Third Misconceptions Seminar Proceedings (1993)

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Keywords: Research Methodology,Educational Medthods,Comcept Formation,Participatory Research,Curriculum Design,,,,
General School Subject: Physics
Specific School Subject: Optics
Students: Elementary School

Macintosh File Name: Asoko - Light
Release Date: 10-16-93 A, 11-4-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

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First steps in the construction of a theoretical model of light: A case study from a primary school classroom

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ABSTRACT

This case study details the planning and teaching of a unit of work on light for a class of 8-9 year olds in a British primary school and the learning which ensued. It is one of a series of studies, involving collaborative work between teachers and researchers, in which teaching is planned utilising information about children's thinking on aspects of science, together with theoretical perspectives on conceptual development or change.

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INTRODUCTION

The case study described in this paper forms part of an ongoing programme of work within the Children's Learning in Science Research Group, into the teaching and learning of science concepts in schools. Teachers and researchers, in collaboration, utilize information about children's thinking about aspects of science, together with theoretical perspectives on conceptual development or change, to plan and implement teaching within specific concept domains for specific classes. Previous case studies within this research programme have focussed upon teaching and learning in secondary school classrooms (Scott et al 1992 (b), Scott 1993). The work documented here is an initial exploration of the use of similar frameworks in a primary school in planning and carrying out teaching designed to develop children's conceptual understanding of the topic `light'. Harlen (1992), reviewing issues related to science teaching and learning in the primary school, points out that, in comparison to post-primary science education, little research has been done in this area. In particular few studies have focussed upon planning, classroom practice and teacher-pupil interactions and it is around these concerns that this study is based.

Much science teaching in primary schools in England and Wales, at the present time, is characterised by the provision of activities and experiences which encourage children to explore phenomena and events. Whilst not denying the importance of this, by itself it is not enough if teaching aims to encourage children to develop and use science concepts and ways of thinking. The aims of this study were, therefore, to investigate how young children could be stimulated and supported in the development of new `conceptual tools' and whether they could use such new ways of thinking appropriately and effectively in explaining everyday phenomena. From the point of view of the teacher, two practical questions arise: how, from the numerous activities which could be used, can those most appropriate to the task be selected and how can the learning opportunities afforded by them be fully exploited.

BACKGROUND TO THE STUDY

Four experienced teachers of year 4 (8-9 year old) children were invited to take part in the study. Three of the teachers had recently completed a 20 day in-service training course at the University of Leeds, and had expressed a wish to be involved in further work, the fourth had a long association with the Children's Learning in Science Research Group. During the in-service course teachers had been exposed to teaching approaches based on a constructivist view of learning whilst developing their own understanding of science. They had also considered ways of working with children which took account of their existing ideas and had devised and tried out teaching approaches in their own classrooms. All the teachers wanted opportunities to consider ways to use ideas about the way children learn science to inform their practice.

The topic `light and shadows' was chosen, firstly because all the teachers needed to include this into their work in the near future as it is an important component of the Programmes of Study within the National Curriculum, and secondly because it was felt to be a conceptually demanding topic for children.

The four teachers, together with two researchers, were involved in the initial discussions about the teaching. The teaching was carried out by one member of the group, Michael, with his mixed ability class of 30 children in a Leeds primary school. Michael is an experienced teacher with wide ranging interests. He had recently been appointed science co-ordinator at his school and enjoys teaching science. He has no formal qualification in science subjects.

As a group, we felt that primary teachers were well able to provide activities and experiences for children relating to shadows but that thought needed to be given both to the underlying concepts which the teaching would be designed to develop and to the selection of activities with particular purposes in mind.

DATA COLLECTION

During the initial planning meetings all discussions were audiotaped. In the classroom all the teacher's interactions, whether with the whole class, groups or individuals, were audiotaped. In addition researchers made observational field-notes and audio-taped discussions with small groups of children. Samples of children's work were collected as were the sheets from the flip-chart used by the teacher. A post-test was administered one week after the teaching and a delayed post-test 9 months later. The researchers acted as additional adults in the classroom, providing practical support for the children, but not participating directly in the teaching.

