A Comparison of the Developmental Patterns in Students' Responses to Questions in Two Science Topics

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ABSTRACT
This paper reports on a comparison of the results of two studies. This work involved the testing by survey questionnaires and in depth interview schedules. The sample was a random number of students from kindergarten to Year 12, in a NSW school. The two targeted science topics were `evaporation' and `plant growth'. The Solo Taxonomy was the assessment tool used to categorise the students' responses in both the questionnaire and interview situations. The results in both studies show that the responses could be classified into a cyclic pattern within the Solo Taxonomy classification system. These cycles were continuous and ranged from the ikonic to the formal mode of cognition. The purpose of this article is to explore the characteristics of the cycles, particularly at the interface of the ikonic and concrete symbolic mode, with reference to these two scientific topics. This should provide, further evidence for how students' conceptual understandings develop.

INTRODUCTION

The Solo Taxonomy has continued to be modified since its inception in the early 80's. The newer developments have allowed for a greater utilisation of the Taxonomy in different educational practice and research environments, while, at the same time, not negating the initial formulation. Two features of the changes highlight important developmental growth in the implementation of the model. The first, concerns the deeper elaboration of the different modes of intellectual functioning. Here, not only do early acquired modes, such as, the sensory motor and ikonic modes, now seem to develop throughout a person's life, they continue to support learning in other modes. The second feature, concerns the realisation that a single unistructural/multistructural/relational cycle does not do full justice to the diversity of student responses to stimuli, within a mode. As a result, a series of at least two cycles within a mode have been hypothesised. This cyclic nature of developmental response patterns from the ikonic through to the concrete symbolic mode through to the formal mode have been postulated. The focus of this article is to concentrate on the changing characteristics of the responses along the continuum from an early ikonic modal understanding through to responses reflecting relational level understanding in the concrete symbolic mode. It is also hypothesised that this latter mode is the one in which science topics, such as evaporation and plant growth would be better understood at the level of abstraction demanded by the secondary and in some cases primary schooling curricula.

THE MODEL

The Solo Taxonomy can be interpreted within the post neo-Piagetian tradition. There are two basic elements to the Taxonomy. The first, is a series of five modes of intellectual functioning. The second, is a series of levels of response type that are repeated within each mode. The five modes of functioning can be described as follows:

Modes of Functioning

1.Sensory Motor - a person reacts to the physical environment. For the young child, it is the mode in which complex motor skills are acquired. For instance, these play an important part in later life, such as skills associated with various sports.

2Ikonic - a person internalises actions in the form of images. It is in this mode that the young student develops words and images which represents objects and events. For the adult, this mode of functioning assists in the appreciation of art and music and leads to a form of knowledge referred to as intuitive.

3Concrete Symbolic - a person thinks through using a symbol system such as, written language and number system. This is the most common mode addressed in the upper primary and secondary schooling system.

4Formal - a person considers more abstract concepts than in former modes. This can be described as working in terms of 'principles' and 'theories'. Students are no longer restricted to a concrete referent. At an advanced form, it involves the development of disciplines.

5Post Formal - a person is able to question or challenge the fundamental principles or theories or in fact in some instances, foundation disciplines.

These modes of functioning are shown diagrammatically in the following figure, which is the latest version of Biggs and Collis' SOLO Taxonomy.

Modes, Learning Cycles and Forms of Knowledge

Figure 1. Adapted from: Biggs, J.B. & Collis, K. F. "Multi-model Learning and the Quality of Intelligent Behaviour" (1989).

One important difference between these SOLO modes and the work of Piaget, is that in the former model, there is a belief that persons can function in more than one mode, that there are opportunities for a person to use different modes to support learning and cognition in another mode. In figure 1 above, examples of different forms of learning involving different modes are indicated by horizontal and vertical arrows. Obviously, there are numerous possible combinations of these forms of learning involving different groupings of modes.

Associated with each mode is a series of response levels. These are referred to as:

- 'Unistructural', where a person focuses on one element of a question or stimulus. This fact is reflected in the response;
- 'Multistructural', where a person focuses on several elements but does not see relationships between the elements; and,
- 'Relational', where a person can see interconnections between various elements. The pattern, within modes, of the U-M-R levels is indicated in figure 1 above.

