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An exploration of the notion of cycles of levels within modes of the SOLO Taxonomy.

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Abstract

The SOLO Taxonomy of Biggs and Collis has evolved in several ways since its inception. One important advance has been the identification of more than one unistructural - multistructural - relational cycle within a mode. While this finding was implicit in the original development it has been made explicit through attempts by several researchers to explain understanding over a fuller concept range. However, there have been differences in the interpretations taken of the cycles. This paper explores the notion of multiple cycles within a mode by considering empirical evidence drawn from studies carried out in mathematics and science topics. Differences in the nature of these cycles are highlighted and implications are drawn which have consequences for both the SOLO Taxonomy and the nature of the development of students' understanding.

Introduction

The SOLO Taxonomy has continued to be modified since its inception in the early 80s. 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 change highlight important developmental growth in the model. The first concerns the deeper elaboration of the different modes of intellectual functioning. Here, not only do earlier acquired modes, such as, the sensori-motor and ikonic now seem to develop throughout a person's life, they continue to support learning in other modes. The second feature, and this is the focus of this article, concerns the realisation that a single unistructural - multistructural - relational cycle does not do full justice to the diversity of responses to stimuli within a mode. As a result, a series of at least two cycles within a mode has been hypothesised.

Before considering two examples (one in Mathematics and one in Science) of how cycles of levels might be applied to code responses within the concrete symbolic mode of the SOLO Taxonomy, it is appropriate to describe briefly key aspects of the model.

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 attainment that are repeated within each mode. The five modes of functioning can be described as follows:
Sensori Motor - a person reacts to the physical environment. For the very young child, it is the mode in which complex motor skills are acquired. These play an important part in later life as skills associated with various sports evolve.

Ikonic - a person internalises actions in the form of images. It is in this mode that the young child develops words and images which represent 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.
Concrete Symbolic - a person thinks through using a symbol system such as written language and number systems. This is the most common mode addressed in the upper primary and secondary school.
Formal - a person considers more abstract concepts. This can be described as working in terms of 'principles' and 'theories'. Students are no longer restricted to a concrete referent. In its more advanced form it involves the development of disciplines.
Post Formal - a person is able to question or challenge the fundamental principles of theories or disciplines.

Figure 1. Adapted from: Biggs, J.B. & Collis, K.F. “Multimodal learning & the Quality of Intelligent Behaviour” (1989).

One important difference between these SOLO modes and the work of Piaget, is the belief that persons can function in more than one mode, and that there are opportunities for persons to use different modes to support learning and cognition in another mode. In Figure 1, examples of different forms of learning involving 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 (U), where a person focuses on one aspect of a question or stimulus; multistructural (M), where a person focuses on several aspects but does not see relationships between the aspects; and, relational (R), where a person can see interconnections between various aspects. The cyclic pattern, within modes, of the U-M-R levels is indicated in Figure 1.

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;
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 to be fixed, i.e., they cannot jump or skip levels; the language used by students changes as they proceed through the levels and modes; and, there are characteristic ways of responding at different levels.

As indicated earlier, studies carried out by the authors on topics within Mathematics and Science have identified more than one unistructural - multistructural - relational cycle within the concrete-symbolic mode. The topic areas used for these investigations were: Plant Growth, Evaporation, Geometry, Algebra , and Statistics (see, for example, Levins, 1992; Levins & Pegg, 1993; Pegg, 1992).

The remainder of this paper addresses this issue in two sections. The first provides an overview of the results identified by Pegg in Geometry, and Levins and Pegg in Plant Growth in an attempt to provide empirical evidence for the cycles identified. The second section contrasts the findings offered by the two studies.

Empirical evidence and Analysis

The Mathematics Study

This study consisted of a questionnaire surveyed across students ranging from Year 3 to Year 7, i.e., 8-13 year olds from schools in Queensland and New South Wales (see Pegg & Davey, 1988). The students were asked to draw a square. Students were then asked to give their best description of the figure. This was repeated for some other 2D figures, i.e., rectangle, parallelogram and rhombus. A sample of students was interviewed to test the robustness of the students' written response.

Results

The responses were classified into homogenous groupings. In all, five broad groupings of responses, coded A - E, were found. Typical examples of student responses for the four figures in each group are provided below.

Category Am

The students' answers focused on the global image of the shape.

Square:"it (h)as to (be) even on each corner"
Rectangle:"it is almost the same as a square but it is larger"
Parallelogram:"it is like a rectangle that has been pushed to one side"
Rhombus:"is a square on a lean".

Category Bm

The students in this group focused on the lines. However, it was also common for the students to provide some reference to a global image as if to offer additional support for their answers.
Square:"straight lines its a flat shape"
Rectangle:"4 straight sides"
Parallelogram:"it has four sides"
Rhombus:"4 sides but they are diagonal".

