COGNITIVE LEVELS AND MODES OF RESPONSE IN YOUNG STUDENTS' EXPLANATIONS OF SIGHT AND REFLECTION.

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ABSTRACT

The developmental model of cognitive functioning based on the updated SOLO Taxonomy (Biggs & Collis, 1991; Collis & Biggs 1991) is being used to evaluate students' understanding of science concepts. In a pilot study of primary school children, conceptions of how objects are seen directly and in mirrors were explored by examining students' responses to common phenomena depicted in drawings and text using a questionnaire and individual interviews. Evidence was sought to support an hypothesis for increasing levels of response within one or more cycles of learning related to the concepts of sight, light, reflection and image.

INTRODUCTION

Research in the area of students' alternative conceptions in science has generated many hundreds of papers in the last two decades (Pfundt & Duit, 1991). The majority of these papers attempt to map the most common conceptions in various school science topics and raise important issues about effective teaching and learning methods. For example, in the topic of 'light and vision', students' beliefs about the nature and behaviour of light have been described by Stead and Osborne (1980). Also, a range of beliefs about how we see objects have been reported by Andersson & Kärrquist (1983) and Guesne (1985) from studies involving Swedish and French speaking students respectively. More recently, the ideas of Australian students concerning phenomena related to light and the process of seeing were collected in a questionnaire study conducted by ACER (Adams, Doig & Rosier, 1990). In their analyses researchers have drawn attention to the similarity of some students' conceptions to those recorded in the history of science and also to their persistence in spite of serious teaching of currently acceptable scientific views. However, it appears that few analyses in this type of study have involved a consideration of the nature of cognitive processes involved in the different types of responses given by students to stimulus questions or situations.

The following description outlines the application of a developmental model of cognitive functioning based on the SOLO Taxonomy (Biggs & Collis, 1982; updated in 1991) in order to provide another interpretive window into the nature of students'

views about aspects of 'vision'. The theory is illustrated with reference to children's responses to questionnaire and interview items in a pilot study.

SOLO TAXONOMY AND MULTI-MODAL FUNCTIONING

The SOLO Taxonomy (Biggs & Collis, 1982) has been used to analyze the structure of children's understanding of mathematical concepts and problem solving abilities over a wide educational span from primary to tertiary levels (e.g. Chick, 1988; Pegg & Davey, 1989; Watson, Chick & Collis, 1988; Watson & Mulligan, 1991). It has been applied in a limited way in the area of science (Collis & Davey, 1986; Levins, 1992; Jones, Collis & Watson, in press). The SOLO theory, which was significantly updated in 1991 (Biggs & Collis, 1991; Collis & Biggs, 1991) builds upon Piaget's stages of development and suggests 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, abbreviations and common ages of 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), but they should not be confused with Piagetian stages. In earlier proposals each successive mode, with its increased level of abstraction, was seen as replacing its predecessor. However, with the recognition that 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).

Sensorimotor functioning is associated with the performance of skilled motor activities and relates to tacit knowledge, although one may be unable to explain how one interacts with the physical world. The ikonic mode is associated with intuitive knowledge, that which is perceived or felt directly and which involves the imaging of objects and events. Functioning in the concrete symbolic mode involves the use of symbol systems which have referents in the material world and facilitate the communication of declarative knowledge. Lastly, the formal and postformal modes are the most abstract ones and involve theoretical constructs having no material referents. Within these modes individuals are able to consider not only what is perceived to be

real but what may be possible.

The cyclical structure for responses within each mode, in order of increasing complexity, features
(i) prestructural responses (P) which represent no use of relevant aspects of the mode in question;
(ii) unistructural responses (U) which represent the use of only one relevant aspect of the mode;
(iii) multistructural responses (M) in which several disjoint aspects are processed, in sequence;
(iv) relational responses (R) in which several aspects of the mode are related into an integrated whole;
(v) extended abstract responses (EA) which make use of higher order principles and may take the whole process into a new mode of functioning at the unistructural level. Figure 1 (adapted from Biggs & Collis, 1991) shows the transition between modes of functioning and the equivalence of the extended abstract response of one mode with the unistructural response of the next mode.

