

**Constructing Understanding in  
Primary Science:**  
An exploration of process and outcomes in the  
topic areas of light and the earth in space

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## Abstract

This study explored the process and outcomes of constructivist methods of enhancing science understanding in the topic areas of light and the earth in space. The sample was drawn from a group of 41 nine-year-old children, delivered in four two-hour weekly sessions. Each session involved different combinations of interactive discussion and practical investigative activity. Criterion-referenced pre- and post-intervention assessment indicated very large gains in participant understanding. These gains were promoted by building upon participant prior understanding, use of attuned questioning and scaffolding by an adult, and undertaking structured practical science investigations. The study showed that gains in complex learning outcomes could be achieved using a combination of scaffolding and building together with practical activities. The implications for classroom practice are discussed.

**Keywords:** social constructivism, science education, talk, light, earth and space, practical science

## Introduction

In recent years, science in the primary school has been shown to be generally poorly taught. Harlen (2001) reported the results of a two-year study of primary teachers' understanding of concepts in science and technology. This showed that confidence in teaching science was low. Some teachers had no experience of science. Others had negative attitudes to science based on their own science education. Weak teacher knowledge and low confidence in the teaching of science have been reported to result in teachers who focus on process skills in science and avoid concept development (Harlen and Holroyd, 1995).

Piaget (1985) proposed that science understanding developed in children through the processes of assimilation and accommodation, associated with the construction of internal schemas for understanding the world. This might be termed cognitive constructivism. Vygotsky (1978) placed greater emphasis on the role of social interaction, language and discourse in the development of understanding, particularly interaction with more advanced learners, but at an appropriate level of challenge. This might be termed social constructivism.

Trumper (2001) outlined four key aspects that were essential components of a social constructivist approach to teaching science:

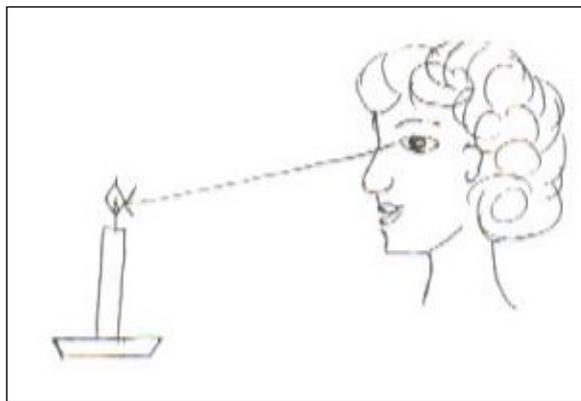
1. having knowledge of the learner's existing understanding in targeted conceptual areas and making this the focus of teaching,
2. students should be aware of their own views and uncertainties,
3. students should be confronted with currently accepted scientific views,
4. experiences should be provided for students that will help them change their views and ideas and accept a scientific view of a concept.

It has been reported that knowledge of pre-existing understanding in conceptual areas is essential to facilitate effective learning and teaching and promote cognitive development in children (Millar, 1998). Harlen (2000) reported that the role of the teacher should be as a facilitator of learning in science- guiding pupils through scientific thought processes, and encouraging them to question, hypothesise and test their ideas. In this role it is reported that the teacher plays an important role in helping children make pre-existing conceptions (and mis-

conceptions) explicit. By so doing the learner can focus upon key areas for exploration and reflection.

Children's conceptual development can be explored through language, but also through graphic interpretation. For example, the Science Processes and Concept Development (SPACE) project studied children's ideas of how we see things in the context of a wider study on children's perceptions on the nature and properties of light (Osborne, Black, Smith and Meadows, 1990). The children were asked to draw how they thought they saw a lighted candle. Figure 1 illustrates and explicates a misconception. In this figure the child wrongly indicates that light travels out from the eye and illuminates the candle allowing it to be seen.

**Figure 1: Child's picture of vision as an active process with light travelling from the eye to the object and illuminating it (Osborne, Black, Smith and Meadows, 1990)**



Listening to children and engaging in conversation with them can also give a good insight into their ideas. Children often do not have a clear vision of what they already know and their ideas are not well organised. A child of six was heard to say, "I don't know what I think until I hear myself say it" (Ollerenshaw & Ritchie, 1998). Speech can be used as a tool for thinking as well as communication. Children are likely to discuss ideas and concepts more purposefully when planning an investigation to test them. The nature of the activities and teacher/pupil and pupil/pupil interaction are all likely to influence the development of process skills and attitudes. Some of the explanations reported to be given by eight and nine year old children in response to the question of what happens to the sun at night include (Osborne, Wadsworth, Black and Meadows, 1990):

*'The Earth turns round and it blocks the Sun's way so that it is dark.'* Nazia, Age 8