Category Cm
The students in this group had improved slightly on those from Category B. It was as if they knew that mentioning lines was not sufficient. The students here tried to provide some qualification although they were unsuccessful. It is worth noting that there were no responses obtained in this category for either a square or a rhombus.
Square:no responses recorded
Rectangle:"is simuler (sic) to the square but the sid (sic) are longer than the two on the top and bottom
Parallelogram:"is like a rectangle except tilted to one side a bit and the two end sides face the same way"
Rhombus:no response recorded.
Category Dm
The focus of the responses in this group is also predominantly on straight lines but there are real attempts to provide the key characteristic, namely, equality.
Square:"4 even lines"
Rectangle:"two sides are longer than the other two, four corners, smooth sides"
Parallelogram:"the two sides are the same. But the other two sides are on a slant"
Rhombus:"is like a half squashed all sides are equal".
Category Em
The student responses in this category focused on more than one property of the figure. These type of responses would be, in general, the best that could be expected from students answering this question.

The reason for this being the word 'describe', in this context, implies that what is required is a list of all the 'aspects' that are known about the figure.
Square: "is a shape that has 4 sides and 4 angles. The angles are all 90 degrees. All sides are even and equal to each other"
Rectangle: "has all parallel sides. The angles are all 90 degrees. Two lines are the same but are larger than the other two

lines”
Parallelogram:“has 4 sides two of them are equal to each other the other two are equal to each other. If you run the lines forever they will never meet”
Rhombus: “has 4 equal sides and 4 equal angles* is also called a diamond”. (* note: in the interview the student clarified that 4 equal angles meant equal in pairs)

The analysis of the categorisation of the groups of responses, identified two main features when considered within the framework offered by the SOLO Taxonomy. The first feature concerned Category Am. Here, the responses focused on the global nature of the figures. Students described the given figures in terms of known shapes. Some features were mentioned, such as, corners. However, these were also global notions. During interview sessions students would refer to “corners of rooms” to explain what they meant. These characteristics of the response are indicative of those associated with the ikonic mode.
The second feature of the responses concerned the remaining categories. Category Bm, Cm, and Dm showed a gradual evolution of the notion of a single property. The groupings satisfy the unistructural, multistructural and relational levels, respectively. Category Dm responses can be interpreted in two ways. They can be seen as providing some overview of the features, i.e., sides and equality. In the second case, this coding would represent a unistructural level response, i.e., a focus on one property. This is then followed by category Em in which students’ responses provided several properties.

In summary, a two cycle pattern became evident. In the first cycle, students focused on what could be described as the features of the geometric shape, e.g., the sides of a square and the quality of the side. There is a definite development of ideas towards the relational level for example when the students' responses reflect their ability to relate all the ideas about one property that describes a figure. The first cycle appears to develop the idea that a certain characteristic of a figure is invariant.

The students responding in the second cycle progress to identify other properties that are necessary for the correct description of a geometric shape, i.e., other properties, e.g., right angles that exist as a characteristic for the description of the geometric figure-a square. The second cycle develops on the base line established in the first cycle and identifies a number of properties, that are characteristic for particular 2D geometric figures.

Further studies (see, for example, Pegg and Davey, 1991 and Pegg and Woolley, 1994) have extended this work and helped elaborate several other features. The relational level (R2) has been identified where a student can describe a square by referring to a rectangle or parallelogram, e.g., "a square is a parallelogram with adjacent sides equal and all angles right angles."

From (R2) there appears to be two paths. One is indicated by students responses which are able to take into account more difficult questions regarding proportions. This would be represented by a third cycle

within the concrete-symbolic mode. The second path moves into the formal mode. This is characterised by the ability to distinguish the necessary and sufficient conditions required to describe shapes.

The above description can be summarised in a diagram as follows in Figures 2A and 2B

Figure 2A.Two cycles within concrete symbolic mode.

KEY

( ):descriptor s Æ sides, a Æ angles, p Æ parallelism, d Æ diagonals, sy Æ symmetry,...

Capital Print:usual path of overt growth

[U2(a),...]:single elements not usually overtly referred to unless directed

subscript 1:first cycle, focus on visual aspect leading to identification of an invariant feature or property

subscript 2:second cycle, focus on properties leading to relationships between properties

new mode:being able to invoke necessary and sufficient condition within descriptions. Initially one, then a number, finally some overview of the conditions.

new cycle:more complex application of relationships between properties of figures

Figure 2B.Diagrammatic interpretation of student growth in 2-D Geometry.

