounces onto the sides.
Ms. S.	So it still bounces onto the sides. Who agrees with that? *(many children raise hands)*
Ms. S.	So what does that mean?
John:	Cos when you look into a mirror, you can see your face. So like, you can see the light in the mirror all the way, so then when it gets to that mirror *(pointing at one of the mirrors)* then it goes to that mirror *(pointing to the other mirror)* and then it goes to that mirror again, so like it's bouncing off the mirrors.

In the discussion so far, Ms. S. has raised a puzzle about how the light is seen in the mirror if it is not directly shone into the mirror. Children who have contributed, use the term bounce, but it appears that full understanding of reflection for some children is incomplete. As John explains, when a person stands in front of a mirror, the image of the person is seen. He therefore does not need to invoke the step, sought by his teacher, that light from the flashlight must have bounced up from the carpet in order to be seen in the mirror. Once the image is visible in one mirror, John then explained that the image bounces backwards and forwards between the two. As noticed and commented upon by other researchers, (Guesne, 1985) children's thinking can be driven backwards when it is dominated by their perceptions. Here, John is able to call upon the bouncing metaphor for reflection of light from mirrors, but this analogical thinking is driven backwards by the perception that the light from the flashlight appears to be stationary on the carpet.

The class was attentive and leaning forward, with many children eager to contribute. Ms. S. continued:

Ms. S.	Yes I think that's interesting. So you don't necessarily have to shine your torch directly onto the mirror. Did you realise that?
Rachel:	The mirror can reflect off to see the ground and when you shine it onto there.. *Gilda could not quite believe what she heard, and interrupted to check.*
Gilda:	The mirror can see the ground? I am a bit puzzled. *(Although Gilda rarely interrupted a class discussion, Ms. S. and the children, by this time, were comfortable about her presence in the*

classroom and the discussion continued for a short time between Gilda and the class). Several children attempted to explain. Gilda chose to listen to Jenny, unfortunately forgetting that she had interrupted Rachel.

Gilda: What did Jenny say?

Jenny: If you shine it [light from the flashlight] onto the ground and it [the mirror] might be tilting a little, and if the mirror is tilting a little over that, so it's [the light from the ground] going over that. *Jenny accompanied this explanation with gestures, showing that she meant the light from the flashlight moved from the ground to one of the mirrors and then across to the other mirror.*

Gilda: So the light is going onto the mirror from the ground - that's what Jenny thinks.

Rachel: No.

Molly: Actually I reckon it's the mirror that makes the light shine onto itself. You know how the mirror makes you see yourself. The mirror is looking at the flashlights and it can show the light. It can also show the flashlight so you can see the light in the mirror.

Gilda: How does the light get into the mirror?

Molly: The light is on the ground, but the mirror is like shining onto the light and that's why it looks,

Mary: The mirror can see everything that's in front of it, so it would be able to see the light. That's what I am trying to say.

We do not interpret the animistic form of expression used by Rachel, Mary and Molly as meaning that they literally assumed that mirrors are active viewers of what is in front of them, in the same way as people view objects. Rather, to us, this form of expression seems to indicate that these children, having rejected consciously or unconsciously, the explanation that light can bounce from the ground to the mirror, are left with an explanation of the mirror as an object that renders objects in front of it visible. This explanation is reminiscent of that reported by La Rosa, Mayer, Patrizi, & Vincenti-Missoni (1984) about 10 of 63 secondary students aged 16 or 17 tested with pen and paper questions. For those students, "the rules of reflection are rules that relate to objects but not to light, except that reflection cannot be observed except in the absence of light" (p. 393)

Many children were ready to contribute to the conversation, but John and Jim, better positioned in the centre of the class through ownership of the experiment, continued building upon what had been said previously.

John: When you look into the mirror, you can see yourself in there, cos when you shine something not in the mirror, you can still see.

Jim, apparently not realising that he was about to say something different to John, began his contribution, as though he were simply adding to John's idea.

Jim: Because the mirror, the, it's [the light] facing down and one mirror is at an angle which will like, when it's in an angle, it [the light] will bounce into that [the mirror] and it will keep bouncing down. *(Jim's explanation was also accompanied by gestures that indicated the path of the light. Jenny recognised his explanation was the same as hers.)*

Jenny: That's what I said.

Gilda: So you've actually got the light bouncing from the ground into the mirror?

Jim: Yes, because it's angled.