THE PLANNING PHASE

In deciding the overall strategy for the teaching, we explicitly considered three factors: the nature of children's existing ideas about light and shadows, the nature of the learning goals for the topic and the nature of the intellectual demands involved in developing the science view (Scott, Asoko, Driver 1992a). The children in Michael's class had not, so far as we could ascertain, had any teaching on the topic of light in previous years at school. Research on children's ideas about light (Osborne et al, 1990; Guesne, 1985; Ramadas & Driver, 1989) together with our experience of teaching children of this age led us to anticipate that we might expect:

- most children to be comfortable with the idea of a source of light and to be able to identify the sun, light bulbs, torches etc as such
- some children to think that we are surrounded by a `bath of light' and few of them to have considered the idea of light travelling
- children to be familiar with the phenomenon of shadows and with some aspects of their behaviour. However, it was unlikely that they would have explored these phenomena in systematic ways or to have given much thought to explanations for their observations. Some children were likely to confuse shadows and reflections.
- children to be aware that we need light in order to see.

In identifying the goals for the teaching we considered the concepts which children would need to develop if they were to be enabled to do more than simply **describe** phenomena such as shadows, reflections and vision. We wanted to provide children with a conceptual framework which would allow them to begin to construct explanations, initially to be used for shadow formation but with the potential to be used across a range of contexts. The components of a basic understanding of the behaviour of light were identified as:

- light travels
- light travels in straight lines
- darkness is an absence of light.

If children were to be able to think about and communicate ideas easily, they would also need to be introduced to the conventional way of representing light as lines or rays.

We therefore decided that the first stage of the teaching was to facilitate the development of this theoretical model of the behaviour of light in children's minds. Exploring the phenomenon of shadows would not be sufficient since the ideas are not self-evident. The teacher would therefore need to structure activities and discussion thoughtfully to enable children to `see the light' in a scientific sense. The second stage of the teaching would then need to provide opportunities for children to use this model to move from descriptions to explanations of aspects of the behaviour of shadows. This application phase would concentrate on the ideas that:

- shadows are a relative absence of light
- shadows are formed when the path of travelling light is blocked by an object

and would allow opportunities for children to begin to consider why the size or shape of a shadow can be changed by altering the relative positions of the source, object and screen.

Once the overall strategy for the teaching had been decided upon, discussion centred upon particular activities which might be appropriate. The final decisions about which activities to use were left to the teacher concerned, Michael.

CONSTRUCTING A THEORETICAL MODEL OF THE BEHAVIOUR OF LIGHT

The classroom in which the children normally worked was provided with curtains which were heavy enough to produce reasonably dark conditions in the room. There was, however, a high skylight which could not be blacked out. With the children sitting under this skylight Michael alerted them to the topic on which they would be working `light' and discussion began by considering the light in the room. The children all agreed that this was coming through the skylight and that it was sunlight. Michael then developed this idea:

Michael: *Where does that sunlight come from? Manmohan?*

P_1: *From the Sun.*

Michael: *From the Sun. You mean you're actually telling me that the light that's coming through that window has come from the Sun?*

Ps: *(Several simultaneous replies)*

Michael: *Is that what you're telling me?*

P_2: *It's from the heat*

Michael: *Pardon?*

P_2: *It's from the heat of the Sun because its so hot it makes a bright light.*

Michael: *So how does it get here? If the light is at the Sun, how come it's here as well? Martyn?*

P_3 *'Cos the Sun's shining on us.*

Michael: *But its 93 million miles away, give or take a bus ride! So how come the light from the Sun is here on the table?*

P_4: *Is it because of the ozone layer?*

[there then followed a short exchange in which several pupils contributed ideas about the hole in the ozone layer allowing more sunlight through after which Michael re-posed the question:]

Michael: *But how does the sunlight get here?*

P_5: *It travels here.*

Michael: *Does anybody disagree with that? Does anybody disagree with the statement sunlight travels?*

P_s: *Yes.*

[The small group of children who disagreed were still considering the effects of the ozone layer. After a short discussion Michael again redirected attention:]

Michael: *...... Caulton says, and his exact words are, that it travels here. In other words light moves from the Sun to here ....*

P_5 *Yes.*

Michael: *...93 million miles. Is that right?*

P_s: *Yes (chorus of many voices).*

Having thus highlighted the idea of light travelling, and the great distance involved and indirectly indicated that the Sun `shining' was not a specific enough answer, Michael focussed the attention of the class first on the normal room lighting and then, with the room again in darkness, on a 12v light bulb connected to a power supply.