The Science Study

To investigate ideas associated with plant growth, a short questionnaire was developed. It consisted of a reference diagram (see Figure 3) and five questions. This specific diagram was provided so that both the younger and older students had the same diagrammatical configuration from which to work. It was felt that the diagram would assist in directing students' ideas while, at the same time, allowing students to answer the questions according to their individual meanings of the words "plant growth".

Figure 3. Reference diagram for the investigation of ideas associated with plant growth.

The five questions used in the study were:

1If you were asked to give an explanation suitable for a Science dictionary, how would you explain plant growth?
2How would you know if the plants were growing?
3What 'things' would the plants need to take from the surroundings to help it grow?
4In as much detail as you can, explain how the necessary 'things' that the plants take from the surroundings help the plants to grow?
5Explain how photosynthesis is a necessary part of a plant's growth?

Several important features were built into the set of questions. There was a deliberate attempt to relate the questions to the students. That is, the emphasis was on students providing their personal views/ideas about the questions rather than learnt responses. In particular,

question 1 and 2, attempted to establish this context for the answers. The questions were also designed to elicit 'open' and 'closed' responses. Questions 1 and 5 were 'open' in nature. Here, the questions were asked to try and prompt a sequential development of the responses that could be offered by the students.

Results

Again, as in the Mathematics study, the analysed responses to the questions could be classified into homogenous categories, according to like responses. These are provided below under seven headings, categories A s- Gs.

Category As

Responses which were classified into this category were those in which students denied any understanding of the question, answered tautologically or refused to respond. For example, to the instruction, "Explain how photosynthesis is a necessary part of plant growth", typical responses were: "So we live."(Year 7); "…if it didn't have it, we would die" (Year 9).

Category Bs

In this category, students were capable of recalling only one aspect to answer the question. For example, one Year 9 student wrote,"…how much a plant would grow in a certain period of time". This statement indicates that the student understands that time is a necessary feature of plant growth.

Another response focuses on the feature of size, e.g.,

"…is a measurement that a plant would show" (Year 10).

Category Cs
Responses were classified into this category if the student described two or more features, which would be necessary for a plant to grow. "What 'things' would the plants need to take from the surroundings so that they could grow?" Two examples of such responses to the question are,"…H_2O, CO_2 and soil" (Year 8) and "Water, soil, sun" (Year 7).

Category Ds
The students who responded in this category were able to draw conclusions and form generalisations. They could make linkages and identify relationships between features necessary in the growth 'process'. For example: Given the instruction "In as much detail as you can, explain how the necessary 'things' that the plant takes from the surroundings help the plant to grow", typical responses were: "…through photosynthesis, nutrients and water are converted to starch and then cellulose to be used as building blocks for the plant" (Year 10); "…they use photosynthesis, which means the supply of light, soil and air, so the plant can make its own food" (Year 7).

Category Es
This category of responses reflects an understanding of the process of photosynthesis required for growth, but no linkages are made between the reactants in the process and the products which ultimately provide the materials necessary for plant growth. For example: When asked "If you were asked to give an explanation suitable for a Science dictionary, how would you explain plant growth?" A typical response at this level was: "…the plant will need water and sun light to grow. As it grows it will take in CO_2. The leaf is where the plant makes its own food using photosynthesis" (Year 7).

Category Fs

Responses in this category reflected on overall understanding of the photosynthetic process and intermediate processes involved. To illustrate this, a typical response from a Year 10 student follows: "Plant growth is the way a plant creates more of itself by absorbing external matter. Plants achieve this by using the process photosynthesis, whereby chlorophyll in the leaves, nutrients and water from the soil, and CO_2 are combined by energy from the sun to form simple sugars that the plant uses to build itself".

Category Gs
The student responses (there were very few) which were coded into this category, showed a far greater degree of understanding than responses classified in any other category. The responses classified into this category reflect the fact that the students were able to understand the underlying processes (photosynthesis and cellular respiration)

necessary for plant growth, i. e., they were able to deal with abstract ideas and relate them to the concrete world. An example identified was: "Plants convert; $CO2 + H2O + Energy > glucose + O2$. This is very important because plants waste product is O2 and this is essential for animals to breathe. The glucose which is produced by the plant is often stored as starch, however, when the plant uses glucose (respiration), this allows the cells to live, grow and reproduce" (Year 12).
In this response the student has shown a fuller understanding of plant growth. With the inclusion of the process of respiration in the answer, the student has brought in information from outside the context of the question to explain the concept of plant growth more fully.

It became evident in this study that the students' responses could be classified at two 'levels'. Firstly, the unistructural, multistructural and relational descriptors could satisfy the student responses in Category Bs, Cs, and Ds respectively. For example in answer to question 3 above, the student responded by focusing on soil or water or size, (i. e., one feature surrounding the concept of plant growth). This would be classified as unistructural.