Recent work in mathematics on Volume Measurement (Campbell,Watson & Collis, 1992) and Fractions (Watson, Collis & Campbell, 1991) suggests that there are in fact two major cycles for this kind of content within the concrete symbolic mode. The first shows heavy reliance on the IK mode to develop the concrete concept and the second uses the CS mode as such but utilises ikonic support for problem solving

MODE FORM OF KNOWLEDGE

OVERVIEW AND METHOD OF THE STUDY
Probing Students' Understanding About Vision.
Visual sensing is a dominant part of everyday experience from

early childhood and thus the topic of 'sight and light' has much potential for the engagement of children in interesting activities in school science across a wide age range. It also has potential for responses over the range of modes of functioning. Consequently, as a first step in our study we obtained random samples of scripts from the large ACER questionnaire study (Adams et al.,1990). Children's 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., in press) 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. The first item portrayed a four part scenario concerning the use of a torch to see objects in a dark room and the remaining items portrayed common circumstances involving the formation of virtual images by mirrors and mirror-like surfaces.

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 6 (n=106) in a suburban primary school near Hobart. After an inspection of the written responses, two children from each grade were selected for individual interviews on the basis of their answers to one or more of three items which seemed to prompt the most response. Children were selected where it was thought that conversation might clarify certain written responses or validate inferences made. The same questionnaire was used as the basis for individual interviews with 12 children from Grades K, Preparatory and 1 whose verbal responses were recorded on audiotape and later transcribed. For the purposes of this paper Item 3 only, and the analysis of responses to it, will be reported in detail.

Questionnaire Item 3

The cartoon sketch in Item 3 (Fig. 1) shows a rear view of a girl looking into a mirror with her right hand raised. Her image is drawn in the mirror except for her hand. The children were asked to draw how she would see her raised hand in the mirror and then to write an explanation of why they drew it where they did.

The girl is looking into the mirror and puts her right hand up.
Draw how she would see her hand in the mirror.
Why have you drawn it where you have ? Explain.

Fig. 1 Questionnaire Item 3.

RESULTS

Children's responses to the item were grouped in terms of their relevance to the question and the degree of complexity of the explanation given. Four groups of responses were readily identifiable ranging from those who did not, or said they could not, offer any explanation to those whose explanations of a correctly drawn hand made reference to image reversal by mirrors. However, it should be noted that none of the explanations involved any direct reference to light, either in relation to the object or the mirror.

The number of children responding in each of the four groups is set out by Grade level in Table 1 and is based on a consensus of

a group of the authors. The various responses were later associated with ikonic and concrete symbolic SOLO modes of

functioning. Table 2 shows the number in each Grade who drew the hand correctly on the right hand side of the mirror.

TABLE 1
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	Total
Group 1.							
Correct or incorrect. No explanation.	25 (3)	47 (7)	23 (7)	22 (5)	21 (4)	11 (2)	24 (28)
Group 2.							
Hand correct. Experience recalled.	67 (8)	33 (5)	27 (8)	39 (9)	21 (4)	21 (4)	32 (38)
Group 3.							
Hand incorrect. Image reversal used.	0 -	13 (2)	37 (11)	22 (5)	33 (6)	32 (6)	26 (30)
Group 4.							
Hand correct. Reversal mentioned. Based on experience.	8 (1)	0 -	3 (1)	9 (2)	21 (4)	37 (7)	12 (14)
Unclassified.	0 -	7 (1)	10 (3)	9 (2)	5 (1)	0 -	6 (7)
Number in Class	(12)	(15)	(30)	(23)	(19)	(19)	(118)

TABLE 2
PERCENTAGE OF CHILDREN IN EACH GRADE WHO DREW HAND CORRECTLY
(Number of children is shown in brackets)

GRADE =	K-1	2	3	4	5	6	Total
%	92	60	50	61	63	68	63
n =	(11)	(9)	(15)	(14)	(12)	(13)	(74)

In the following description of the groups, each typical example of the responses is followed by an indentification code in which

the 'v' and 'x' indicate correct and incorrect placement of the hand, m and f refer to gender and the last digit is the respondent's Grade.

