PROGRESSION IN STUDENTS' UNDERSTANDING OF REFLECTIONS IN A POND: AN ACROSS-AGE PILOT STUDY

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(Paper for presentation at AARE Conference, Newcastle NSW, November 1994)

ABSTRACT

In a pilot study of school children (K-10), conceptions of how and why objects are seen when looking at the surface of water in a pond were explored by examining students' responses to drawings and text depicting this common phenomenon. Using a questionnaire and individual interviews, 214 responses to two items were obtained. A developmental model of cognitive functioning based on the updated SOLO Taxonomy (Biggs and Collis, 1991; Collis and Biggs, 1991) was used to analyse the data. Students' understanding of the reflection of a tree appears to progress from an intuitive idea of a picture on the water to a virtual image described in concrete symbolic terms using concepts of reflection and light rays which have particular properties. Some responses which appear to reflect alternative conceptions of why things happen as they do are evident in this progression.

INTRODUCTION

Light is an essential feature of everyday life and hence children have some informally derived understanding of light and light-related phenomena from a very young age. All objects on earth reflect light to some extent but such a notion is not common among young children (Guesne, 1985). Students conceptions about the reflection of light by mirror have been well documented (Bendall, Goldberg & Galili, 1993; Goldberg & McDermott, 1986; Guesne, 1985; Ramadas, 1981; Stead & Osborne, 1980), however researchers have not looked at children's interpretations of reflection phenomena in any detail using naturally occurring surfaces such as water. In addition, few analyses have involved a consideration of the nature of the cognitive processes involved in the different types of responses given by students to such stimulus situations.

A developmental model of cognitive functioning based on the SOLO Taxonomy (Biggs & Collis, 1982; updated in 1991) is being used to provide another interpretive window into the nature of students' alternative views about aspects of 'vision'. This study is part of an exploration of the nature of cognitive processes involved in responding to stimulus questions or situations involving physical phenomena.

SOLO TAXONOMY AND MULTI-MODAL FUNCTIONING

The SOLO Taxonomy (Biggs & Collis, 1982, 1991; Collis & Biggs, 1991) has been used to analyse the structure of children's understanding of mathematical and science concepts. The SOLO theory, involves a five-level cyclical structure for responses within each of five modes of cognitive functioning. The theory postulates that modes of functioning begin to appear sequentially from infancy and each one may remain operational and develop further throughout life.

The modes, and periods of first appearance, are: Sensorimotor (sm:

infancy), Ikonic (ik: early childhood to preschool), Concrete Symbolic (cs: childhood to adolescence), Formal (fm: early adulthood), Post Formal (pf: adulthood). They should not be confused with Piagetian Stages.
The sensori-motor and ikonic modes provide their own distinctive forms of knowledge in adult life; they are viewed as developing throughout life, and in interaction with other modes. Such co-existence of qualitatively different forms of functioning provides the opportunity for multi-modal learning where learning within one mode is supplemented by experiences and activities in concurrent modes (Collis & Biggs, 1991).The features of these modes are detailed in Table 1 and described elsewhere in detail in relation to science by Jones, Collis and Watson (1993).

TABLE 1: DISTINCTIVE FEATURES EXHIBITED WITHIN EACH MODE OF COGNITIVE FUNCTIONING

OVERVIEW AND METHOD OF THE STUDY

Students' Understanding About Vision.

Initially, we obtained random samples of scripts from the large questionnaire study, conducted by the Australian Council for Educational Research, of science learning of Victorian school students in Grades 5 and 9 (Adams, Doig & Rosier, 1990). Students' responses to those items concerning 'light and vision' were re-analysed in terms of their structure according to the SOLO Taxonomy and its recent theoretical developments relating to modes of functioning. On the basis of this analysis (Jones et al., 1993) further questionnaire items have been developed to fill gaps in the available data.