Jenny: You can shine the torch onto that one, then it will go there and then it will go there. *(Again accompanied by gestures indicating that she meant the light had to first bounce up from the carpet.)*

Opinion in the class, when Ms. S. asked for a show of hands, was divided, between those who agreed with Jenny and Jim, that the light would need to come from the carpet to the mirror, and those who disagreed. Examination of children's facial expressions, nods of heads, thrusting of arms in the air seemed to indicate that one or other of these ideas resonated with most children. In view of Guesne's (1985) research that indicates how firmly young children's views are dominated by their perceptions, it was a little surprising that many children agreed with Jenny and Jim, that light could bounce from the carpet to the mirror and that many accepted the explanation first generated publicly by John, that light bounced from mirror to mirror.

This conversation, and the interest and enthusiasm with which children joined into it, bears closer examination. Here are children aged from eight to ten years generating ideas about the behaviour of light, an abstraction whose effects only are visible. Like scientists, they attempted to make predictions and justify their ideas, as they offered them for scrutiny by peers. Thus Jim explained that the mirror needed to be angled downwards, if light from the flashlight were to reach it. (Although this condition was not pursued, it could have led to a test that called for straightening of the mirror. Further consideration and deliberation could have produced another significant idea, that light travels in all directions from the flashlight, not preferentially, as Jim appeared to assume.) The keenness with which children were following the exchanges is shown by Jenny's rapid assessment that Jim advanced the same idea as she did herself.

However, closer interactions with one group of Year 4 children, Narelle, Rachel and Anna, revealed that, for Narelle (and perhaps Rachel), this class conversation may have been too late. In contrast to the ease with which Jenny and Jim theorised that the carpet reflected light, Narelle and Rachel rejected firmly the idea that paper could reflect light. Perhaps their ideas on this subject were no longer plastic, and therefore less easily subject to scrutiny and change.

Story of non reflection from paper and cardboard: Part one

During individual and small group explorations in lesson 3, Narelle, Rachel and Anna were shining a flashlight into a large mirror and observing the reflection on a white covered book held in front of the mirror. Rachel explained to Gilda what the group was doing.

Rachel:	We're getting the flashlights and getting them on the mirror, and say you had the book like this (*holding the book up about one metre in front of the mirror*), reflecting off the mirror onto the book,
Gilda:	And what's actually doing the reflecting? (*not quite understanding what she meant).*
Rachel:	This mirror.
Gilda:	What's actually coming off the mirror?
Rachel:	A reflection.
Gilda:	A reflection.
Rachel:	The light.
Gilda:	And you said it's hitting the book.
Rachel:	Yeah.
Gilda:	And what happens then?
Rachel:	Nothing.
	As already stated above, research indicates that children's perception that surfaces other than mirrors do not reflect, blocks later understanding of vision (Guesne, 1985). Gilda took an opportunity to try to develop the girls' thinking about reflection from paper.
Gilda:	Say I said to you that I think the paper reflects too. Can you work out a way of proving me right or wrong?
Rachel:	Yes, because the paper doesn't reflect.
Narelle:	Yeah, because the paper doesn't reflect like a mirror does.

The reply given by Rachel and Narelle is a reminder of the way some students view knowledge as being driven by the data at hand and perceptions. According to Carey & Smith's (1993) classification, this is an example of a constructivist epistemology they call knowledge unproblematic; both girls have justified their belief in terms of their perception.

Gilda then raised the possibility with the children that the mirror may be a different type of reflector than the paper and that therefore, they may need to plan how to detect any reflection from the paper more carefully. The girls briefly tried holding a white screen closer, to detect any light reflecting from a piece of paper and claimed not to notice anything on the screen. Still highly certain that their paper did not reflect light, they nevertheless decided to test the idea in a darker place. The three girls moved into the adjacent room, next to their classroom. They asked Gilda if they could borrow the camera to video their experiment. The girls carried out the following in the absence of adults, with Anna videoing proceedings.

Narelle and Rachel set up the experiment with two pieces of paper and a large mirror. They used the mirror as a support for one piece of paper, the possible reflecting surface. The other piece of paper acted as the screen. Anna interrupted, telling them they had to first explain what they were trying to do.

Rachel: What we're trying to experiment is that Mrs Segal thought that as you bring the paper [i.e. the screen] closer - she thinks that if we bring the flashlight closer to the paper and put paper [i.e. the screen] behind it, [the flashlight shining on the paper] she thinks it [i.e. the screen] gets brighter, but we don't think so.
Narelle: Yeah, we don't think so.