*'The Sun goes down and the moon comes up.'* Romana, Age 9

*'It (The Sun) changes into a moon.'* Aaron, Age 9

It has been reported that the majority of 7 and 8 year old American pupils are not able to demonstrate understanding of the rotation of the Earth as the cause of day and night (Klein, 1982). Trumper reports that nearly 50% of Israeli thirteen year old pupils and 65% of sixteen year old pupils are able to give a scientifically correct explanation for day and night. Baxter (1989) reported that the majority of 9 year old American pupils believed that the phases of the moon were caused by cloud cover or the shadow of the Earth. Bisard, Aron, Francek & Nelson (1994) report that by age of twelve, 35% of American pupils are able to give a scientifically appropriate explanation for the phases of the moon. Suzuki (2003) reported that similar misconceptions were present in a small sample of student teachers in Japan. There is therefore a requirement to develop effective learning and teaching methodologies to teach about the relationships between the sun, moon and Earth. A possible cause for the prevalence of misconceptions is that learners in these studies were not able to make the necessary links between concepts concerning the properties of light and shadows and more abstract concepts regarding how these properties exhibit themselves in respect of day and night and the phases of the moon. It has been reported that faulty or limited constructions can distort or impede new construction (Novak, 2002).

In order to counteract the effects of faulty or limited constructs four cognitive processes have been reported to be necessary (Ausubel, 2000):

1. progressive differentiation of existing concepts eg in this project children used the mind mapping exercise, drawing/talking and written instrumentation to explore their concepts about the properties of light and how they experience these in their life
2. subsumation-new concepts are linked with existing concepts and learning is therefore scaffolded for the learners eg in this study initial activities focused on the basic properties of light.
3. superordinate learning-the learning should contribute significantly to cognitive development in terms of seeing the links to the overarching ideas in science eg in this study

the phases of the moon and workings of the periscope were linked to the overarching properties of light

4. integrative conciliation may be required-allowing learners to make links between concepts eg in this study between how a shadow can change dependent on the position of the object casting the shadow and how the shadow of the moon gives rise to the phases that we observe from our position on earth.

According to Harlen (2000), the nature of interactions that promoted these cognitive processes in children included encouraging children to:

- observe, question and hypothesise
- talk about their ideas and listen to other's ideas
- test the ideas discussed
- make conclusions based on evidence
- compare new ideas with existing ones
- consider how the investigations could be improved

Ollerenshaw & Ritchie (1998) discuss ways in which teachers can support children through scientific observation:

- First thoughts – naming, labelling
- Second thoughts – comparing use and properties
- Closer look – smaller differences between similar things.
- Seeing more – grouping differently, thinking differently
- Looking deeper – focus on object watching, recording, comparing

The quality of questioning can also be important. Black and Harrison (2000) discuss the importance of the way in which children are questioned. Questions should encourage thinking rather than demand a quick response that encourages guesswork. Black and Wiliam (1998) reviewed research from over 250 research studies and concluded that effective questioning involves:

- allowing the children time to discuss the question in pairs and then asking for a response.

- giving the children a number of possible options to consider and then asking for a response and justification of the response.
- questioning, using open questions, phrased to invite pupils to explore their ideas and reasoning.
- asking the children to communicate their thinking through drawing, artefacts, actions, role play, concept mapping, as well as writing.

Inter alia, questioning should seek to elicit the child's hypothesis about what is happening. However, children might offer more than one hypothesis. Predictions are hypotheses about future events. It is important to make a distinction between a prediction and a guess as directs the enquirer on how to plan to find an answer (Hollins and Whitby, 2001). Young children may see their predictions as guesses, but they should be helped to see how their predictions were derived from evidence and theory. It is reported that this gives children a question worth answering and promotes enhanced attainment in science (Gilbert and Qualter, 1996; Watts, Barber and Alsop, 1997).

Children may also engage in active practical investigations. Goldsworthy (1998) discusses six main types of investigation, of which children should be aware so that they may decide on the most suitable method when planning:

- Fair testing - one variable is changed in testing, all others must remain constant
- Classifying and identifying grouping objects or events according to criteria (e.g. classify objects by: living, once alive now dead, inanimate objects)
- Pattern Seeking surveys (e.g. differences in plants in shade and those in sun)
- Exploring observations made over time (e.g. development of frog spawn)
- Investigating models (e.g. computerised models allowing the exploration of seashore, rainforest etc. Some may allow variables to be changed and ideas tested)
- Making things/Developing systems (e.g. making a bridge to withstand weight of a human out of newspapers).

Goldsworthy (1998) found that fair testing was the predominantly used investigation in primary schools. This is unlikely to be appropriate for all investigations and it is important that children are aware of other methods.

Children who have little experience of interpreting data might jump to conclusions based on one result and ignore other conflicting information. As children progress, they should take more of the data into account before reaching conclusions. Children should become more expert at looking for patterns, trends and links between variables in their observations, while also developing a sharper sense of the key data salient to the investigation.

Scientific vocabulary is also likely to be developed through scientific investigation. New words and their meanings are likely to be learnt as the child experiences new concepts and semantic demands (e.g. evaporation, reflection, forces). Sometimes children might learn and use these words without initially fully understanding their meaning, so it is important that the teacher ascertains what the child understands by a particular word.