The Questionnaire and its Trial

A set of nine questionnaire items, in cartoon format, were generated to explore children's beliefs about how people see objects and the role of light in this process. In order to test the effectiveness of each item to determine children's understanding of the key phenomena, the questionnaire was administered to whole classes from Grades 2 to 10 (n=202) in suburban primary and secondary schools in or near Hobart. The same questionnaire was used as the basis for individual interviews with 12 children from Kindergarten to Grade 1 whose verbal responses were recorded on audio tape and later transcribed. Each item in the questionnaire gives the student the opportunity to indicate how certain he or she is about their answer by circling one of three certainty levels available at the end of the item. The choice is between -

I'm guessing I'm not too sureI'm sure I'm right
C1C2C3
For the purposes of this paper Items 6 and 7 only, and the analysis of responses to them, will be reported in detail.

Questionnaire Items 6 and 7

Items 6 and 7 present a situation where reflection can occur in nature, namely, a pond with a tree or trees nearby (Fig.1 and Fig.2). The water acts as a potential reflector, the shape and clarity of the reflected image depending upon factors such as the weather and the position of both the object and the observer. The cartoon sketch in Item 6 (Fig.1) shows a view of a pond with a pine tree standing on its bank. The student is asked to decide if he or she could see a reflection of the tree in the pond if standing at X and to write an explanation as to why they have answered in this way. The student is then asked to draw what would be seen if the answer is in the affirmative.

Item 7 presents a cartoon sketch of a pond with a different tree at either end of it and a reflection of one of the two trees visible in the water (Fig. 2). The student is asked to indicate where he or she would have to stand in order to see the tree in the pond as shown in the sketch and give reasons for this answer.

All responses to the two items, as well as the indication of certainty, were entered into spreadsheets. Item 6 was used in the categorisation of the responses and Item 7 was used to provide supporting evidence for these groupings.

"If you were standing at X, could you see the tree in the pond?
Explain your answer.
If you could see the tree, draw in the pond what you could see."
Fig.1 Questionnaire Item 6

"Draw where you would have to stand so that you could see the tree like it is shown in the pond. Explain why."
Fig.2 Questionnaire Item 7

RESULTS

The students' responses to Item 6 were grouped in terms of their understanding of the reflection phenomenon as indicated by the nature of their explanation and the orientation of the accompanying drawing. Many students did not include a drawing of any kind and this provided a very important clue to their understanding of the concept of reflection. The term 'reflection' was used very frequently but usually as a name for what students saw on the pond rather than as an explanation of a process which results in their perceptions.

Five groups of responses were identifiable (summarised in Table 2) ranging from those which suggested a belief that what is seen in the water is a picture (and self evident or unproblematic) to those which suggested the phenomenon is dependant upon various environmental conditions and observer positions. Such a progression is also associated with a change in students' expressions of certainty about

their answers. As students' understanding appears to develop, the degree of certainty that they express about their responses rises to C3 (I'm sure I'm right). However, further progression is accompanied by a drop in the level of certainty.

TABLE 2: CHARACTERISTICS OF EACH GROUP OF RESPONSES, CATEGORISED ACCORDING TO UNDERSTANDING OF THE CONCEPT OF REFLECTION

Group	Characteristics of Each Group
1	A drawing was produced (with incorrect orientation = upright). The 'tree' can be seen in the pond; like a picture. (Certainty Levels not obtained - verbal responses only)
2	NO drawing produced. The 'tree' can be seen in the pond; like a picture. No explanation. (Certainty Level 1 or 2 selected)
3	A drawing was produced (with correct orientation = inverted). The 'tree' can be seen in the pond. The term 'reflection' NOT used. Explanation in terms of shadow of tree OR no explanation given. (Certainty Level 3 selected)
4	A drawing was produced (correct orientation generally) The 'tree' can be seen in the pond. A concept of 'reflection' was used as an explanation. (Certainty Level 3; few Level 2)
5	A drawing was produced - correct orientation (inverted). A concept of 'reflection' used or inferred and associated with one or more variables e.g., relative positions of the observer and/or sun. Responses emphasized conditions associated with reflection and mostly interms of shadows. (Certainty Level 1 or 2 selected)

The number of children responding in each of the five groups is set out by grade level in Table 3 and is based on a consensus of the authors. In the following description of the groups, typical responses are

followed by an identification number, then as being made by a male (m) or female (f) and by school grade of the respondent . The certainty level (C1, C2 or C3) selected by the student is also included.