In this exchange, Rachel and Narelle again repeated their expectation of their findings. It seems clear that they are convinced that paper does not reflect light. The paper that they placed on the mirror was very thin and Narelle commented that she could see the light on the mirror through the paper. They therefore decided to replace the thin paper with white cardboard. Rachel took up the commentary.

Rachel: OK now we're going to try putting cardboard on the mirror. Now Narelle is bringing the paper [i.e. the screen] closer and closer, right in.
They both turned their heads and briefly looked at the paper screen.
Rachel: No, I'd say it doesn't work on the cardboard.
Narelle: But hang on - if we put that there *(she changed the position of the flashlight and shone it on the paper screen. The video clearly shows the reflected light from the paper on the cardboard, that now acted as a screen)*
Rachel: No, I don't think it works on paper. *Rachel and Narelle continued, trying out some green paper, and also concluded that the green paper did not reflect.*

The story so far raises several questions. Did the girls feel they had a vested interest in proving their original idea (that paper does not reflect light) to be correct, as a means of triumphing over Gilda's idea that paper does reflect? This cannot be discounted. Gilda tried to put forward her idea mildly, to defuse any idea of a competition between respective ideas, but the girls may have felt an allegiance to their own belief for this reason alone. Next, was Gilda's decision, to encourage the girls to experiment in the absence of adults, as useful as if she had stayed with the girls? Evidence is equivocal on this point. Prior to the girls' moving to the adjacent room, Gilda had tried to ensure that the girls understood that their previous results may have depended upon their expectation that the paper would reflect in the same way as a mirror. Before they left the classroom, they had rehearsed with Gilda where they might look for a reflection from paper, but decided that their classroom was too well lit. Their experimental method indicated that they did understand this point, as they correctly looked for the reflection, and brought the screen closer and closer, to try to find it. However, perhaps the presence of another independent observer was needed to step in at the critical stage where the reflection was observed, yet denied.

The three girls came back into class in time for small groups to share findings. They showed the class what they had done and reported that they had found that paper and cardboard do not reflect light.

Story of non reflection from paper and cardboard: Part two

Before resumption of the unit two months later, Gilda conversed with many of the children to find out their ideas and feelings about the unit. Conversations were different with each group, dependent upon their previous experiences in class. As with other small group interviews, equipment was present and children experimented with it, as they conversed. Gilda vividly recalled Anna, Rachel and Narelle's certainty about the results of their experiments concerning reflection of light from paper, and was uneasy that the girls had cemented an incorrect scientific idea. She was also curious about what they now thought about paper reflecting. After about five minutes, she brought this up while the girls were shining their flashlights at the ceiling.

Gilda: You know what I am suddenly reminded of? Do you remember our discussions where you said that you didn't think some things reflect there.

Girls:	Yes.
Gilda:	Have you changed in your minds about that?
All:	No.
Anna:	No. Paper does not reflect.
Gilda:	Paper does not reflect.
Rachel:	Only if you hold the mirror in your hands, the paper shines. It reflects off the mirrors onto the paper.
Narelle:	It reflects off the mirror onto the paper.
Gilda:	Onto the paper.
Narelle:	But the paper cannot reflect because it is not a mirror.

Not only did the girls recall their experiment, they were quite certain of the meaning of their experimental results. Gilda let the subject drop. The conversation then became very extended, as the three girls (especially Rachel) became intrigued with how light from a large flashlight could apparently travel up to the ceiling, in spite of the fact that she had a (small) mirror over the top of the glass. Their speculations about their observations and the many questions they asked each other were quite breathtaking. Their willingness to consider a variety of explanations seemed to contrast with the fixed ideas that they had about light not reflecting from objects other than mirrors. Eventually, this subject arose again.

Gilda:	I just saw something that I was interested in before and I think I could. Look, Narelle, if I shine that at your jumper there, if I put something in front will it bounce off your sweater?
Narelle:	No, hang on, yeah, it does! There it is there. So that works.
Gilda	So it is not just the mirrors that will reflect light.
Anna:	Oh, golly!
Rachel:	Gosh.
Gilda:	Yes, that's a puzzle. I think we have done quite a lot of working out. *(Again, Gilda did not want to press the point, as she had no wish to alter the atmosphere that the girls had created through their questioning and experimentation).* Can I now just ask you a little bit about what you think about having to work all these sorts of things out? Do you like doing that?
Rachel:	Yes.
Gilda:	But what about when you don't get answers?
Narelle:	Well we just have to test it and if we get different answers each time we have got to try and work out what one is the right one.
Rachel:	See, we've got to see,
Narelle:	If we get three different answers out of three, and then we do it again but we get one of these answers again, we will probably know that the answer that we got the first time and we got it again, that's right.