From this, it is evident that assessing learning progress in science is not straightforward, and certainly goes beyond the scope of a crude knowledge test. According to Bell and Cowie (2001), assessment procedures should be integral to teaching and learning and have a formative rather than summative function. Assessment should provide information about children's progress, identify the next stage of learning, and so inform planning and more specifically identify individual learning issues and needs. Learning & Teaching Scotland (2004) report that when children are involved in their own assessment, marked improvements can be seen in their learning. Assessment of content knowledge and understanding on a pre-post basis should be supplemented with continuous assessment of the process skills and attitudes that children have acquired. Harlen (2000) suggests that observations of children engaged in hypothesising, predicting and other process skills is difficult unless done in the context of the topic being studied, as different predictions and questions will be raised depending on the topic.

Evidence identified in the literature surrounding children's learning of science concepts led to the formulation of specific research questions. These questions were written with the aim of exploring the role and contribution of scaffolding, building and practical activity on children's learning of science. In this study, the topic used was light - the nature of light and light in the solar system. This topic was identified as providing an appropriate context for the investigation of these issues.

## Research Questions

This study focused on the following questions:

1. How can children use their previous knowledge and experiences to help them understand new experiences in science?
2. Can development of conceptual knowledge and understanding about simple science concepts through practical activities promote effective gains in children's understanding about more complex, abstract scientific concepts?
3. How do children apply understanding about simple concepts to understand more complex concepts about how light influences how we experienced the solar system from earth?

## Research Design and Method

The study collected pre, during and post intervention data from 41, nine year old pupils. The pupils (24 girls and 17 boys), were drawn from three Primary 5 classes based in two different Primary schools in eastern Scotland. The schools were selected on the basis of their willingness to participate and the fact that they displayed broadly similar profiles in respect of pupil attainment and socio-economic status of the pupils. Data presented in Table 1 reports the percentage of o fpupils in the sample classes who passed 5-14 National Curriculum tests to attain the national target scores in reading, writing and mathematics in the previous school year. The national targets set by the Scottish Executive for results in these subjects are that 80% of 8 year old pupils should have attained the target scores in these curriculum areas. Data also shows the class size and the percentage of free-school meals allocated to pupils in the sample classes was also similar.

**Table 1: Attainment and social comparators between schools selected for the sample**

	Percentage of pupils attaining national target scores in writing from class at age 8 year old	Percentage of pupils attaining national target scores in reading from class at age 8 year old	Percentage of pupils attaining national target scores in mathematics from class at age 8 year old	Free school meals per class	Average class size
School A	81	85	90	24%	19
School B	84	83	90	25%	20

Three pupils were absent from either the pre or post testing data collection reducing the sample size to 41 pupils. Data from these pupils is omitted from the data set presented in this paper. A series of activities, experiments and discussions was completed over four weeks during one session of two hours per week within the topic of light and earth and space. The lessons aimed to deliver carefully structured learning experiences. In particular the structure ensured children had appropriate scientific knowledge about the properties and nature of light upon which they could build and the teacher could scaffold the more abstract and complex concepts surrounding the earth in space. Therefore, the design of the intervention adopted for this study aimed to look at how the principals of constructivism could be embedded into a programme of science work in order to ensure that learning experiences carefully built on previous learning and concepts held by the children. In addition the teaching methodology adopted aimed to investigate the role of the teacher in scaffolding learning opportunities onto pre-existing concepts to promote concept change through social constructivist techniques. In these respects the research was building on previous work concerning children's science concepts, but was importantly establishing links between two science concepts that in previous work were examined separately and in isolation.

Evidence was collected through direct observation by the researcher, discussions and children's written products. The researcher tracked how each child progressed in relation to pre-specified learning outcomes. Data gathered were both qualitative and quantitative, concerned with process and with outcomes. The qualitative data consisted of video recordings and subsequent transcripts of conversations, throughout the research. The quantitative data showed the number of learning outcomes achieved and how they were achieved. These data collection methods were previously used by the SPACE project (Osborne, Black, Smith & Meadows, 1990) (use of drawings and talk to explore children's understanding), by Julyan and Duckworth (1996) (use of concept maps) and Trumper (2001) (the science attainment test). The study involved participant observation, in which one researcher was solely responsible for both teaching and assessing concepts. The researcher who undertook the research was a primary school teacher who was only teaching the study classes for the purposes of this intervention.

Learning outcomes relating to the nature of light and the solar system were specified, involving understanding of the following:

- Outcome 1 Light is produced by a range of sources.
- Outcome 2 Light travels outwards from these sources.
- Outcome 3 Vision occurs because light enters the eye from the object.
- Outcome 4 Light can be reflected.
- Outcome 5 Light travels in straight lines.
- Outcome 6 Shadows occur because objects block light.
- Outcome 7 The length of a shadow is dependent on the position of the light source and so the position of the sun in the sky determines the length of the shadow.
- Outcome 8 Light from the moon is reflected light from the sun.
- Outcome 9 The moon's phases are as a result of the relative position of the sun, the moon and the earth.
- Outcome 10 Light and dark are caused by the earth turning.
- Outcome 11 Light travels in straight lines and is reflected – practical application using a periscope

The study identified outcomes 1, 2, 3, 4, 5 and 6 as simple concepts and outcomes 7, 8, 9, 10 and 11 as complex outcomes about the properties of light. This distinction between simple/complex was made as simple concepts could be demonstrated easily in the classroom whilst complex concepts required the use of a model or analogy to represent what was happening. The complex outcomes therefore required the children to be able to apply knowledge and understanding gained through concrete experience into more abstract areas of study.