Michael: *When I turn on this switch, what will happen?*
P_1 *The bulb's going to light up and shine.*

Michael repeated this answer and then developed it further by asking where it would have most and least effect. Several children suggested that inside the bulb or close to the bulb would be brightest and one small group became very excited about their idea about where the bulb would have least effect. This turned out to be an unanticipated, but useful, response:

Michael: *Go on then.*
P_1: *Is it underneath?*
P_s: *Underneath the table (chorus)*
Michael: *That's rather good isn't it? Underneath the table. Why not?*
P_1: *Because the table's in the way*
P_2: *It's blocking it*)
) *simultaneous*
P_3: *The table's on top*)
P_4: *It's blocking the light from coming down.*
Michael: *Ay, Ay, Ay ... do you know that's very clever. That's not what I was thinking at all! I was thinking that if would have least effect in the corners of the room but you've out-thought me haven't you. You're quite right, it would have least effect under the table. Why? Perdip?*
P_5: *Because the table's blocking the light.*
Michael: *The table's blocking the light. Yes, yes. That's a good word.*

After a little more discussion about the likely effects to be noticed, Michael switched on the bulb. The predictions were accurate. The idea of light travelling was emphasised again:

Michael: *You've said to me that light travels. Is there anything there that tells me that light travels?*
P_s: *No/Yes (chorus - majority say `yes')*
Michael: *Simon?*
P_1: *There's a kind of light beam going up (noting the halo effect).*
Michael: *There's a kind of light beam going up. Are you telling me then that the light goes in this direction? Or that direction? (indicating with hand movements)*
P_s: *(excited) No!*

It goes round..... It goes everywhere

P_2: *It spreads about to the edge of the table.*

P_3: *It goes in every direction.*

Michael: *It goes in every direction. How come I can't see it travelling? Look - watch me travel! (walking about slowly). There you are, you can see <u>me</u> travel!*

P_s: *It goes at light speed (several voices)*

P_4: *Its fast.*

P_5: *You can't see it.*

To consolidate the idea that light travels too fast for us to see, Michael turned the bulb on and off very quickly to produce a `bit' of light.

Michael: *So, watching this bit of light, I should be able to see it go..*

P_1: *No you couldn't.*

P_2: *You couldn't see it go like that. You might see it shine (on a surface) but you wouldn't be able to see it travel.*

Michael: *Why not?*

P_s: *Because its fast (many voices)*

Michael then asked the class to think what would happen if he covered the bulb with a box and switched it on, and then carried this out.

The class was then subdivided into groups of 3-4 children each group provided with a set of equipment comprising a 12v bulb taped centrally under an octagonal box approximately 35cm across and made of thick card. In the centre of each face of the octagon a vertical slit, about 120x5mm was cut. The equipment was set up on tables covered with white paper. Children were asked to think about what they would see when the bulb was switched on and to draw what they expected to see on the paper. Almost all the children drew straight lines at 90^{o} to the surface, extending from the slit to indicate the path of the light. The lines varied in length from 2-3cm to about 30cm. A minority of the light paths were shown as diverging. When all the children had made at least one prediction, all the lamps were switched on simultaneously in the darkened room. The effect was quite spectacular and caused some excitement and not a little surprise when children realised that instead of travelling only a short distance, the beams of light continued across the paper and could be seen, in a vertical plane, when they met a surface such as the wall or a child's body.

Following the mid-morning break, Michael once again called the class together to discuss their observations. He drew a representation of the octagonal box, in plan view, on the flip chart and first asked children about conditions inside the box. He then pointed out that everyone had been correct in their predictions of the position of the line but:

Michael: *I think where people went wrong was that they thought the light would stop. Is that right?*
P_1: *No, it carries on.*

Michael: *It carries on. How long would it carry on?*
P_2: *Right to the end. Just keeps on carrying on.*
P_3: *Just keeps on carrying on, is that ...*
P_4: *It can't stop. You can't stop light without you turning it off.*

Michael: *So the light goes on forever?*
P_s: *Yes/No.*

It appears, that some children were thinking about light travelling through distance while others (P_4) were thinking about the light continuing as a phenomenon in time, ie. that it would still `be light' unless it was switched off.

A little later in the same discussion:

P_1: *It (the light) just fades away.*

Michael: *Somebody was saying to me that the light would travel forever.*
P_2: *No, I told you until the electricity runs out.*

In order to focus attention on the light travelling, Michael introduced a thought experiment:

Michael: *.... supposing then, I imagine that I turn the light on and off in a flash and a bit of light sets out by itself. When does it stop? Does that stop or does it keep on travelling when I turn ...*
P_1: *Keeps on travelling)*
P_2: *Stops) simultaneous*
P_3: *Stops and disappears)*
P_4: *Fades away*

Michael curtailed the speculation by indicating that he wanted the class to think about these ideas when they did an activity using a projector later.