Narelle here articulated a very important feature of scientific investigation, that of repetition. This was surprising as children had not discussed this in class. It was also rather in contrast to the way in which she and her friends were not prepared to tolerate any possibility that their previous experiment with paper could be subject to change.

When it was time for the next group of three (John, Jim and Mike) to be interviewed, the girls asked if they could stay in the room. They showed the boys some of the puzzling observations they had made. After preliminary conversation, the boys began to experiment with the flashlights, shining them around the room, including onto the laminex (plastic) table top. The girls then moved away, amusing themselves quietly in the background.

Mike:	You say it bounces on that.
John:	Yes, because that plastic could reflect.
Mike:	Yeah.
Jim:	But plastic doesn't reflect.
Gilda:	Doesn't it?
John:	But cardboard does.
Mike:	Well this could be going back down.
Gilda:	John said cardboard reflects.

John:	Yeah.
Gilda:	Why do you think that?
John:	Yes, cos the other night I went down with some cardboard down the back and it was really dark and we only had one light on down there, and I could see this light shining somewhere else in a really dark spot, and when I moved the cardboard the light down there moved. I didn't have a flashlight or anything.

Gilda called the girls over.

Gilda	Listen to what John is saying and see if you agree. He said cardboard reflects.
Narelle	Oh,
John:	Well, like it had,
Mike:	It may go through, but not really reflect.
John:	It was really smooth cardboard but, it was really smooth cardboard, like we had this light hanging down and I was moving the cardboard.
Gilda	Let me have Mike and Jim here turning their flashlights off for a minute and just listen to what John was saying and see if you agree with that or not.
John:	I was going down the back taking some cardboard down to put in the recycling bin and I was moving it a bit and there was a light shining down, and I could see this light in a very dark spot - I was just going like that - and the light was moving, in the same direction, but it was very smooth cardboard, very, very smooth.
Narelle:	We did an experiment with paper, to see if paper reflects, and if cardboard reflects, why didn't paper? *(This was said in a tone of voice that disputed the validity of John's observations).*
John:	It was very smooth cardboard,
Anna:	But paper's thin. *(Here Anna may have been trying to resolve the impasse raised by Narelle. The thinness of the paper may have explained its apparent inability to reflect.)*
Mike:	Yeah, paper is thinner.
Gilda	But do you think maybe if Narelle had been out at your place in the dark, it would have made any difference?
Narelle:	I don't think it does reflect.
John:	Well cardboard did.
Gilda	Can you do an experiment for us in the same place, with paper?
John:	Okay, I will take some newspapers down tomorrow.
Gilda:	Are we going to accept the evidence, Narelle, or do you want it done more than once? It has to be really dark John says.
Narelle:	Yes.
Gilda:	So what he was saying was he was moving the paper around - don't forget what you said before about doing things more than once.
Mike:	I bet Narelle's right.

John was reminded of his observations of light reflecting from cardboard, by the suggestion that the plastic table top was reflecting the light from the flashlight (even though his friend Jim rejected this possibility). Interestingly, this was a reversal of the roles taken in class discussion about reflection from cardboard. There John did not agree with Jim's idea that light could bounce from carpet. Here Jim himself does not think that light can reflect from either the plastic table top or from cardboard.

As John was describing his observations at home, he repeated often, that the cardboard was smooth. It may be inferred that he assumed that this smoothness assisted its reflective property. He also indicated why he was sure that the cardboard was reflecting, as when he moved the cardboard, the reflected light moved in the expected direction. This conversation drew Narelle back to consider yet again, her experiment with paper. Once more, she remained steadfast in her opposition to consider any other possibility, this time supported by Mike.

These differing positions illustrate some of the complexities that contribute to understanding the generalisation that objects other than mirrors reflect light. Narelle immediately made the link between the reflective properties of paper and cardboard. She inferred that if one reflected, so should the other. She preferred to believe in her own idea and perception, *in spite of the fact that she had seen and commented upon cardboard reflecting in their earlier videoed experiment and in spite of the very recent observation that her jumper reflected light.* John and Jim, on the other hand, either did not recall, or invoke their previous theory about reflection or non-reflection from carpet in this discussion. For John, his experience of viewing and testing the reflection from smooth cardboard, made that notion certain; for carpet, no such experience occurred. Smoothness of the reflector may have been the essential property and hence other children's ideas that rough carpet could also be a reflector was not recalled or reconsidered. For Jim, the idea that the carpet reflected light, was one step in his multiple-stepped explanation of light appearing in mirrors. He apparently did not generalise from that context that other materials may reflect light. He may not even have extracted from that context, the idea that carpet is a reflector of light under all circumstances.