The Scottish national curriculum 5-14 attainment targets (Scottish Executive Education Department, 2000) to which these outcomes link are:

#### Energy & Forces

- give examples of light (attainment level A)
- identify the sun as the main source of light (attainment level B)
- link light to seeing (attainment level B)
- link light to shadow formation (attainment level C)
- give examples of light being reflected (attainment level C)

## Earth and Space

- link pattern of day and night to the position of the sun (attainment level A)
- describe how day and night are related to the spin of the earth (attainment level B)
- describe the solar system in terms of the Earth, sun and planets (level C)

Along with these, the pupil should develop the process skills of scientific investigations that will allow them to predict, hypothesise and test their ideas.

The 5-14 skills covered at attainment levels B and C are:

- preparing for tasks
- carrying out tasks
- reviewing and reporting on tasks.

To explore the children's previous knowledge, each child completed a concept map and a pre-topic test. The concept map was a bank of words relating to the subject to be taught and the concepts involved and the children individually found as many ways of linking each word as possible. This gave evidence of concepts already held and enabled clarification of any misconceptions. The technique of concept mapping was an adapted version of those developed by Novak (2002). The pre-topic test was a 12 item written test adapted from those developed by Trumper (2001). Results from the post test were triangulated against observations and results from discussions and concept maps. This allowed the test to be assessed for reliability and validity. Good correlations between the test and other data were observed in the sample. The same instrument was utilized to measure post test gains. Subsequent progression in concept development was also evidenced by individual writings or drawings, as well as verbal utterances. A small sub-sample was selected from the study sample. In depth video recordings were made of these children as they undertook the science activities. The recordings and transcripts allowed the tracking of each child's thinking and showed how previous knowledge was used or adapted during concept development, as well as how the researcher "scaffolded" (supported, questioned, challenged and extended) the children's learning. The researcher made field notes as activities were undertaken that indicated the techniques used to promote cognitive development (building and/or scaffolding and/or practical activity). A summary of the instruments utilised for data collection is presented in Table 2.

**Table 2: Data gathering instruments and how the information was obtained contributed to the results**

Assessment instrument	Notes on implementation	Contribution to results
12 item test	The test was administered pre and post implementation	Statistical analysis of the results from the pre and post test results was used to obtain a measure of learning.
Achievement of pre-defined learning outcomes	Field notes and children's products were collated with evidence from the pre and post test results.	Specific questions related to outcomes were used to contribute to the assessment as to whether the learning outcomes had been attained (the data was cross referenced to other observations).
Concept maps	This was essential to ensure that the planned programme of work was pitched at the right level to allow building and scaffolding during the intervention.	Data from the concept maps was used to carefully structure the planned programme of work and reflect on the nature of the interactions required between the learners and the teachers during subsequent learning experiences.
Transcript analysis from video tape	A tripod and unidirectional microphone was utilized to allow the data to be captured whilst the researcher scaffolded learning interactions with the children.	Data is presented as transcripts to explore the nature of interactions between the learners and the teacher-researcher and how these interactions may have promoted learning.

## Results - Outcomes

Data presented in Table 3 shows the pre and post test results. The tests were scored out of 20 marks. Data indicated significant gains in learning as evidenced through the instrument and tested by a one-way ANOVA ( $P < 0.001$ ,  $df = 1, 80$ ,  $F = 3.96$ ).

**Table 3: Pre and post test results of pupils**

	Score
Average pre-test result	5.76 (sd 3.68)
Average post test result	17.31 (sd 4.50)

Change	+11.55
Results of one way ANOVA of pre-post test results	P<0.001, df 1, 80, F=3.96

The following tables (Tables 4 & 5) summarise to what extent the individual learning outcomes were achieved, and how. Data in these tables was drawn from a wider source than just the pre and post test results. Pupil products, drawing and concept maps were cross referenced with research field notes to make decisions as to whether the learning outcome had been achieved. A very large gain in understanding was evident, fairly evenly distributed across all participants. Given the brevity of the intervention, it might be assumed that this was considerably greater progress than would normally be expected given traditional science instruction. However, although the intervention was brief (8 hours in total), it was intensive and involved a good deal of attention from a skilled and motivated adult.

The processes that led to the achievement of learning outcomes were defined by three processes:

Activity – where the pupils worked independently to complete a practical science task that facilitated the learning

Building- where the work built directly on previous knowledge and the pupils were able to build on these previous experiences to achieve learning

Scaffolding - where the work built directly on previous knowledge and the pupils were assisted to build on these previous experiences to achieve learning through discourse with the teacher-researcher

It appeared learning outcomes were achieved through a single strategy for learning in outcomes 1 and 8, either building or scaffolding. For other outcomes two or more strategies were employed. The most common strategies were the combination of scaffolding and activity (outcomes 2, 3, 7, 8 and 9) and the combination of building plus scaffolding and activity (outcomes 5, 6, 10 and 11). The least common strategy being building alone (outcome 1) and

building with activity (outcome 4). A few learning objectives were not achieved for some children irrespective of strategies used.