Group 1. The students had an intuitive idea of a 'picture' of the pine tree on the water. Without exception, the trees that they drew in the pond were upright representations of a tree. If the term 'reflection'

was used, it was meant as a name for what is seen as self evident. It did not appear to indicate an understanding of a process by which the image appears 'on the water'. The majority of these responses were given by students who were interviewed and the level of certainty of their responses was often not ascertained. Typical responses are of the following type:

* Yes, because when you look at the tree a little bit and then you just draw it butthen you look at it a little bit more. (116f 1)
* Yes...just a picture. A picture with copies. (114m P)
* Yes, because you're looking at the tree and the water. (52m 4) C2
*...Because it's reflecting. Reflecting means it's not really on the water, it's justits shadow facing on the water but it's not really growing in the water. (107m K)

TABLE 3: PERCENTAGES OF CHILDREN BY GRADE IN EACH SPECIFIED GROUP OF RESPONSES (number of children is shown in brackets)

GRADE	K-1	2	3	4	5	6	7	8	9	10	Total
Group 1	84	7	0	9	0	0	0	0	0	0	6
	(10)	(1)	(0)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(13)
Group 2	8	26	7	4	11	0	12	0	0	0	6
	(1)	(4)	(2)	(1)	(2)	(0)	(3)	(0)	(0)	(0)	(13)
Group 3	0	7	20	9	5	5	12	16	4	0	9
	(0)	(1)	(6)	(2)	(1)	(1)	(3)	(4)	(1)	(0)	(19)
Group 4	0	33	53	56	42	58	40	56	17	57	44
	(0)	(5)	(16)	(13)	(8)	(11)	(10)	(14)	(4)	(13)	(94)
Group 5	0	0	13	22	42	32	24	16	57	39	26
	(0)	(0)	(4)	(5)	(8)	(6)	(6)	(4)	(13)	(9)	(55)
unclassified	8	27	7	0	0	5	12	12	22	4	9
	(1)	(4)	(2)	(0)	(0)	(1)	(3)	(3)	(5)	(1)	(20)
Number in class	(12)	(15)	(30)	(23)	(19)	(19)	(25)	(25)	(23)	(23)	(214)

Group 2. Responses in this group were, in all cases, made without the inclusion of a drawing of a reflection of the tree in the pond. Again, the intuitive idea that there is a 'picture' of a tree on the water is present but now there seems to be a large element of doubt about how the 'picture' actually looks. None of the students use the term 'reflection' in their responses and most students indicated that their responses were made with little certainty, e.g.,

* Yes you could see the tree in the water. (62m 4) C2
* You would. It would look like it would be on the water. (70m 5) C2
* Yes because the pond is so big you can't see the land over the other side. (10f 7) C2

Group 3. The most important indication that there has been a

development in the understanding of how a reflection is made is that the students in Group 3 now include a correct, inverted drawing of the tree in the pond. Its orientation appears important with respect to where the 'real' tree is located and what is in the pond is no longer considered to be a picture. Again, the responses in this group are

interesting in that none of them include the word 'reflection' in their explanations. A high level of certainty is expressed in most responses, e.g.,

* Yes, it would be upside down. (29m 3) C3
* Well, yes you probably could because say you can see the tree then you look inthe pond you could probably see it upside down. But I don't know how toexplain the rest. (79f 5) C3
* Because you're standing in front of the tree not behind it. (24m 7) C2
* The pond is light and the tree is shadowing on it so you can see a shadowshaped like the tree. (34m 8) C3