After resumption of the unit, there was no further mention of reflection of light from objects other than mirrors from anyone in the class. The last time the matter arose was in an end of year interview with Anna and Narelle.

Story of non reflection from paper and cardboard: Part three and finale

Gilda asked Anna and Narelle what they had enjoyed in the unit.

Anna:.	I liked when we all, we all did things together and when we tried experiments, like can light go through paper? or things like that. I enjoyed that.
Narelle:	I just worked out something. Light can go through paper,
Gilda:	Yes?
Narelle:	Or it can sometimes anyway. It depends how strong the light source is.
Gilda:	Yeah and what were you going to say?
Anna:	Remember we tried that out?
Gilda:	Yes.
Anna:	And we didn't think it went through.
Gilda:	And then you found it did or it didn't? Or are you talking about reflection?
Anna:	I'm talking about, you know how we got some paper, like this, I was standing here.
Gilda:	Yes.
Anna:	And Rachel had the flashlight and Narelle was standing next to me. And me and Narelle held a bit of paper up, like this. Rachel put it on and we looked for behind, and we were standing like that and we looked for behind, because behind us there was no light, so,
Gilda:	So you concluded the paper did not reflect.
Anna:	Yeah, but then we tried cardboard, and then we tried a different colour and paper and it worked.
Gilda:	Oh really? I didn't know that.
Narelle:	What?
Anna:	Remember we tried the green and you were there? We tried green and it reflected. I don't know if it were a different kind of paper or what.
Gilda:	Yes. Were you there when they? Yes.
Anna:	Narelle was there.
Gilda:	And do you remember doing that too?
Narelle:	Yes.
Gilda:	And you were a bit puzzled about the green as well?
Narelle:	Yes.

This conversation, led by Anna, refers back to the experiments that the three girls carried out in the absence of adults. Anna was videoing, and must have seen, although she did not comment at the time, that the white cardboard and the green paper reflected. Even Narelle seems to concede now that the green paper reflected. It appears from this extended example, that to challenge children's perceptions and common sense intuitions, many experiences with different materials, time to discuss observations with both adults and peers are needed. This extended example indicates the complexities associated with attempting to change people's ideas on the point that objects other than mirrors reflect.

Home context: Problematic role in development of scientific understanding

The revelation of John's observation of reflection of light from smooth cardboard at home was of interest. It appeared that the combination of a different context at home in which reflection from cardboard was apparent, and conversations at school about reflection could have contributed to his making sense of those home observations. To do this, he needed to carry out informal experiments to validate his theory that very smooth cardboard reflects light. John was one of several children who confirmed, through spontaneous discussion of ideas or experimentation at school and/or at home, the assumption that concepts embedded in the topic Light are personally meaningful to children and can stimulate children to pursue those concepts for their intellectual value.

In the final interview conversation with Matt and Simon, Matt's disclosure that he had initiated additional experimentation at home is another illustration of the way that abstract ideas engage young children. However, not all observations and inferences that children make at home lead to scientific understandings.

Gilda:	You have both talked about reflecting - do you think - and you have both talked about mirrors, or sheds reflecting, do you think everything can reflect, or do you think ....
Matt:	No. Some things can. Walls and dark colours, they don't reflect and some things like carpet, that won't reflect.
Gilda:	What do you reckon Simon?
Simon:	Well, windows don't.
Gilda	Why do you think windows don't?
Simon:	Because there is a layer and you can see through them.
Gilda:	Oh, yes. So what do you think reflecting means? If you had to use another work for reflecting?
Simon:	When something bounces off another. Like light.
Gilda:	Okay. Would it be like a ball bouncing off something?
Simon:	Yes.
Gilda	Okay. And you are pretty sure that these dark things and the carpet don't reflect - did you try that at all or is that what you think?
Matt:	Yes, I have.
Gilda:	Do you remember how you tried it?
Matt:	Well, I shined the flashlight against the carpet and I just saw the [light from the] flashlight lying on the carpet, and I shined it at the brick wall and nothing really happened.
Gilda:	Are you looking for it to be a bit like the mirror perhaps and seeing your image in there?
Matt:	No, if something bounces off.
Gilda:	So did you try and have something to collect the bounce?
Matt:	Yes, I did actually. I had a piece of paper.