**Table 4: Pre-test assessment of learning outcomes**

Learning Outcome	Number of children displaying knowledge and understanding in relation to the learning outcomes
Outcome 1 Light is produced by a range of sources	41
Outcome 2 Light travels outwards from these sources	25
Outcome 3 Vision occurs because light enters the eye	25
Outcome 4 Light can be reflected	4
Outcome 5 Light travels in straight lines	3
Outcome 6 Shadows occur because objects block light	1
Outcome 7 The length of a shadow is dependent on the position of the light source and so the position of the sun in the sky determines the length of a shadow	1
Outcome 8 Light from the moon is reflected light from the sun	0
Outcome 9 The moon's phases are as a result of the relative position of the sun, the moon and the earth	0
Outcome 10 Light and dark are caused by the earth turning	4
Outcome 11 Light travels in straight lines and is reflected – practical application using a periscope <sup>b s a</sup>	1

**Table 5: Post-test overall assessment of learning outcomes**

Learning Outcome	Number of children displaying knowledge and understanding in relation to the learning outcomes
Outcome 1 Light is produced by a range of sources <sup>b</sup>	41
Outcome 2 Light travels outwards from these sources <sup>s a</sup>	41
Outcome 3 Vision occurs because light enters the eye <sup>s a</sup>	38
Outcome 4 Light can be reflected <sup>b a</sup>	39
Outcome 5 Light travels in straight lines <sup>b s a</sup>	39

Outcome 6 Shadows occur because objects block light <sup>b s a</sup>	37
Outcome 7 The length of a shadow is dependent on the position of the light source and so the position of the sun in the sky determines the length of a shadow <sup>s a</sup>	32
Outcome 8 Light from the moon is reflected light from the sun <sup>s a</sup>	31
Outcome 9 The moon's phases are as a result of the relative position of the sun, the moon and the earth <sup>s a</sup>	30
Outcome 10 Light and dark are caused by the earth turning <sup>b s a</sup>	33
Outcome 11 Light travels in straight lines and is reflected – practical application using a periscope <sup>b s a</sup>	38

In Table 5, outcomes associated with building on previous knowledge are marked b, outcomes associated with scaffolding are marked s, outcomes associated with investigative activities are marked a.

## Results - Process

A sub-sample of six children from one classroom situation was selected for in-depth analysis in respect of their responses during initial questioning and subsequent practical activities. Results from this small sub-sample are reported below. In the samples of discourse that follow, unattributed utterances were from the researcher. Children's utterances are identified by an initial for each child.

### Learning outcomes 1 - Light is produced by a range of different sources & 2 Light travels outwards from these sources.

The children all had experience of light and where light comes from, however they may not have considered the variety of sources and that light comes from these sources. The children were asked to use what they knew about where we get light from during the day and at night. All were able to name and draw at least 8 sources of light which included natural and man made sources. All children had included the sun and all had drawn a stylised version of the sun with radiating lines. Only one child had drawn radiating lines on other sources of light - a torch and lamp post indicating light coming out from these sources. When children were

asked about radiating lines on the sun, they replied that it would be the moon if it did not have these lines and that was how they drew the sun. This would mean that the lines did not represent light. When the individual who drew radiating lines from other sources was asked about this, he said that this showed the light coming off.

#### **Learning outcomes 4 - Light can be reflected & 5 - Light travels in straight lines**

The researcher reflected light from a mirror on to the ceiling. The children were asked why they thought the light from the torch shining in one direction (away from the ceiling) was able to change direction. All children were able to explain that it bounced off the mirror. Two children used the word “reflect”. The children were familiar with the concept that light can be reflected. The children were given a mirror and a torch and experimented with reflecting light on to different parts of the room. They were then asked to place the mirror in front of them and the torch behind and to the side of them and try to see the light in the mirror. They were asked to explain this. One child said the light was going round him, another said he was reflecting light. The children then made drawings of what they thought was happening. Only two children gave an indication of light travelling to the mirror and bouncing back into their eyes. This can be seen in Figures 2 and 3.



Figure 2

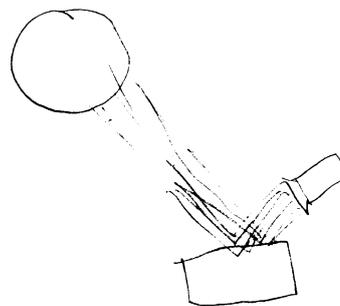


Figure 3

Both show an understanding of light travelling but figure 3 represents light as a number of lines being reflected – a very accurate representation of what is happening.

## **Learning outcome 6 - Shadows occur because objects block light**

The children knew from their own experience that there are lots of shadows at night. However, the initial discussions suggest that the children were not aware of why shadows are formed.

When do you see lots of shadows?