Group 1. No explanation was given. Whilst a large majority of children in this group drew the hand on the correct side of the image, no one offered an explanation in terms of a mechanism as to why they drew it there. Typical responses were of the following type; "I'm not sure." x(010f3)

"...that's how you might have to put it up there because it might have a sore arm." 'v'(112fP)

"Because it's shown there." v(045m3)

"That's where our hands go." x(006f2)

"Because she's looking into it." v(067f4)

Many were statements of what the world is like, from ones' experience, rather than why it happens the way it does.

Group 2. The hand was drawn correctly and at least one element of an explanation was given. Some made a logical connection between aspects of the girl and her image e.g.

"Because her hand is on the right." v(054m4)

"Because she put up that hand." v(027m3)

Others referred to the concept of reflection, but generally as a name for what is perceived in the mirror. e.g. "Because it's a reflection of her." v(093m6)

Some appeared to refer to an elementary type of reflection process, e.g.

"Because when you hold your right hand it reflects." v(003f2)

"The mirror reflects exactly the same thing as you do." v(088m6)

"Because it reflects on the same side." v(033f3)

These statements also appear to arise directly from experience of what the world is like, and incorporate primitive elements of why it happens the way it does.

Group 3. The hand was drawn but NOT correctly. These responses appeared to indicate that they had applied, albeit incorrectly, a concrete symbolic notion of lateral inversion. e.g.

"Because if you put your right hand up it would look like your left hand." x(016f3)

"The mirror reflects the opposite side." x(046f4)

"It reverses your image; so say you had a freckel on your left, it would still be on your left in the mirror for example." x(086m5)

" Because the mirror reflects. If you put up your right hand in the mirror it would be your left hand because it has been reflected backwards." x(096f6)

"Because if you ... look in a mirror with writing on your clothes it is back to front." x(094m6)

Group 4. The hand was drawn correctly and explanations were given which made reference to some aspect of the phenomenon of lateral inversion by mirrors. It would appear that these children were able to imagine the image as another person (inside the mirror as it were) with a left hand raised, as well as to perceive the image directly from outside the mirror. That is, they were able to handle the two perspectives without confusion although the basis of their drawings appeared to be their recollection of past visual experiences. Typical responses were as follows.

"Because the reflection is showing it on that side. She can see it on that side but the reflection has it on its left." v(061m4)

"Because that's how she'd see her hand but if you turned to look the way the reflection is looking, it's the left hand. She is putting up the right hand but the reflection is doing the opposite." v(100f6)

"when you look in the mirror like if you write 'toH' in the mirror it would be 'Hot'." v(057m4)

"Because the right becomes left and left becomes right." v(103f6)

"The mirror reflects the image on the wrong side but the right hand in the mirror, (?) because the mirror reflects the right with the right and the same with the left." v(090m6)

"I've drawn it there because when you look in a mirror it gives you a mirror image. It's like looking face to face with yourself." v(081f5)

"If I said to put your right hand up it would be opposite to my right hand but a mirror is different it will be the same side." v(044m3)

"The mirror isn't like a person facing you." v(073m5)

A more extended response made during the interview of a Grade 1 girl elaborated the insight expressed in the last quotation about images in mirrors:

"There's something not the same about reflection. Because if you have something like a school jumper you can see it back to front. And that's probably left (pointing to the right side of the image) that would be if it was real, and that (pointing) would be right; but that's right and that's left (pointing in reverse). v(115f1)

An inspection of the frequency data across the grades reveals a change in the distribution of children between the four groups. This is shown graphically in Figure 1 which is a plot of the data from Table 1. The frequency of Group 1 responses across the

grades is generally low (11%-25%) except for a sharp peak to 47% in Grade 2. The frequency of Group 2 responses drops off sharply from 67% in Grades K-1 before decreasing gently to 21% in Grade 6 while Group 3 responses have a similar but inverted change, rising sharply to Grade 3 and generally leveling out just above 30% in Grades 5 and 6. Group 4 responses decrease from 10% in K-1 to zero in Grade 2 before increasing in a smooth curve to 37% in Grade 6. The possible significance of these apparent trends is discussed below.