Matt had defined reflection as bouncing in the second lesson and his description of his experiment at home illustrates his ability to extend this definition through a prediction of what should happen if objects other than mirrors reflect. We do not have information that indicates why he chose to investigate this phenomenon. It is possible that his investigation followed the class discussion about the carpet in the class room reflecting, or the negative report by the three girls, about paper reflecting.

In this conversation, it is clear that Simon too, uses reflect to mean bouncing. Interestingly, he attempts to apply this understanding to the case of light travelling through a window, and is partially led astray by the perception that windows are clear glass. Simon also reported a home discussion of reflection from objects other than mirrors.

Gilda:	Do you talk much about what you do at school?
Simon:	Yes, sometimes. I get my Mum to think about it. They *(it is not clear who he means here, but he is probably referring to Narelle, Rachel and Anna, as no other group reported this to the class)* tried paper and they.. The paper, sort of reflected. And my Mum didn't know that.
Gilda:	Yes, oh yes. Did you believe that the paper reflected?
Simon:	Yes, I saw it.

If Shane is referring to the demonstration of Narelle, Rachel and Anna, it is certainly interesting that he reports seeing a reflection that they claimed did not exist. The other possibility is that he tried this himself at home, with his mother. Shane's comment that he "gets his Mum to think about it" suggests that he converses with his mother on these matters. This is just the approach to natural learning that Tizard and Hughes (1984) identified and which we too espouse.

We are hopeful, rather than pessimistic, when we hear about children's home theorising, but recognise that conditions at school need to be changed, to take advantage of connections children make between home and school, even though, in the first instance, these connections may reinforce everyday understandings, rather than scientific ones. This issue will be developed in the next section.

DISCUSSION

This research has confirmed our view that science learning at school can be based in natural learning. For the class discussion of reflection from the carpet was one of many which illustrates what we mean by natural learning. Permitted by the extended time available to generate and test their own ideas of how to make light turn a right angled corner, all children succeeded in the task, with one group producing an unusual solution, dissimilar to others in the class and unexpected by the teacher. That learning was moved along by interaction which ensued: children contributing the experimental part of the context and the teacher initiating an intellectual extension of that experimental finding. Guided by their teacher (herself informed by recent research findings about the significance of how understanding of some concepts in light are linked to later understandings of vision, children were given ample time to discuss the implications of their classmates' demonstration. In action, this is the very generate-and-test heuristic which Minsky (1985) described. During this discussion, children expressed their understanding of common-place observations of reflection of objects in mirrors. From this context, it is possible, judging by a show of hands, that tentative understanding that carpets reflect light emerged in about half the class. As important, in our estimation, is our observation that all children were attentive and most wanted to contribute to discussion.

The children's willingness to enter into conversation that allowed them to approach a scientific understanding of reflection of light from objects other than mirrors was enhanced by:

1 members of the class introducing the context through their own experiment;
2 the teacher, (acting upon knowledge gained through our program), being able to ask a critical question, thus beginning a conversation about the abstract property of light embedded in the children's experiment,
3 children being encouraged to state their views, without some of them being rejected dismissively and summarily.

This research has shown that the apparently abstract nature of light concepts is not a barrier to teacher and children holding animated, intellectual and motivating discussions about possible theories that could explain observations. Through natural learning, rather than instruction alone, teachers and children are able to converse about abstract ideas in the same way that they converse about phenomena, by raising ideas and testing them. In these conversations, children need not contend with the additional pressure of having their ideas judged by another (perceived to be an authority) as correct or incorrect *as soon as they are raised*. We contend that these young children have been assisted to keep plastic their ideas about reflection of objects other than mirrors, awaiting further evidence from other contexts.

This finding is felicitous. The nature of reflection in mirrors and of the reflection from objects other than mirrors have been raised as problems to be considered seriously, not taken for granted. Alternative theories, other than those that are perceptually dominated, have been considered, and an assumption of our research is that children are better enabled to re-examine these ideas later, without being constrained by unexamined perceptions.

Gilda's conversation with Matt (on reflection as bouncing) illustrates the potency of children's innate capacities to generate clever theories. However, a challenge for teachers is to find ways of tapping into that outside-the-classroom learning culture in order to shape the theorizing in fruitful ways, perhaps leading to the generation of ideas which scientists would recognise as scientific. This is difficult, we know, for as Brickhouse (1994) has pointed out, certain classroom practices can, and do make this learning inaccessible. However, we and colleagues (Segal & Cosgrove, 1994; Cosgrove & Schaverien, in press) think that this process can be initiated by teachers through extended conversations with small groups of children about every-day phenomena. Through these conversations and the further investigations they will inevitably engender, children's ideas will be kept active and so will not lose their plasticity. The low structure in this type of teaching makes it more likely to be successful than in a highly structured whole-class teaching episode.