Returning to the flip chart, he selected eight children to come up to draw rays of light emanating from each slit in the octagonal box. All the children could do this easily and extended their lines from the slit to the edges of the paper. Michael then encouraged the class to reflect on their knowledge:

Michael: *What puzzles me is why so many people from the very beginning were right about the direction of those lines? .... Why does everybody draw that line, why does nobody draw that line? (drawing a line at 45^{o} to the side of the box).*

P: *Because the bulb isn't down there.*

Michael: *The bulb isn't where? Come on then (calling the child out) ... You tell me where the bulb would have to be for me to draw that line there? For that line to be right. There you are (handing over the felt tipped pen).*

P: *If it was coming out there, it'd have to be somewhere like there. Yes.*

Michael: *Right. Is that what everybody thinks?*

Ps: *Yes (chorus)*

Michael: *In other words you say if the light is travelling that way, then to find out where it's coming from I have to go in the opposite direction and its somewhere on there?*

At this point, Michael went on to review for the class the ideas that had been discussed - that light travels, that it does so too quickly to see and that it does so in straight lines. He also started to use the words `ray of light' to describe the lines representing the path of the light and drew children's attention to the fact that the rays got wider further away from the box. Discussion then moved to what had been noticed <u>between</u> the rays. The children offered two ideas, a shadow and darkness, and Michael asked what a shadow was. In the discussion which followed, to which many children contributed, some of the ideas expressed were:

- a kind of reflection

- it's like a reflection but its not coloured

- The shadow's grey and dark ... because, its standing in the way of the light so light, when it reflects onto the light, it makes it darker

- Like when the light strikes on to something and then your shadow goes into the light and it makes you look dark.

When Michael asked what caused the shadow, a pupil replied:

- because of the sun, if the sun was in front, your shadow would be behind you.

Michael asked if everyone agreed and received a chorus of `yes'. He repeated the statement and, after a little more discussion about the nature and formation of shadows, returned to consideration of the diagram of the box. The question now posed was what was <u>inside</u> the box. Everyone agreed it was light. Michael invited a child to draw in the light and then asked which way the light was travelling. The child indicated this with arrows on the lines -

P: *That way, it's going outwards from the bulb.*

Michael: *Right, I agree with you. Forwards (referring to a previous description) doesn't seem to mean much to me but outwards from the bulb does. So, we're agreed about that?*

P_s: *Yes.*

Michael: *Then why doesn't it get there? (indicating a place outside the box).*

P_s: *Because there's not a slit there.*

Michael had, by now, introduced and discussed all elements of the theoretical model of the behaviour of light which had been identified as goals for the teaching and the ideas of light travelling, fast and in straight lines had been repeated many times. These ideas had not appeared problematic for children to accept, although their conceptualisation of `travelling' was not clear. Michael had highlighted two major points for later consideration: what happens as light gets further from the source and the differences between shadows and reflections. The teaching up to this point had taken a total of 80 minutes, a large part of which had been whole class discussion.

USING THE MODEL

Having been introduced to the components of the theoretical model of the behaviour of light, the second phase of the overall teaching strategy was to provide opportunities to use the ideas and, in so doing, to consolidate, refine and better understand them.

A circus of sets of three practical activities was set up and pencil and paper activities were also provided. The children worked in groups of three, moving between activities at their own speed but were brought back into the whole class group at intervals to discuss progress and as points of particular difficulty arose. The activities had been selected to highlight particular features about shadows on which we wanted children to focus. The pencil and paper activities included consideration of sources of light and exercises including predictions of the position of the shadow of an object given the position of the source and vice versa. The practical activities were not done in any particular order.

Activity 1 - children were asked to use a torch, on a stand, to make a clear shadow of a wooden block and to indicate the direction the light was travelling. They were then asked to keep the block in the same place, make a new shadow and repeat the drawings. The aims of the activity were to draw attention to the fact that the shadow was on the opposite side to the source, a point which had already been mentioned in class discussion in relation to personal shadows, and to encourage children to use lines with arrows to represent the direction in which the light was travelling.