Group 4. Responses of this group are characterised by the use of some concrete concept of reflection. The term 'reflection', or a derivative, is used with a variety of meanings from a noun to a process. Often, as a technical term, it is the entire explanation. At this stage of understanding the orientation of the reflection in the water becomes of secondary concern and although most drawings are correctly orientated, some reflections are drawn upright. It should be noted that the majority of students indicate a high degree of certainty about the correctness of their responses. This feeling of confidence may be arise from the use of a technical term, e.g.,* Because it is a reflection. (25m 2) C2

* The water reflects the tree. (4f 2) C3
* Yes, it's reflecting the image (of the tree). (8m10) C3
* Yes, because the tree reflects onto the water. (105f 6) C2
* You could see it because of the reflection. (61m 4) C3
* Yes, water would reflect the tree like a shadow. (23f 8) C3
* Because the pond reflects the vision of the tree. You ... see a mirror image. (24f 8) C3
* Because you look onto the water it reflects off the water and you can see thelight reflecting off the tree. (2m 10) C3

Group 5. There is an indication that what can be seen in the pond by those in Group 5 is dependent upon a number of environmental variables such as the position of the sun and the observer, and the condition of the water. The term reflection is used with more discrimination but sometimes the concept is only inferred in the explanation. The concrete concept of reflection appears to be becoming more abstract and as such this progression is often accompanied by the students expressing less certainty in their answers. Typical responses were:

* You could see the tree but ...only see the tree in the water if the sun was behind it so it could reflect onto the water. (100f 6) C1
* You have to be opposite the thing you want to see in the water. (9f

3) C2

* Yes (depending on the weather) the light and image is reflected in the water in front of the object. (20f 8) C2
* Yes, but only just. It would be very distorted because you are in front of thetree, it would appear very short and would be very blurred. (1f 10) C3

The data in Table 3 is portrayed in two graphs for clarity, (Figs. 3 and 4). The distribution of the children within the five groups changes across grades but it is acknowledged that due to the small size of the samples from each grade this may not be representative of the larger population. Group 1 responses are at a peak of 84% in the K-1 age group, the frequency decreasing sharply to zero by Grade 5. The frequency of Group 2 responses across the grades is generally below 12%, except for a small peak of 26% in Grade 2, such responses are not in evidence after Grade 8. Group 3 responses reveal two main but small peaks in Grade 3 (20%) and 8 (16%) with all other Grades revealing a frequency of less than 12%. By Grade 3, the frequency of responses in Group 4 is between 40% and 60%, except for a sharp drop in frequency in Grade 9 (17%). The frequency of Group 5 responses peaks in Grade 5 (42%) but falls off in early secondary school before peaking again in Grade 9 (57%). It could be that the reduced frequency in Grade 10 is specific to the particular grade surveyed.

The overall percentage of responses in each group is represented graphically in Fig. 5. Group 4 responses are the most frequent (44%) followed by Group 5 (26%). However these results may be accentuated by the relatively small numbers sampled in Grades K to 2.

Responses to Item 7 in the questionnaire generally support the theoretical structure presented above for grouping responses to Item 6. Figure 6 portrays graphically the relationship between the frequencies of correctly oriented reflections in Item 6 and correctly positioned observers in Item 7. The graphs show a gradual increase in the success rate to orient the reflection correctly, across grades, for Item 6. It is virtually mirrored by the data from Item 7. It was very rare for the students to predict the correct position of the observer in Item 7 without first having drawn the tree's reflection correctly in Item 6. By far the most common incorrect alternative for placing the observer was under the pine tree on the right side of the pond. Overall, 35% stated this alternative which they justified most commonly on the grounds of proximity and sometimes clarity e.g.

* ...you would be closer to the reflection. (5m 10) C2
* ...because you are standing at the tree that is reflected. (30f 9) C2
* ...because you are looking from the same way as it is reflected. (17f 7) C2
* ...because you wouldn't have the sun in your eyes. (61m 9) C2

However, one boy who located the correct position under the willow tree probably reasoned from an alternative conception of reflections when he stated that it was

* ...because if you were on the other side you would block out the sun. (61m 4) C2

In both questions there is a sharp decrease in the frequency of success in Grade 4.