These characteristics are reflected in the way the students respond to a question or environmental stimuli.

The levels associated with the Solo Taxonomy have several properties, as the focus shifts from unistructural to relational, which include:
1.a growing complexity in understanding;
2.an increased ability to consider more information simultaneously;
3.an increased ability to accept complexity; and,
4.an increased ability to delay in providing an answer.
Other features of the model include:
•the levels are sequential and students' progression through the levels is thought, at this time, to be fixed, i. e., they cannot jump levels;
•the language used by students changes as they progress through the levels and modes, reflecting increased complexity of word usage and patterning; and,
•there is a characteristic and unique way of responding at different levels.
As indicated earlier, studies carried out by the author on topics in science have identified more than one unistructural-multistructural-relational cycle within the concrete symbolic mode. The topic areas used for these investigations were `evaporation' and `plant growth', see Levins (1992); Levins and Pegg, (1993).
The remainder of this paper addresses this issue in two sections. The first section provides an overview of results identified by Levins (evaporation) and Levins and Pegg (plant growth). The second section deals with the empirical findings resulting from many in depth interview sessions with students ranging from Kindergarten to Year 6, i. e., age 5 years to age 12 years.
Empirical Evidence and Analysis

To investigate ideas associated with evaporation and plant growth, survey questionnaires were developed. In each, a reference diagram, (see figure 2 and 3) were used followed by a series of five stimulus items. The diagrams were included so that any difference in ability was to a degree discounted, i. e., every student, independent of ability, had the same diagrammatical configuration from which to work. These reference diagrams were included to enable all students' perception of the two science concepts, to converge into similar senses of 'reality' of what the scientific terms meant to each and every student.

Figure 2: Reference Diagram for the Investigation of Ideas Association with Evaporation.

Figure 3:   Reference Diagram for the Investigation of Ideas Association with Plant Growth.
Several important features were built into the set of questions in both the surveys. There was a deliberate attempt to relate the questions to the students' own 'reality'. That is, the emphasis was on the students to provide their personal view/ideas about the questions rather than learnt responses. In particular, from the plant growth questionnaire, question 1 and 2 (i. e., 1. If you were asked to give an explanation

suitable for a science dictionary, how would you explain plant growth?, and 2. How would you know if the plants were growing?) aim to establish the students context from which their understanding of the concepts develop. In both cases, the questions were sequential in nature to aid in the progression of the response type, reflecting a developmental pattern of the understanding of scientific concepts.

Results

In both studies, the analysed responses to the questions could be classified into homogeneous categories, according to descriptors that reflected the structure of like-responses. The data when coded and analysed was placed into categories without pre-empting the framework of the Solo Taxonomy.

As a result of the analysis, the responses to the questions contained within the two surveys could be placed into seven categories, i. e., A to G, refer to Levins (1992) and Levins and Pegg, (1993).

The following two diagrammatical models show how the categorised responses could be placed within the existing SOLO Taxonomy. The responses which constitute the framework for the models are contained within the concrete symbolic mode, since the properties of the response types fall within the specified criteria for a concrete symbolic response structure. Both diagrams follow a progressive trend of developmental levels, repeated in a cyclic pattern.

Figure 4Two Cycles within the Concrete Symbolic Mode. Topic: Evaporation.

Figure 5Two Cycles within the Concrete Symbolic Mode. Topic: Plant Growth.

It became evident, that what was emerging was a definite discernible two cyclic pattern in the concrete symbolic mode. The second cyclic pattern reflect the idea that students' understandings was extending into the area of scientific 'processes', e. g., first, the physical processes necessary for evaporation to take place, and second, the chemical processes and abstraction of the concepts necessary for the actuality of plant growth.