Activity 2 - two children set a problem for the third child to solve. They arranged a torch on a stand and a small toy animal on a sheet of paper to produce a shadow. They drew around the shadow, left the torch in place and removed the animal. The third child then had to reposition the animal correctly and then test out their idea by switching on the torch. The aims of this activity were to raise awareness that the shadow was in contact with the object, that it had no features and that the shape changed according to the orientation of the object relative to the source.

Children appeared to have no difficulty carrying out either of these activities or explaining how the shadows were produced in terms of the path of the light being blocked.

Activity 3 - involved a slide projector set up at a fixed distance from a wall. Children were asked to switch on the projector, hold a piece of card close to the lamp and then move the card slowly towards the wall, observing the spot of light and explaining what they noticed. They were then asked to make small and large shadows of their hands on the wall, to cut out a face shape from card, with eyes, nose and mouth and to make a face shadow on the wall. In contrast to the other two activities, this focussed attention initially on the light rather than the shadow. It was intended to draw attention to the divergence of the beam producing a larger and dimmer spot of light and to the effect on the shadow of changing the position of the object in relation to the source. Cutting out shapes from the card reinforced the idea of travelling light being blocked by opaque material in its path.

As groups of children commenced work on the activities, it became apparent that the use of directional light sources (projectors and torches) as opposed to unshielded light bulbs from which light spread in all directions was causing some difficulty. Michael highlighted the problem with the whole class by encouraging them to consider what was needed in order to view a slide. After collecting and discussing the ideas he summed up:

`I think that's something we ought to have talked about before we went from this bulb where the light is going in all directions to this bulb which is .... controlled, is the light isn't it? ......   I think what

you've got to think about is the fact that this beam, all the light is directed forward by the mirror and the beam gets wider.'

The second, and more fundamental problem for the children was the difficulty of explaining why the light spot got less intense as the card was held further from the projector. Almost every group needed help to think about the problem. The following dialogue was repeated in a similar fashion with several pupils or groups, with Michael modelling the behaviour of the light using his finger tips, first held close together and then spreading apart.

Michael: *(reading a child's work) When the piece of paper is close to the light it's smaller and brighter, when it's far away it's duller and bigger. Right. But the light ... why's that?*

P: *Because when its closer it got more light to cover.*

Michael: *It hasn't got more light. How much light is there there?*

P: *A bit.*

Michael: *How much light is there there? (holding the card from the projector)*

P: *A lot*

Michael: *Are you sure? Where's the light start?*

P: *There (pointing to the projector)*

Michael: *There, right .... but is there the same amount of light there as there was there (moving the card away) ... surely there must be because if the light starts there, if I could slow it down, if I turn this off and imagine my fingers are the light, the light starts off, lets say we've four lumps of light. What happens as it goes? As it spreads out. Is that right? Is there the same amount of light there? Look at my fingers.*

P: *Yes.*

Michael: *Yes, the same amount of light, the only thing that's happening is its spreading out. So, turning this on again, it goes so quick you can't see it can you, but it travels from here to there but it does it so quickly that it's unbelievable. There there's the same amount of light as there is there, but there it's concentrated isn't it, so its very bright. There its spread out. Same amount of light but its spread thinner. So it looks dull.*

Although this conversation was between one pupil and Michael, the other boys in the group were listening. Some time later they were asked, by a researcher, about the projector activity:

R: *Tell me what you found out.*
P_1: *When we move the card towards the projector it gets smaller and brighter.*

R: *What does?*
P_2: *The light*

R: *What's making it small and bright?*
P_3: *The light, but when it gets closer........*

P_2: *Yes but when you move it away it gets bigger and bigger.*

P_3: *Yes, when it's closer it's lighter and smaller but when it's going away it's spreading out but it's the same amount of light so it gets duller ... and if it gets really far you can't see it.*

R: *Why can't you see it if its far away?*
P_3: *It's run out of light*

R: *It's run out?*
P_3: *Yes*

P_1: *It's faded.*

P_3: *It's faded so it can't go any more.*

A little later in the same conversation, the group was asked if the projector light could reach the city centre if there was nothing in the way. They said it could not because:

P_1: *It wouldn't be strong enough. You'd have to have oh, really, really, really, really, about a million volts to make it go*.

It appeared that although, as has been noted earlier, some children in the class had appeared to accept the notion that light would keep travelling in the same direction unless it hit something, this was difficult to reconcile with the intuitive notion that things go further when given a big push (Stead and Osborne, 1980; Andersson 1986).