Fig. 3 Percentage of responses within groups 1, 2 and 3 by grade level

Fig. 4 Percentage of responses within groups 4 and 5 by Grade level

Fig. 5 Percentage of children within each of the five groups of responses

Fig. 6 Percentage of children with correct orientation of tree reflection in Item 6
and/or observer position in Item 7

DISCUSSION

Further analysis of the groups of responses, using the SOLO model, indicates that the understanding of the reflection phenomenon progresses from intuitive and experiential through a more concrete conceptual understanding towards a more abstract one. Students in the first four groups appear to be responding in the ikonic mode. Those in Group 1 can visualise what a tree normally looks like and they draw it upright in the pond whereas those in Group 2 recall from experience, albeit vaguely, that the orientation of the 'picture' is problematic. Group 3 respondents appear to be able to recall visually their experiences of inverted representations on reflective surfaces and get the drawing correct. A few explain the phenomenon by mentioning

shadows. In Group 4 a number of respondents explain the 'reflection' by associating it with shadows and the illumination of objects by light. Others make a simple linkage with mirrors. Group 5 responses are more extended and refer to conditions necessary to produce reflections, often, quite clearly, in terms of the conditions for producing shadows. However, most of these also are construed as ikonicly derived connections between images of experience. Only a very few responses may represent a transition towards concrete symbolic thinking such as, for example, the Grade 9 boy who wrote;

* The angle of sight that is apparent if you are looking at the surface of the water reflectsthe image of the tree. (49m 9).

Although ambiguous, it is reasonable to believe that the boy understands there is an angular relationship between the position of the observer's eyes and what is seen in the pond.

With regard to the higher level of certainty of those whose responses are in Group 3, their feeling of confidence may arise from their ability to use a technical term such as 'reflection', at least to name a phenomenon. Their subsequent thinking may show up the inadequacy or limitation of that ability and prompt the need to generate further meaning with its initial inherent uncertainty.

Although an increasing complexity of the responses from Group 1 to Group 5 has been noted, it does not appear to be associated with the development of a school science explanation of vision. Indeed the responses of some students can be interpreted plausibly in terms of the alternative conceptions of vision already documented (Guesne, 1985). As already noted 'reflections' were explained by some students in terms of shadows. In all, 17% of the sample made direct reference to shadows or to the importance of having the sun behind the tree on the opposite side of the pond in order to explain how the reflection of the tree could be seen in the pond, e.g.,

* The sun is behind it making shadows on the water. (42m 8)
* You could see the tree but you could only see the tree in the water if the sun wasbehind it so it could reflect onto the water. (100f 6).

It appears that these students may believe that objects or surfaces do not reflect light (in contrast to the current scientific view) but they do block its travel. Light travels from sources such as the Sun but stops at any object in its path thus creating a shadow beyond surrounded by an illuminated surface. The shadow is 'the reflection' of the object. This explanation of reflection may arise from the alternative view of vision we term the 'object illumination' view in which light as an entity travels from its source to an object making the object bright but there is no object-eye connection with regard to light.

A second alternative, the 'visual ray view' of seeing, appears to be used by at least one student, from Grade 9. In this view, eyes emit one's 'vision' (or 'rays') towards objects to detect their presence. The boy wrote;

* ...you could see the tree...because the water would act as a reflective surface andreflect your eyesight directly onto the tree. (54m 9) C2

Notwithstanding the examples already discussed, very few students referred to light in their explanations except in the production of shadows and fewer still stated or implied a transmission of light from the pond surface to the eyes. Such abstractions which would characterise concrete symbolic and formal modes of thinking were largely absent also in student responses to a different context in another study (Jones, et al., 1993).

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DRAWINGEXPLANATION

GROUP	Drawing correct	Drawing 'reflection' used	Word expln.	Shadow expln.	Other Confidence
1	*	rare	rarerare	?	
2	1+ 2				
3	*	*	*	3	
4	*	mostly	*	*	2+ 3
5	*	*	*	**	1+ 2