M: Summer time – When the sun shines on a wall and you're standing there you can make shadow puppets on the wall.

In the summertime when there's lots of.....?

All: Sun – Sunshine.

H: I can see lots of shadows at night time.

Why do you see lots of shadows at night time?

G: Lampposts cast shadows at night.

K: When you switch the lights on when it's still dark, then you see shadows because there's darkness outside.

(The children had linked light and dark to shadows from their previous experience. The children then made shadows on a sheet of white paper on the table using torches and small objects such as wooden bricks, pencils, rulers, etc., and were asked to think about why the shadows were formed.)

What do you need to have to make shadows?

G: There wouldn't be a shadow if there wasn't anything to cast a shadow off of.

We need something to cast the shadow. What else?

R: Light.

Light, because if it's all dark then ....?

M: If it's all dark we would see nothing.

That's right - if it's all dark, everything would be a shadow.

(The researcher then returned to the original question about when lots of shadows can be seen, and two of the children pre-empt the discussion.

When do you see lots of shadows?

G: When light can't get round things.

R: When light is being blocked.

(The other children agree with this. The children are learning from each other's responses to questions.)

**Learning outcome 7 - The length of a shadow is dependent on the position of the light source and so the position of the sun in the sky determines the length of the shadow.**

The children were given torches and wooden bricks, and were asked to make shadows. They were asked to try changing the position of the torch relative to the brick to see what effect this had on the shadow. The following discussion took place.

When you've got your object, think about what happens to the shadow when you put the light up and down and move it around.

(The children experimented. Some held the torch above the object and moved it round but not down to create different lengths of shadows.)

How would you make a long shadow?

G and R: We've got a really long shadow.

(They had shone their torch from the same level as the object.)

Can you think of an occasion when you get long shadows outside?

M: Sunny days.

Yes, what time of day do we get long shadows?

R: I think it's about 5 o'clock.

(The researcher demonstrated using a torch, moving it in an arc above the object to simulate the "apparent" movement of the sun.)

When the sun is up high in the sky, do we get much of a shadow?

R: No when it's down low – yes.

You'll get long shadows at what time of day?

R: Morning and night.

(The link had been made that when the sun is low in the sky the shadows are long. The children then experiment making long shadows. All children discovered that the higher the torch, the shorter the shadow and the lower the torch the longer the shadow. They had been able to relate this to the sun's position in the sky.)

**Learning outcomes 8 - Light from the moon is reflected light from the sun & 9 - The moon's phases are as a result of the relative position of the sun, the moon and the earth**

When discussing shadows, one child introduced the idea of the earth making a shadow.

R: The earth makes a shadow to us at night time.

What do you mean by that?

R: Not sure.

Imagine you are out in space looking at the earth.

G: You know when you see the moon – full moon and half moon. It isn't always a full moon because it's just the earth's shadow casting on to the moon.

(G has the concept of shadow causing the phases of the moon.)

Where does the light from the moon come from?

D: From the sun.

From the sun. That's right – but sometimes you see a half moon. Why?

R: It's the clouds.

But sometimes it's a clear night and there are no clouds about and you can still see a half moon. Why is that?

(The children had no knowledge of the reasons for the phases of the moon other than G who knew it concerned shadows. An analogy was used by the teacher to explain.)

Imagine I have a ball here and I shine a light on it from this side. The light's shining on this part of the ball. What's happening on the other side of the ball?

K: The light is trying to block the darkness from the ball.

(The researcher assumed that what K meant was that the ball was blocking the light. The researcher demonstrated by shining the torch on to one side of a ball and drew attention to how it appeared depending on the angle from which it was viewed.)

Here is the sun shining on the moon. What are you seeing here?

M: I'm seeing half a moon.

(M has linked the torch and ball to the moon and sun.)

That's right; you're seeing half of it because half of it is lit. What's happening when you see half a moon?

R: We know that the sun doesn't move.

But we do.

R: Yes, we do and the moon does, so that's why we see - sometimes we can see half of the moon.

(The researcher moved the position of the ball/moon relative to the torch/sun to show how different proportions of the ball appear to be lit from a central position (that of the earth in this model). The children tried this activity and with relevant questions from the researcher, they had a model with which they could explain the phases of the moon.)

### **Learning Outcome 10 - Light and dark are caused by the earth turning**

This L.O. is a difficult concept unless viewed from space and so an analogy was used. This required the teacher to help. The following discussion showed what the children knew about the sun and why it gets dark at night.

Why do we need light? What is light for?

K: We wouldn't be able to see.

What happens when it gets dark? Why is there no light?

M: The sun goes in and the moon comes out so it's still a bit bright.

G: Because if there wasn't any sun, it would be night all the time.

(This shows understanding of the fact that when it is dark, the sun is not in the sky.)

So we get light from.....?

H: The sun.

D: I've got another answer. It's because the world turns round.

Because the world turns round? Can you explain that a bit more?

D: No.

None of the other children could explain this. They knew that the world turns round and this had something to do with day and night. The researcher gave an explanation about the earth spinning and moving around the sun. The children modelled the solar system. Using this, the researcher pointed out the position of different parts of the world and asked the children why the earth turning round meant that there is no light at night.