When considering why sunlight is able to travel such a long distance the group said:

P_3: *Because it's strong*

P_2: *Because it's hot*

P_1: *Because it's really, really, really hot. The most you could get far away from it would be about at the most 10 miles because*
P_2: *you'd melt.*

P_1: *You'd melt, you'd just go (hand expression)*

R: *So how is it the light can get all the way to us then?*
P_1: *Because it's really, really, really strong.*

Whilst involved in activity 3, one group of children noticed that by holding the card horizontally below the beam of light they could see it spreading out. A second group described the light as behaving like jam spread on bread. In a whole class review and discussion session, Michael utilised both of these ideas in an attempt to help children to appreciate that as the light travelled out from the source, it spread out over a wider area, but that it could still be there even though it might not be detectable by our senses. This inevitably led to a consideration of the eyes as receptors of light. Although this had not been one of the aims of the original teaching we were well aware of the models of thinking about seeing which have been identified (Andersson and Karrqvist 1983; Guesne, 1985; Ramadas and Driver 1989). By the use of analogies which equated the ability to taste a substance with the ability to detect light, we hoped that for some children the development of `active eye' models might be avoided.

The two analogies presented involved the same quantity of orange squash diluted with three increasing amounts of water and a teaspoonful of jam spread over three increasingly large slices of bread. All the children tasted the three samples of orange and the three pieces of bread and jam. Following discussion with the whole class about the role of taste buds in tasting and the differences they had noticed, Michael summed up:

Michael: *As the jam is spread over a bigger and bigger piece of bread there is, in fact, less jam to each bite isn't there?*
P_1: *Yes, it isn't as sweet.*

Michael: *It isn't as sweet. But what's the other part that needs putting in? What is it that does the tasting?*
P_2: *Your taste buds.*

Michael: *Your taste buds. And as you get less and less jam to each bite what happens? Yes?*
P_3: *Your taste buds can't detect it.*

Michael: *Your taste buds aren't able to detect it as easily are they?*

Michael then related these analogies,together with a third model in which he blew up a large balloon with the outline of a rectangle inked on to it, to the behaviour of the light travelling from the projector which could be `spread' so thinly that it could not be detected.

The final activity in the teaching sequence involved children in predicting and then observing the length of a shadow when the height of the source was changed. The aim of this was to provide a model which related to the changing length of shadows dependent on the position of the sun in the sky. Unfortunately, on the days that the teaching was taking place, the weather was consistently dull so that, although we had initially intended to consider shadows produced by the sun, suitable opportunitites did not arise!

EVALUATING CHILDREN'S LEARNING

One week after the teaching, the children were asked to complete a written post test. Nine months later the post-test was re-administered. Due to a reorganisation of the education system, only 17 of Michael's original class remained at the school, divided between two classes. The post-test was therefore given to all 61 children of that year group present, allowing some comparison to be made between those children who had participated in this teaching, Group A in Figure 1 and a group of 9-10 year olds who had not, Group B in Figure 1.

Details of the post-test questions can be found in Appendix 1.

Question	**Teaching Group (A)**	**Non-teaching Group (B)**
	n=17	n=44
1a	71 (85)	43
1b	41 (62)	11
1c	35 (23)	45
1d	6 (8)	2
2a	71 (88)	50
2b	65 (81)	27
2c	59 (73)	59
2d	100 (85)	55

Figures in brackets refer to the original post test results (n=26)

FIGURE 1 DELAYED POST-TEST RESULTS: PERCENTAGE OF CHILDREN GIVING SCIENTIFICALLY APPROPRIATE ANSWERS

The post-test results are of interest as an indication both of the learning and of some of the difficulties encountered by the children.

In question 1 the children from Michael's class appear better able to predict and explain the effect of moving the torch away from the wall when compared to their classmates. However, questions 1c and 1d, relating to a cast shadow when the source is moved away from the object, posed problems for all the children. The majority of children who had participated in the teaching anticipated that the shadow would get larger and, from the explanations given, it appeared that they expected the shadow to behave in the same way as the light. The discussion of the use of directional, diverging, beams of light in projecting slides and the balloon analogy may well have contributed to this idas:

`I think the shadow gets bigger because as the torch is moved away the light spreads out as well and so it pulls the shadow and makes the shadow bigger'.