The results from both studies support the conclusion that students require the first cycle to build on their basic ideas that the students already possess, i. e., students' responses reflect 'reality' as they perceive it. These foundation ideas underpin the development of the more cognitively demanding abstraction of ideas into process-orientation. Both studies resulted in a cyclic pattern of response development within the concrete symbolic mode. Since this is the mode within which most schooling takes place, it would seem important to interpret these results within the bounds of students' conceptual understanding. The first cycle appears to link closely with the students perception of 'reality' associated with the ikonic mode. The following section provides a description of what students' understandings of scientific topics, evaporation and plant growth, 'looks like' in the ikonic mode and at the interface of the two modes, i. e., ikonic and concrete symbolic.

Ikonic Mode and its Interface with the Concrete Symbolic Mode

Methodology

It was determined that the strategy for data collection would be by way of structured interview schedules, with a random selection of students from Year 3 to Year 6. (refer to interview schedule in Appendix 1.) The transcripts of 19 students were coded and analysed. In summary, the interview schedule investigated the following characteristics of the students' understandings of two scientific concepts.

1. Causality.
2. Intuitive and instructional understanding.
3. Spontaneous and non-spontaneous responses to stimuli.
4. Generalisabilty.
5. Functional and optimal response to questions.

All of the above descriptions of intellectual variations surrounding the theme of scientific conceptual understanding, is able to be classified at a model level with reference to the SOLO Taxonomy (the description of responses). It is also possible to classify the responses within the mode into subcategories or levels.

The next section outlines the results of using a protocol of classification, according to descriptors, of the transcripts provided by the 19 students.

Results of Interviews of Year 3 to Year 6 Students

The results were first tabulated and second, a descriptive analysis was produced as an overview, as follows:

Table 1 (a) Interviewee Age

Student	Age in Years
A	7
B	8
C	8
D	9
E	9
F	9
G	9
H	9
I	10
J	10
K	10
L	10
M	11
N	11
O	11
P	12
Q	12
R	13

In all the following tables, the dissecting lines suppose categories of like characteristics, grouped together according to differentiating classification descriptors. The diagram mentioned, refer to the stimulus items shown to the students at the outset of the interview.

Refer to Appendix 1.

Table 1(b): Descriptions relating to Diagram 1(a) and 1(b)

StudentN° of DescriptionsN° of promptsDifference
Q324
A724

D42
E324
F514
G524
H234
I534
B424
C514
K134
M224
N324
O1324
P614
J434
K134
L224
R1024

Table 1(c): Diagram 1(c) and 1(d) - Descriptions/Prompts

StudentN° of DescriptionsN° of promptsDifference
C214
A314
B314
H314
Q414
E414
I414
K414
F514
L514
P524
M614
J714
N714
G724
O1014
R1314

Table 1(d): Results from Diagram 1(a) and 1(b)

StudentResult AResult BSunHeatEvapCausalAdversativeGroup
Q4441
A444
D44442
E4444
F4444

G4444
H4444
I4444
B444443
C44444
K44444
M44444
N44444
O44444
P44444
J44444
K94444444
L444444
R44444445
Key:Sun: mention of sun in the response.
Heat: mention of heat in the response.
Evap: mention of the word evaporation in the response.
Causal: shows alibility to link cause and effect in response.
Adversative: shows ability to explain the results of an adversative

phenomenon.
Table 1(e): Descriptions Relating to Diagram 1(c) and 1(d)
StudentResultCausalityEvap
UnderstoodNon-
spontaneousGenerality
Linked
A44
Q44
E444
J44N/S
N444
B44G
C44G/L
I44G/L
M44G/L
K44N/SG
F444G/L
L44N/SG/L
G444N/SG/L
P444N/SG/L
H444UN/SG
R444UN/SG
O444UN/SG/L
Key:Causality: shows ability to link cause and effect in response.
Evap understood: mentioned the word evaporation in response and seemed to understand the meaning in scientific terms.
Non-spontaneous: response offered, seemed to be linked to instruction and/or school environment.
Generality linked: response showed the student had the ability to

generalise and linked response to the specific event given in the interview.