The second finding was again similar to that in the Mathematics Study. There became evident a definite, discernible two cycle pattern in the concrete symbolic mode. In the science investigation the second cycle is clearly described by the students showing an understanding of the processes involved in the scientific idea of plant growth. The responses allocated to Categories Ds, Es, and, Fs were characterised by their increased awareness of the necessary processes underlying the actual growth of a plant. This can be depicted by Figure 4 below.

Figure 4. Two cycles within the concrete symbolic mode

The responses placed into Category Gs showed an understanding that brought ideas from outside the context of the question, such as, the students who felt it was necessary to "talk" about respiration to fully explain plant growth. This Category was placed into the Formal mode.

The results from this study support the conclusion that students require the first cycle to build the basic concepts, i.e., students' responses reflect reality as they perceive it. These foundation ideas underpin the development of the more demanding cognitive abstraction of ideas into process-orientation. With reference to the specific concept, plant growth, the first cycle describes the concrete features involved in plant growth and the second cycle describes how these features are used in the process of photosynthesis. This chemical process is only one necessary for plant growth, but almost exclusively, it was the process mentioned in the responses collected in this research. Perhaps photosynthesis is the process that teachers

concentrate on in the classroom.

Comparison of Results

Both the Mathematics and the Science studies resulted in a cyclic pattern in the level 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 student learning and conceptual understanding.

The first cycle, in both disciplines, is fundamental to further understandings of concepts. This cycle is bedded in the concrete world, i. e., in Mathematics, the student is able to relate to one important visual feature that they believe determines a 2D geometric figure; in Science, the student is able to relate to ‘things’ he/she can ‘see’ surrounding plant growth, e. g., increase in size.

In both disciplines this first cycle identified, links closely with thought processes associated with the ikonic mode. That is, the students’ responses relate closely to images. In 2D Geometry it was the focus of attention on the most obvious feature of figures, namely, the sides that heralded this change. In the case of Plant Growth it was the features that surround a plant, for example, air, soil and sun that are first identified. In both cases, there is a clear move away from reliance on affect-laden imagery.

It would appear that the students whose responses are classified into the categories in the first cycle are in a state of transition. Their responses show features of being able to think more abstractly than in the ikonic mode, but their responses reflect a reliance on imagery to reinforce their answers. The students are more confident about their response when ‘allowed’ to think in ‘pictures’. As the response categories shift from unistructural, multistructural to relational, more complex conceptual understandings are reflected in the response groupings. This increase in the ability to conceptualise is continued into the second cycle in both studies.

Comparison of models

In the studies described above, two different metaphors were developed to explain the results identified (see Figures 2A and B and 4).

The two models (Figures 2 and 4) have much in common. In particular, they both identify as equivalent the relational level in the first cycle and the unistructural level in the second cycle. However the models do suggest that, despite their equivalence, there may be some differences in these two levels. Also, implied in the models is that while development from R2 may be to a U3 still within the concrete symbolic mode, it is anticipated that the next category of quality of response would be a unistructural response in the next mode (Formal Mode). The major difference between the models was the observation in the study of concepts surrounding Plant Growth, that the second cycle picked up and expanded on aspects identified by students in the first cycle. There was no indication of this at all in the 2D Geometry study. Here, students continued to refer to the element or aspect identified in cycle 1 and, in the second cycle, drew in other elements not previously referred to.

Conclusion

This paper has offered empirical evidence to substantiate the claim that there are at least two cycles of growth within the concrete-symbolic mode. This result has important implications which offer the teacher a clearer insight into how students' understanding might develop. The first cycle represents a transition from visual thinking into the concrete-symbolic mode. The second cycle identifies

what many secondary teachers would see as the main focus of activity in the secondary school. In 2D Geometry it would be the consideration of the invariant features of figures, while in Plant Growth it would be the processes associated with scientific phenomena.

Also considered was the implications, to further understanding of the cycles, of the two metaphors used as summaries to the findings of several investigations. Differences and similarities were identified in the models lead to the formation of an important research question. Can a single model be developed which explains both sets of mathematics and science data? Is this difference in response a feature due to perceived differences between the two disciplines? That is, does science draw, initially, on more relevant and contextual aspects that are more salient to a student than mathematics? To explore this, the development of student responses in the science questions at R1, U2 and M2 will need to be more closely investigated and analysed. In particular, the growth in response for the individual science processes, such as, from identifying air to mention of carbon dioxide. It would not only help the process of more accurate assessment but would assist in the planning of a more appropriate learning and teaching environment.

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