This research supports our advocacy of a classroom culture in which there is persistent exploration and development of intuitive ideas by natural learning. This environment substituted the tentative generation and testing of theories for the authoritarian delivery of canonical knowledge, so that both the problematic nature of scientific knowledge and children's innate capacity to learn established a new milieu. While these features are not usually found in elementary school science we did note that the school teachers here had little difficulty in appropriating them.

Towards refining aims for elementary science education

In our research, we sought ways of bringing children's ideas alongside those of scientists without damaging children's existing ability to generate and test ideas that were useful to them. This may mean that it may not be appropriate to introduce all children (and especially elementary aged children) to scientists' theories; a matter which Freyberg & Osborne (1985) have addressed in advocating a progressive set of aims for school science. Above all, we do not wish to damage children's self-esteem in contrast to the way Shapiro (1994) described this for a young girl Donnie, struggling to learn the scientists' views about light. Perhaps the problem for Donnie was that she was introduced to scientists' science too soon, or not progressively. We believe that for elementary school children, there must be plenty of room for the creative and analytical aspects of science discussed by Duckworth (1987). Then, perhaps through intermediate steps (transitional frameworks, Cosgrove, 1995) teachers can guide children into the world of authentic science - the world that Medawar (1969/1982) sees as an integration of imagination and criticism.

SUGGESTIONS FOR FUTURE RESEARCH

To take these ideas further we see a need for longitudinal studies which start (like ours) from an assumption that children can articulate views of physical phenomena early in school. This could be of much significance to those who are trying to understand why so many children are excluded from science.

We propose that this research should be used in conjunction with any similar projects, to identify certain seminal concepts in the physical sciences, with a view to introducing them early in school. Criteria for selection should be:

1. concepts are critical for later understanding of the discipline;
2. concepts should have been shown by previous research, to be very poorly understood, in spite of school teaching and
3. concepts should be capable of being embedded in personally and/or socially relevant, gender inclusive contexts.

The concepts will probably be those, as stated by Ausubel (1968) to be dominated by perceptions related to primacy and frequency of use and thus result in loss of plasticity at an early age.

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REFERENCES

Anderson, C. W. & Smith, E. L. (1984). Children's preconceptions and content-area textbooks. In G. G. Duffy, L. R. Roehler, J. Mason, (Eds.), Comprehension instruction: Perspectives and suggestions (pp. 187-201). New York: Longman.

Andersson, B., & Karrqvist, C. (1983). How Swedish pupils, aged 12 - 15 years, understand light and its properties. *European Journal of Science Education*, *5*(4), 387 - 402.

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. New York: Holt Rinehart & Winston.

Biddulph, F., & Osborne, R. (Ed.). (1984). *Making sense of our world: An interactive teaching approach*. Hamilton, N.Z.: S.E.R.U. University of Waikato-Hamilton Teachers College.

Brickhouse, N. W. (1994). Children's observations, ideas and the development of classroom theories about light. *Journal of Research in Science Teaching, 31*(6), 639-656.

Bronowski, J. (1973). *The ascent of man*. London: BBC.

Carey, S., & Smith, C. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist, 28*(3), 235-251.

Cobbin, A., Bingle, K., Brown, G., Greenaway, V., Hughes, R., & Willis, A. (1989). *Investigating: Science K-6. Evaluation*. Sydney: NSW Department of Education.

Cosgrove, M. (1995). Science-in-the-making as students generate an analogy for electricity. *International Journal of Science Education, (17)*2, 181-196.

Cosgrove, M., & Osborne, R. (1985). Lesson frameworks for changing children's ideas. In R. Osborne & P. Freyberg (Eds.), *Learning in science* (pp. 101-111). Auckland: Heinemann.

Cosgrove, M., & Schaverien, L. (in press). Children's conversations. *International Journal of Science Education.*

Duckworth, E. (1987). *"The having of wonderful ideas" and other essays on teaching and learning*. New York: Teachers College Press.

Eaton, J. F., Anderson, C. W., & Smith, E. L. (1983). When students don't know they don't know. *Science and Children, 20*(7), 7-9.

Edelman, G. M. (1992). *Bright air, brilliant fire*. New York: Basic Books.

Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.) *Handbook of research on teaching*. New York: Macmillan.

Erickson, F. (1992). Ethnographic microanalysis of interaction. In M. D. LeCompte, W. L. Millroy, & J. Preissle. (Eds.), *The handbook of qualitative research in education* (pp. 201-225). San Diego: Academic Press, Inc.