The percentage of correct responses is relatively low in the middle primary grades of the school declining from almost 100% in the K-P-1 group to 50% in Grade 3 before rising to 68% in Grade 6. This is shown graphically in Figure 2 and suggests that a U-shaped development of understanding about mirrors may occur in the population of which the school is a sample of convenience.

Fig.1 Percentage of responses within four groups by Grade level.

Fig. 2 Frequency of correct hand drawings in each Grade level.

DISCUSSION

In relation to knowledge and understanding about mirrors and its hypothesized U-shaped development with increasing age of children (Fig. 2), three possibly confounding factors are acknowledged. First, the data comes from an across grade study rather than a longitudinal one yet it is reasonable to accept it as prima facie evidence with a view to exploring the matter further as such development has been documented before in a number of cognitive domains (Strauss, 1982). Second, as the school is relatively small there is a greater chance of variation between nominal Grades, although this is reduced somewhat by the fact that all classes above Grade 1 are composite of two Grade levels i.e. 2/3, 3/4, 4/5 and 5/6, thus variance due to different teachers is reduced. Third, the high success rate in K-1 Grades could be associated with the fact that the children were individually interviewed, however, this is unlikely as the questionnaire was read aloud to all other grades and its wording was used as the basis of conversation for the interviews. Should the U-shaped success curve for this task be validated one might find a reason for it in the nature of the explanations offered by the children, that is, in relation to the four groups of responses, as follows.

It is proposed that the reason why most children in the youngest grades (K-1) had the highest success in drawing the hand correctly is that they relied upon ikonic functioning alone. They readily recalled past visual experience of seeing their image in a mirror and probably had no other knowledge to divert them from

its application to answer the simple question. It is the most appropriate mode of functioning in this context. As children get older their developing knowledge can lead to confusion through its inappropriate application. It appears that after Grade 1, children are developing concrete symbolic knowledge about lateral inversion by mirrors and begin to apply rules such as 'mirrors

reverse your image' and 'left becomes right and right becomes left' to answer the question under discussion. However, this knowledge about lateral inversion does not help one explain why the raised right hand appears on the right side of the mirror and, indeed, it leads many to arrive at an incorrect answer particularly in Grade 3. Over the succcessive years an increasing proportion of children appear to revert to ikonic functioning to provide a correct drawing, nevertheless they still make reference to this irrelevant concrete symbolic knowledge in their explanations and accept an anomaly with the perceived correct position of the hand. The image reversal phenomenon itself is a dominant perception which appears to affect the personal interpretation of what is seen in the mirrors.

Thus, in respect of the children whose answers were allocated to Groups 3 and 4, it is claimed that there is evidence of interaction between concrete symbolic and ikonic modes of functioning, albeit in relation to knowledge about two different aspects of mirrors. Answers resulted from the dominance of the concrete symbolic mode in the case of Group 3, and the ikonic mode in Group 4. Those in the latter group show evidence of having resolved, at least in part, the confusion between two types of functioning.

It is interesting that none of the children's explanations involved any direct reference to light, either in relation to the object or the mirror. This is consistent with the findings in a related study by three of the current authors (Jones, et al., In Press) that very few Grade 9 students use the idea that light is reflected from objects to explain how one sees them. Many appear to use an alternative framework to explain vision such that objects become bright or 'lit up' and are thus visible. In such ikonic functioning dominated by perception no object eye connection, in terms of light rays for example, seems to them to be required.

One would not expect primary school children to have much knowledge about angles of reflection from mirrors and certainly not of the declarative (concrete symbolic) type. However, one might have expected a few to have referred to intuitive experiences of mirrors to see around corners where object and observer are aligned appropriately with a mirror's surface.

Aspects related to this are currently under investigation and two other problem scenarios involving mirrors have been devised to explore the development of related declarative knowledge in the concrete symbolic mode.

CONCLUSION

As this research proceeds hypotheses will be developed about the order of, and influences on, the development of concepts, and typical ages (if any) at which critical shifts in modal functioning occur. It is believed that the updated SOLO theory, when applied in relation to specific science topics, may be sufficiently fruitful to contribute to the design of more effective teaching approaches which enhance a student's scientific understanding of the topics and their ability to make higher level responses in appropriate modes.

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