(Jaswinder 9)

`The shadow would get bigger because the light gets wider'

(Perdip 10)

In question 2a children were only credited with a correct response if the shadow was drawn on the correct side of the object and connected to it. Many of the children in group B drew the shadow between the mug and the lamp. Children in group A were more able to explain why the shadow formed in scientific terms. Examples of group B responses for shadows drawn between the mug and the lamp included:

`the mug has a shadow because the light reflects on the mug and makes a shadow'. `because the lamp is bright'.

Group B responses for correctly placed shadows included:

`because of the lamp sinning (sic) on the mug'

`because the light shines on to the mug and on to the table so it leaves a dark patch' `the shadow is coming from the lamp'

Question 2c highlighted something which we had not ourselves considered, the difference between shadows cast on to a screen, which are unconnected to the object and those cast on a horizontal surface such as the floor or a table top. In the former case, as the distance between object and light source is increased, the shadow becomes smaller. In the latter, as in question 2c, the shadow becomes longer. In retrospect it would be wise not to confuse these types of shadows in the initial stages of the teaching. Only 3 children in total suggested lowering the lamp to lengthen the shadow.

In the first post-test children were also given the opportunity to write in an unstructured way about anything else they had learnt about light. Twenty-two of the twenty-six children mentioned that light travels and sixteen of these also stated that it travels very fast, that it travels in straight lines, or both.

In summary, at the end of the teaching, it appeared that children from Michael's class did have an increased understanding of the behaviour of light and were able to apply this to some aspects of the phenomenon of shadows. Nine months later, these children did better on the post-test than their classmates on all questions except two, question 1c where the teaching may have produced a misconception and question 2c where both groups were identical. The relationships between shadow size and the relative positions of object, source and screen are complex and require an ability to represent the system either in imagination or on paper by some form of geometrical model. Our aims for the teaching had been to start children thinking about such relationships but not to consider them in detail.

The information to be gleaned from such a post-test is, inevitably, limited. It would be of interest to investigate whether children are able to utilise any of these ideas when they meet the topic `light' again, perhaps in the context of reflections.

ISSUES ARISING FROM THE STUDY

The aims of the teaching described in this study were to support children in the construction of the first stages of a theoretical model of the behaviour of light which would be useful to them in explaining a range of phenomena and which would be further developed and refined at later stages of their education. From the outset it was never envisaged that the teaching approach described here would be the `best way' to present the topic, rather it was a solution appropriate to a particular teacher working with a particular group of children.

In the planning phase, the first stage was, therefore, to identify the key features of an understanding of the behaviour of light which needed to be addressed by the teaching. In comparing these features with the ideas which we anticipated children would be likely to hold already, there appeared to be little conflict, rather the children had simply never thought about light in this way before. It was therefore necessary for

Michael to structure activities and discussion in a way which provided opportunities for him to develop children's thinking from what seemed obvious to them - the sun shines, we are in sunlight, the sun is a long way away - by means of small steps making up a reasoned argument, towards the goals - light from any source travels, it does so in straight lines, darkness is an absence of light. The activities with light bulbs and the octagonal box supported the discussion but were used more with the intention of providing clear, uncluttered experiences to focus children's attention than to provide any conclusive evidence. Children were not `discovering' the scientific view by observing phenomena; for the majority of the class the only discovery they made from the activity was that light travelled out of the slits of the box further than they had anticipated. However, by discussing the implications of their observations and ideas, Michael was providing the `scaffolding' (Bruner 1986), which made the science view accessible to the class.

Once Michael was reasonably sure that children had had a chance to think about the important ideas, the circus of activities provided opportunities to apply them in the context of shadow formation. Teacher interactions with pupils as individuals, in groups and in the frequent whole class review sessions provided opportunities to share ideas and experiences, to resolve difficulties and to illustrate how the theoretical model could be used in explaining the phenomena observed. The activities were selected either to highlight particular features of the shadows themselves or to promote discussion of aspects of the theoretical model. In the former case, selection was influenced both by ideas which had arisen in class discussion and by our knowledge of the literature on children's ideas in this area. Thus the activities focussed attention on shadows as connected to the object, featureless and on the opposite side to the light source. With respect to the theoretical model, the ideas to be used and reinforced included light spreading out from a source and being blocked by opaque objects in its path. Consideration of the straight line path of the light allowed predictions and explanations to be formulated about the sizes and shapes of shadows.