Faire, J., & Cosgrove, M. (1988). *Teaching primary science*. Hamilton: Waikato Education Centre.

Feher, E., & Rice, K. (1988). Shadows and anti-images: Children's conceptions of light and vision II. *Science Education, 72*(5), 637 - 649.

Fensham, P. (1988). *Development and dilemmas in science education*. London: Falmer Press.

Freyberg, P., & Osborne, R. (1985). Assumptions about teaching and learning. In R. Osborne & P. Freyberg (Eds.), *Learning in science* (pp. 82-90). Auckland: Heinemann.

Guesne, E. (1985). Light. In R. Driver, E. Guesne, & A. Tiberghien (Eds.), *Children's ideas in science* (pp. 10-32). Milton Keynes: Open University Press.

Head, J. O., & Sutton, C. R. (1985). Language, understanding, and commitment. In L. T. H. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 91-100). Orlando: Academic Press.

Holt, J. (1972). *How children fail*. Harmondsworth: Penguin.

Kelly, A. (Ed.) (1987). *Science for girls?* Milton Keynes: Open University Press.

La Rosa, C., Mayer, M., Patrizi, P., & Vincenti-Missoni, M. (1984). Commonsense knowledge in optics: Preliminary results of an investigation into the properties of light. *European Journal of Science Education, 6*, 387-397.

Lincoln, Y., & Guba, E. (1985). *Naturalistic Inquiry*. Newbury Park: Sage.

Lockman, J. L., & Thelen, E. (1993). Developmental biodynamics: Brain, body, behavior connections. *Child Development, 64*, 953-959.

Medawar, P. (1969/1982). Science and literature. In P. Medawar (Ed.), *Pluto's republic. Includes: The art of the soluble* (pp. 42-61). Oxford: Oxford University Press.

Millson, P., & Sington, D. (Eds.) (1994), *The man who made up his mind.* London: British Broadcasting Corporation.
Minsky, M. (1985). *The society of mind.* New York: Simon & Schuster.
Osborne, J., Black, P., Smith, M., & Meadows, J. (1990). *Primary SPACE research report: Light*. Liverpool: Liverpool University Press.
Papert, S. (1980). *Mindstorms.* Brighton: The Harvester Press.
Papert, S. (1991). Situating constructionism. In I. Harel, & S. Papert (Eds.) *Constructionism.* Norwood: Ablex.
Piaget, J. (1974/1978). *Success and understanding* (Pomerans, A. J., Trans.). London: Routledge & Kegan Paul.
Plotkin, H. (1994). *The nature of knowledge.* Allen Lane: Penguin Press.
Segal, G. (in progress). Developing contexts for gender inclusive learning in primary science education. Research for doctoral dissertation. U.T.S. Sydney, Australia.
Segal, G. (1994, March). "The shadow is there and you just can't see it." A learning environment for young children to investigate shadows. Paper presented at Annual Meeting of National Association for Research in Science Teaching (NARST) Anaheim, CA.
Segal, G., & Cosgrove, M. (1993). "The sun is sleeping now." Early learning about light and shadows. *Research in Science Education, 23*, 276-285.
Segal, G., & Cosgrove, M. (1994). "I want to find out how the sun works!" Children's sociodramatic play and its potential role in early learning of physical science. *Research in Science Education, 24*, 304-312.
Shapiro, B. (1994). "That's not true-it doesn't make sense": an approach to understanding students' views of scientific ideas. *Qualitative Studies in Education*, 7(1), 19-32.
Smail, B. (1987). Organising the curriculum to fit girls' interests. In A. Kelly (Ed.), *Science for girls?* Milton Keynes: Open University Press.
Speedy, G. W., Annice, C., & Fensham, P. J. (1989). *Discipline review of teacher education in mathematics and science (Vol 1)*. Canberra: Australian Government Publishing Service.
Stead, B. F., & Osborne, R. J. (1980). Exploring science students' concepts of light. *Australian Science Teachers Journal, 26*(3), 84-90.
Thelen, E., & Ulrich, B. D. (1991). Hidden skills: A dynamic systems analysis of treadmill stepping during the first year. *Monograph of the Society for Research in Child Development, 56*(1, Serial No. 223).
Tizard, B., & Hughes, M. (1984). *Young children learning:: talking and thinking at home and at school.* London: Fontana.
Wittrock, M. (1974). Learning as a generative process. *Educational Psychologist, 11*, 87-95.