Table 1(f)

Comments on the Diagram of the Trees i. e., Diagram 1(e)

Student	Causality	Concept Equivalence	Generality
A	4		
B	4	4	G
C	4	4	G/U
Q	4	4	G/U
D	4	4	G/U
F	4	4	G/U
J	4	4	G/U
L	4	4	G/U
E	4	4	G/U
G	4	4	G/U
H	4	4	G/U
M	4	4	G/U
N	4	4	UG/U
O	4	4	UG/U
R	4	4	UG/U
I	4	4	UG/U
P	4	4	UG/U

Key:Causality: response reflects student's understanding of cause and effect.

Concept Equivalence: student in his/her response uses understanding to relate a similar phenomenon to the underpinning comprehension of an equivalent concept.

Generality linked: student showed ability in response to generalise and linked understanding to the specific event mentioned in the interview session.

Table 1(g): No. of Differences in Diagram 1(e)

Student	N° of Differences
Q	2
A	3
C	3
F	3
E	3
H	3
N	3
I	3
P	3
B	4
D	4
M	4
O	4
R	7

The tabulated results above provide evidence for the following

generalities.
The descriptive phrases which enable the idea of an overview of the mode in which most of the students are functioning, follow:
1. ability to recognise cause and effect relationships;
2. ability to see difference/s between similar situations;
3. ability to suggest equivalent ideas (concepts) to the event under discussion;
4. ability to generalise from the specific idea towards a more global view.
The reason these descriptive phrases enable the students' responses to be classified into the first cycle of the concrete symbolic mode follow:
1. descriptive words and phrases about incidents which rely on the concrete world around them;
2. inability to fully appreciate both the cause and effect relationship and/or the outcome of an adversative relationship;
3. inability to `hold' many descriptive ideas about an incident in his/her `working space' at the same time.
The descriptive phrases which encapsulate student responses which were classified into the second cycle of the concrete symbolic mode follow;
1. ability to relate concepts in a more abstract form. In the examples cited, the processes of photosynthesis and evaporation could be explained using terms such as `energy', `molecules', `carbon dioxide', `chlorophyll', `steam', `gaseous', to name a few.
2. the responses reflect a fuller understanding of the cause and effect and the adversative effect relationships.
3. The students are able to `chunk' descriptive ideas together and relay in the response only a couple of descriptions which would appear to them, to indicate a much broader picture than the mere words would indicate.
The above data and subsequent conclusions need corroboration and extension. In this quest, students from Kindergarten to Year 3 (two students from each) were interviewed using the same schedule as was used with the older students. The purpose for this procedure was to try and identify data that could help to answer the following research question that became evident whilst analysing the first interview data set. This process of research question identification, is using a form of progressive qualitative methodology i. e., allowing the data to drive the direction of the research. The above interview analysis leads to ask the following:
Research Question
What are the characteristics of the students responses functioning in the ikonic mode and are there equivalent cycles within levels of responses, as in the concrete symbolic mode?
It appears evident that these younger students still respond within the concrete symbolic mode. Therefore, it was necessary to interview even younger students to realise a true 'picture' of the ikonic mode. A

random sample of eight students ranging from Kindergarten to Year 3 were interviewed, using the same schedule as the one used with the students from Year 3 to Year 6.

Analysis

Analysis of the eight younger students' transcripts gives a picture of transience. That is, there are young students operating wholly within the ikonic mode in all areas of what they perceive as 'reality'. As the student grows intellectually, either experientially or by instruction, he/she moves into the concrete symbolic mode with a heavy reliance on the ikonic mode, even to the point where their responses would suggest that at times, they have reverted to functioning wholly within the ikonic mode, with regard to some concepts or ideas within concepts.

Conclusion

The evidence resulting from the analysis of the interviews with students from Kindergarten to Year 6 (age 5 to age 12), suggests the following hypothesis. The postulation that is put forward here, is that the older students (Year 3 to Year 7) move confidently into the first cycle of the concrete symbolic mode. This is the mode in which most of the instruction is carried out in the schooling system, particularly in the secondary schooling system. Unfortunately, students who have missed out on the period of instruction that relied heavily on the alliance to the ikonic mode where imaging and where 'self' seems to be the centre of their 'reality', these students are unable to have the structures in place and move forward without the necessary ikonic foundations in place. In the schooling system which uses primarily the concrete symbolic mode as the vehicle for instruction, these students that have forfeited their basis for understanding will pay the toll and never really keep up or understand the concepts taught in the secondary schooling system. This would mean that concepts which are moving towards abstraction all the time as you move up the system from years 7 to Year 12 would render many students completely disinterested and dysfunctional, simply because they are unable to understand the concepts, because of lack of foundations based within the ikonic mode.