What's light for?

H: To see.

We get light from....?

K: Sun.

At night it's dark because.....?

G: Sun goes behind the moon (explanation of an eclipse).

The reason we don't get sun at night is...?

G: It's on the other side.

(G knows this but still has a misconception that it has something to do with the moon.)

When it's light here where is it dark?

D: The other side of the earth.

(The children established that their position on earth and the relative position of the sun determine whether it is night or day. However, some were still holding on to some idea about the moon also being responsible. The children were asked to draw a picture or write an explanation to show what happens to the light at night.)

### **Learning outcome 11 - Light travels in straight lines and is reflected – practical application using a periscope.**

The children had experience of mirrors and knew that mirrors reflect. From previous experiments, they knew that light travels in straight lines. The children were given a periscope and asked why they could see over walls etc. with this. They were encouraged to think about what they had learned about light coming into their eyes and mirrors reflecting light. The following conversation took place.

I can be down here (below level of table) but I can see you. What do you think is happening here?

D: We're looking in the mirror here. The person that you're looking at – the mirror reflects their reflection down here - into here - into that end. (Points to show how the image travels from outside into bottom of periscope and is reflected up the periscope to the person using it)

(D has used what he knows about reflection and light travelling to explain how the periscope works.)

K: It looks like you're down on the ground.

M: What happens if you reflect light into it? (Points to top of periscope).

Try it. What will happen? Will the light reach her eyes?

R, G and M: Yes.

Why?

G: There are mirrors and when you shine light, it reflects off one of the bits because it's kind of tilted and then goes up a bit.

(G has realised that the mirrors have to be tilted so that the light is reflected in the desired direction.)

If I shine the light in here (top of periscope) then where is the light going?

M: It goes into Katherine's eyes.

How does it do that?

M: Because it's got mirrors.

And what do the mirrors do?

M: Reflect.

If I don't shine a light in here, how can she see anyway? What's going in here to let her see?

(No response. The children know that if they shine a light in the end, it is reflected and travels up the periscope and is reflected again and goes into K's eyes so that she can see this. The children have not yet grasped the idea that other ambient light is going in there too.)

If I cover this up (puts hands over the end of the periscope) would she see anything?

All: No.

Why not? Why won't she see anything?

G: Because it wouldn't be reflecting.

What am I stopping getting in here?

G: Light.

(G has used what he already knew. Light is needed to see. The children then drew pictures of how a periscope works. All produced a picture indicating light travelling and reflecting in straight lines. See Figures 4 and 5 below.)

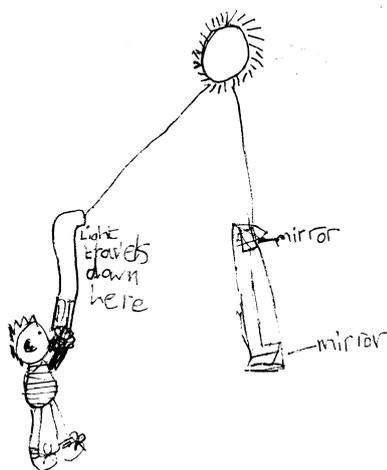


Figure 4

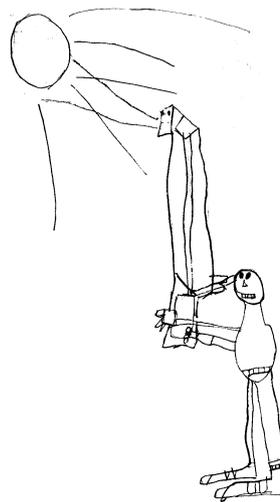


Figure 5

Analysis of the discourse contained in the transcripts indicated that after initial expression of ideas and concepts, children could learn effectively if they undertook practical activities that were supported by social interactions. The data also indicated there were important roles to be played by both the teacher and peer group in this respect. The practical activity appeared to be important in allowing the children to reconstruct meaning from the discussion. An example of this is contained in the transcript that related to Learning outcome 7. Initially the children were guessing when long shadows would be produced by the sun. However, after careful questioning, the practical demonstration using the torch and discussion then the children were able to relate the position of the sun to the shadow that it cast. Similarly in the transcript associated with learning outcomes 8 and 9 initial questioning revealed that the children were not able to establish link between their existing knowledge about light and shadow to the explanation of why we see phases in the moon.

## **Discussion**

This study has a number of limitations in methodology. In the tradition of participant observation, the agent of intervention was also the gatherer of data, which may have introduced bias. The data gathering instruments were of unknown reliability and validity, although they had high face validity. All required interpretation and judgement, but inter-rater reliability was not explored. The sample size was small, and it is unclear how representative of what population, so any generalisation of the findings requires great caution. No control or comparison groups were involved. Nor is it known whether the gains reported would have endured at medium- or long-term follow-up.