However, as well as providing the activities, Michael also needed to provide support for children to enable them to use the ideas, to which they had only recently been introduced, in appropriate ways. This support was provided largely by Michael's verbal interactions with the class in which he capitalised on the learning opportunities available by:

- **responding to children's ideas** - highlighting and using children's language when appropriate, eg *blocking the light* - drawing attention to alternative ideas within the class, *e.g. shadows are like reflections* - encouraging children to reflect on their thinking*eg how they made* *correct predictions about the path of the light emanating from the slits in the box*

- considering, and sometimes utilising, unexpected comments and questions, *eg the light having least effect under the table*.

- exploring the science view - providing explanations which he had thought out and structured in advance

- reinforcing important ideas by repetition and transfer to other contexts, *eg light travels from the sun, a light bulb, out of the box*

- highlighting ideas which are problematic and deserve consideration, *eg why can't we see light travel? how far does light go?*

- providing alternative physical models and analogies and using them to link observed phenomena with the theoretical model, *eg analogies such as jam on bread, representing light rays by spreading fingers*

- encouraging speculation through thought experiments, *eg let's imagine a `bit' of light setting off from the source; suppose there were no clouds, no dust in the air, what would happen to a torch beam shone into the sky?*

- providing access to the appropriate language

- indicating the need for precise language, *eg outwards from the bulb, not forwards; travelling not shining.*

- introducing new words at appropriate times, *eg rays.*

Interactions of this nature are, frequently unplanned, and it appears that the **process** of setting clear conceptual goals for the teaching, reviewing the likely prior understandings of the pupils and how these might develop and selecting activities with specified aims sharpened the awareness of the teacher, enabling him to capitalise both on the activities themselves and on the children's responses to them.

CONCLUSION

Commitment to a constructivist view of learning science implies that a teacher needs to consider the prior ideas, experiences and understandings of the pupils, the ways in which these might develop, the demands of the science which is to be taught and the possible strategies which might support learning before selecting specific activities for use in the classroom. Some characteristics of, and demands on, teachers working in this way have been identified (Appleton and Asoko 1993; Scott et al 1992) and include the ability, not only to plan teaching which takes account of children's starting points, but also to respond appropriately to children's developing ideas during the teaching in ways which cannot always be anticipated.

For many primary teachers teaching science, the provision of experiences and activities for children is relatively unproblematic since these abound, both in teachers' experience and in published resources. However, if the aim of teaching is to develop children's science concepts, provision of experiences and activities is not sufficient, in the same way that simply giving children books will not teach them to read. The problem lies rather in selecting activities with particular conceptual goals in mind and then exploiting the opportunities they provide. The teacher needs to be able to identify appropriate goals, support children in the development of `conceptual tools' in the form of scientific ideas, explanations and ways of thinking, and act as mediator between children's everyday understandings and experiences and the science view. Inevitably the extent to which teachers can achieve this will depend on a range of factors, including their personal understanding of the science and their confidence to use their knowledge flexibly in the classroom. Since recent surveys confirm that many primary teachers feel neither confident nor competent when teaching science (Bennett et al 1992; Summers, 1992) much support will need to be given both in and out of the classroom if science in the primary school aims not just to extend children's experience but also their conceptual horizons.

ACKNOWLEDGEMENTS

This work was supported by a grant from the School of Education, University of Leeds. I would like to thank Mr Philip Scott for his assistance during the data collection, Professor Rosalind Driver for her comments on the paper and of course, Michael and his class.

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APPENDIX 1: POST-TEST QUESTIONS

The post-test was administered one week after teaching and repeated, with question 3 omitted, nine months later. Children were given a question sheet, with space for their answers, and a drawing relating to question 2. Each question was read out to the class and the situations demonstrated before children were asked to write their answers.

Question 1: Phil is pointing a torch at the wall. When he switches on the torch you can see a patch of light on the wall.

a) If Phil moves the torch slowly backwards, what do you think will happen to the patch of light?

b) Why do you think this will happen?

When Hilary puts her hand in front of the torch, it makes a shadow on the wall.

c) What do you think will happen to the size of the shadow if Phil moves the torch slowly backwards?

d) Can you explain why this will happen?

Question 2: On the table is a lamp and a mug.

a) When the lamp is switched on, where will be shadow of the mug be? Draw it on the picture.

b) Can you explain why the mug has a shadow when the lamp is switched on?

c) What could Phil do to make the shadow of the mug longer?

d) What could Phil do to make a shadow on the other side of the mug?

Question 3: In the past few weeks we have done a lot of work about light and shadows.

a) Tell us anything you know about light by writing or drawing about it.

b) Is there anything else that you would like to know about light and shadows or anything which still puzzles you?