A diagrammatical model connects together as an overview, the many faceted indicators of student's modal functioning mentioned in this article. The following table is referred to as

Table 1(h); Characteristics of modal functioning

Years K-3Year 3-6

Ikonic ModeConcrete Symbolic Mode First CycleConcrete Symbolic Mode Second Cycle

Students' responses showStudents' responses reflect the ability to Students' responses show

1.Imaging and/or imagining1.recognise cause and effect1.abstraction of ideas

2.Emotive, intuitive, affective influences2.recognise differences between like events2.fuller understanding of cause and effect and adversative relationships

3.Inability to recognise cause and effect3.recognise conceptual equivalence3.ability to 'chunk' ideas

4.Inability to generalise from one event to another4.generalise4. ability to respond with 'assimilated' and 'accommodated' concepts

5.Inability to recognise conceptual equivalence
6.Inability to note differences between similar diagrams
7.'Nonsense' in terms of scientific 'knowledge'.
8.Student's 'reality' is spoken about as if life is a story
Some students oscillate between modes and depend on the ikonic mode for support to respond in the concrete symbolic mode
The above table reinforces Biggs and Collis's latest 'multimodal functioning' theory; as expressed in their research findings in 1992. This flexibility and freedom of intellectual dependence on 'lower' modes for support to respond at a higher functioning mode, reflects one pathway how cognition and response type are linked. This evidence also

suggests that each scientific concept may be embedded within the student's intellect as a result of past experiences and the schooling process entwined together. Each scientific topic, indeed, each scientific idea, is understood at different levels of development. Therefore, because a student responses concerning a certain scientific concept suggest he/she is functioning within a certain mode, they may respond in a different way, if responding to yet another scientific phenomenon and do so at a 'lower/higher' mode.

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Appendix 1

Interview Schedule

Interviews Year 3 - Year 6 (approx. age 7 yrs. - 12 yrs.). Four children from each year -2 girls and 2 boys.

Research Questions

1.What happens in the mind of the child to the scientific concepts he/she is taught at school?
2.What is the relationship between the assimilating of information and the internal development of a scientific concept in the child's consciousness?
3.Is there an interdependence and interaction between spontaneous and scientific concepts (non-spontaneous - instructional).
Show the three pictures, which follow:
1.Describe in your own words what you see in each picture. (likeness vs. differences - development (generality); language vs. thought).

Figure 1Man in Sun 1(a), Clouded Sun 1(b).
If the person has just come out of the water after a swim,
1.What will happen to the water on his body in picture a?
2. What will happen to the water on his body in picture b?
3.He will dry quickly in a because- (causal relationships).
4.He will eventually dry in b although- (adversative relations).

Figure 22 (c) (stove alight), 2(d) (stove out).
If there is water in the bowl,
1.What will happen to the water if it was left on the heater overnight?
2. Where does the water go?
3.Do you know what we call this? - when water seems to disappear. (causal, modal functioning, level functioning, spontaneous concepts).
4.Are you able to think of something (even as an experiment), you have done at school, which is like the picture i. e., the water disappearing? (non-spontaneous - consciousness).
5.Are you able to think of another example of the same thing happening either at school or at home? (generality of non-spontaneous, scientific concepts).

Figure 31(e) (small & large tree).
1.What does the small plant need for it to grow into the large plant? (SOLO - spontaneous vs. non-spontaneous).
2.Are you sure? Is that all? (consciousness).
3.What would happen to the plant if all the leaves were cut off the large tree?
4. Why? (causality; relational).
5.Give another example of something growing. (intellectual freedom; conceptual equivalence).
6.How do you know when you have grown? (causality; generality).