On the other hand, the activities were naturalistic, and the children had no obvious motivation to respond in anything other than a spontaneous and unbiased manner. The study successfully investigated in detail the process of concept change in a small number of learners in the learning context studied. Further work will be required to investigate how useful such methodologies might be in larger scale studies in wider educational contexts.

The study explored the constructivist development of scientific constructs by children in respect of light and the earth and space, highlighting the important role that language and social contact can play in this. The data supports social constructivism as an effective model of promoting children's learning in science (Vygotsky, 1978).

Campanario (2002) contends that the role of language is vital to allow concept change. Without it children's misconceptions might be often left unexplored (and often not understood by the learner themselves). Therefore, misconceptions can perpetuate in the learner, without the use of talk to explore ideas. Ollerenshaw & Ritchie (1998) emphasise the importance of talk in allowing learners to explore their ideas and subsequently reconstruct them on the basis of experience. The social aspect of constructivism has been asserted as essential to allow effective testing of ideas (Terhart, 2003). Careful questioning and practical activity facilitated the development of a model of why we experience night and day and phases of the moon are experienced on earth. The practical work might also have stopped the talk becoming the kind of closed interaction (initiation, response, follow-up/evaluation) that has been reported to dominate talk in traditional science lessons (Jones, 2000).

## **Conclusion**

This study showed how nine-year-old primary school children construct meaning and develop understanding in science, albeit with a small sample in a specific context. The importance of exploring the child's existing conceptions and misconceptions through interactive discussion was highlighted, as was the importance of expert questioning and scaffolding to build wider and deeper understanding which took those preconceptions into account.

Pre- and post-intervention assessment, criterion-referenced to specified learning objectives, indicated very large gains in participant understanding. Teaching techniques adopted emphasised the importance of building upon the participants' prior understandings, the role of attuned questioning and scaffolding by an adult, and the important role of practical activity science investigations. Simpler learning outcomes could be achieved through either building on existing child knowledge or as a result of scaffolding through careful interaction and discourse. However, more complex outcomes required the use of a combination of these along with investigative practical activities. All of the planned interventions that resulted in the gains in terms of the learning outcomes demonstrated by the children were associated with an element of practical activity. The nature of how these practical activities were integrated into the intervention are illustrated in the transcript reports associated with learning outcomes 4, 5, 6, 7, 8, 9, 10 and 11. Teaching for deep understanding in this way has been widely reported to be desirable, if complex to achieve in practice (Wallace & Loudén, 2003).

Studies and reviews have focused on the tensions between the theories of cognitive and social constructivism. They have often sought to extol the virtues of one at the expense of the other (eg Matthews, 1997; Bee, 2000; Fox ,2001). Data presented in this paper indicates that that learning in science has both a social and cognitive dimension. Planning appropriate learning experiences that take account of the need for both cognitive and social issues to be addressed can result in substantial gains in outcomes for pupils. In particular the study illustrates the need for careful planning in terms of building and scaffolding on previous learning through practical activities. It also indicates that substantial gains in attainment can be achieved when the underpinning scientific concepts are taught in conjunction with more complex ones.

### **Action Implications**

The intervention was a relatively brief (8 hours), but labour intensive in that the adult expert operated only with a small group (n=41) of children. This raises questions about transferability of these methods to the teaching of science to larger classes and indeed to other science areas! However, the principles of:

- making existing understanding and misconceptions explicit,
  - building upon existing knowledge through questioning and scaffolding, and
  - deploying practical activities especially for those learning objectives not amenable to the development of adequate understanding through building and scaffolding alone,
- would appear to be transferable to the larger class situation. Practical investigations are time consuming and organisationally demanding, so it is important that teachers use them strategically. Indeed, some concepts cannot be demonstrated through practical activities and so learning through discussion of abstract concepts might be essential. A number of recent publications have highlighted the benefits of practical activities in science (eg Topping and Thurston, 2004).

Class teachers might need further continuing professional development to facilitate this, perhaps particularly in relation to building, questioning and scaffolding skills (Wallace & Loudon, 2003). The development of the ability to both interpret children's ideas and focus on the nature of the ideas to allow effective teaching and learning in primary science has been deemed essential (e.g. Parker, 2004). Teachers might benefit from video recording of their interactions with children in class, followed by self-assessment and reflection upon the quan-

tity and quality of interaction. In larger class settings, interactive learning of science might also be achieved through peer assisted learning (e.g. Christie, Topping, Thurston, Tolmie, Livingston, Howe, Jessiman & Donaldson , 2004).

Children and staff who have been used to traditional didactic instruction might take time to adjust to a more constructivist way of learning (Wallace & Loudon, 2003). It will be important that they can freely express their ideas and are not inhibited by the possibility of being wrong, so the sociology and ethos of the classroom is likely to be important with respect to collegiality and trust. Giving ownership of scientific investigation to children seems likely to increase motivation and enhance self-efficacy (Kempa and Dias, 1990).

It seems important that children are taught the skills of the scientist as early as possible. They should be encouraged to think in a logical scientific and independent way - questioning, discussing, predicting, hypothesising and testing their ideas. Cognitive development of this nature may result in gains across the curriculum as scientific skills and thinking skills are often indistinguishable.

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