The Curriculum Analysis Taxonomies

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Curriculum Analysis Taxonomy 1: Different aspects of the development of the child's interaction with the world.

Function	*1 pre-operational*	*2A early concrete*	*2B late concrete*	*3A early formal*	*3B late formal*
1.1 Interest and investigation style	Things are believed to be exactly as they appear to immediate perception. Perception dictates decisions. Faced with a mature person's idea of evidence, will deny it, explain it anthropomorphically, or be silent. Does not perceive contradictions.	Will register what happens, but for interest to be maintained after the first obvious observations needs a seriative or simple associative model. Unaided investigation style does not go as far as producing concrete models. (See 1.4, 2A and 2B.)	Will include seriation[1] and classification as tools of perception in finding out what happens, but needs to be provided with a concrete model by which to structure experimental results (classes must be given, and examples of the application shown). Finds interest in making and checking cause-and-effect predictions.	Finds interest in looking for *why*, and following consequences from a formal model. Confused by the request to investigate empirical relationships without an interpretative model. Can use a formal model, (see 1.4, 3A) but requires it to be provided. Can generate concrete models with interest. Sees the point of making hypotheses, and can plan simple controlled experiments, but needs help in deducing relationships from results and in organising the information so that irrelevant variables are excluded at each step.	Finds interest in generating and checking possible 'why' explanations. Will tolerate absence of an interpretative model while investigating empirical relationships. Takes it as obvious that in a system with several variables he must 'hold all other things equal' while varying one at a time, and can plan such investigations and interpret results. Will make quantitative checks involving proportionality relationships.
1.2 Reasons for events	Interprets phenomena egocentrically, in terms of own self.	See 1.1, 1.3 and 1.4 Cause-and-effect only partly structured – 'this goes with that'; so uses associative reasoning. Simple one-factor causes, such as 'force', etc.	Bipolar concepts such as 'alkali destroys acid'. Can use ordering relationships to partially quantify associative relationships: 'as this goes up, that goes down', 'if you double this you double that', i.e. 'the reason' involves describing the relationship or categories, not providing a formal model. Cause-and-effect structured according to general concrete stage schemata as 'adding acid makes the pH lower'.	Looks for some causative necessity behind a relation established with concrete schemata.[2] Allows for the possibility of a cause that is not in 1:1 correspondence with observations. Can consider the possibility of multiple causes for one effect, or multiple effects of one cause. Can suspend judgement and allow results of controlled experiments to constrain choice among various cause-and-effect explanations. Can handle formal models as explanatory provided their structure is simple (see 1.4).	Because aware of multiple causes and effects, can think of reality in a multivariate way, so can make a general or abstract formulation of a relationship which covers all cases in an economical way. Can use deduction from the properties of a formal model – either from its mathematical or internal physical structure – to make explanatory predictions about reality.

[1] Seriation: putting objects in order according to a property such as length, mass, etc.
[2] Schema (pl. schemata): a general way of thinking, a 'reasoning pattern' which can be applied in many contexts. Concrete schemata are those characteristic of concrete operational thinking.

Function	*1 pre-operational*	*2A early concrete*	*2B late concrete*	*3A early formal*	*3B late formal*
1.3 Relationships	Cannot consistently arrange data in an ordered series.	Can order a series, but is unlikely to see that as an obvious way of summing up observations. Nominal[3] scale relationships – 'same distance-same weight' (See-saw).	Can multiply seriations, and hence can find 1:1 correspondence between two sets of readings (e.g. weights and extensions of springs) and, hence, any linear relationship. Readily uses the notion of reversibility. Will use compensation argument to explain a conservation where only *ONE* variable is independent, e.g. of a piece of clay 'you've made it longer, but it's thinner so it's the same'. See also 2.2.	Uses compensation relationships between TWO independent variables, e.g. weights and distances on both arms of a balance can be changed while preserving equilibrium; resistance is related to both area and length, in electricity. See also 2.2. Simple functional relationships beyond linear, and thus acceleration. (Note that this is a more sophisticated version of the concrete modelling described in 1.4 (2B), rather than formal modelling.)	Can reflect upon reciprocal relationship between several variables. Thus, can handle quantitative 'relations between relations' as in proportions, or semi-quantitative relationships as in chemical equilibria. This level of functional thinking is often needed for analysing experimental results so as to order them for lower-level computation, e.g. weight changes in reactions involving different elements and compounds, or density calculations where density is an inferred concept (density of gases, or Archimedes' problems). See 2.4 (3B).
1.4 Use of models	Not possible.	Concrete modelling is the organisation of reality by seriation or classification or 1:1 correspondence. At this level simple comparisons only, and elementary causes – 'this opposes that'. Unstructured notions such as 'pureness'.	Modelling by seriation extends to any linear scale. For classification see 1.5 (2B). For 'cause-and-effect' see 1.2 and 1.3. 'Model' now has dictionary definition of simplified 1:1 correspondence model (skeleton; gear-box, etc.).	Formal modelling is the indirect interpretation of reality by deductive comparison from a postulated system with its own rules. At this level, student usually needs guidance in deducing how a system with several variables may behave. Unless quantitative relationship is simple (as with 'caloric' model of heat transfer, or 'pressure' as F/A) deduction is likely to be qualitative only (exchange reactions with metals and oxides). Model is taken as true, not hypothesis, so this level does not allow critical comparison of alternative formal models.	Can actively search for an explanatory model, extend one that is given, and compare alternative models for how they account for the same data. Since proportional thinking is readily available (relating two independent variables to each other) can formulate quantitative deductions from the model, and reflect on the relations between the variables.

[3] Nominal scale: scale with two values only: 'Four legs good: two legs bad'.

Function	*1 pre-operational*	*2A early concrete*	*2B late concrete*	*3A early formal*	*3B late formal*
1.5 Type of categorisation	Thought is associational,[4] and association of one aspect (e.g. height) not linked to another aspect (e.g. breadth) on anything but an immediate perceptual or temporary basis. Thus, has difficulty classifying objects into even two groups as successive judgements on one object are contradictory.	Elementary classification. Sets of objects are classified according to one major criterion at a time, e.g. colour, size, shape, etc. Children can also switch criteria. Soon they can also multiply classifications, i.e. 'big blue squares/small blue squares', 'red big squares/red small squares'.	Class inclusion and hierarchical classification. Classification is still the dominant mode of categorising reality, but now the classes are less tied to one simple property, and can also be partially ordered, e.g. animals – flying animals – domestic birds. Bi-polar classifications such as 'acids and alkalis as opposites'.	Generalisation. Now the classifying operation is used to impose meaning over a wide range of phenomena. A general formula like $V = hlb$ will be used as an instruction for computing volume. Asked to choose the next term in the series 'Etna-volcano- . . .' would pick 'mountain' as the best classifier.	Abstraction. By contrast, would prefer 'geological notion' to 'mountain' as next stage of categorisation. Because of the multivariate nature of reality it is sometimes more powerful to search among the many properties for the essence of the underlying association. Mountain is a higher class, but geological notion abstracts so that connections with non-mountains can be explored. In $V = hlb$, the way in which h and b vary in relation to one another for constant l and V.
1.6 Depth of interpretation (of descriptive passages)	Does not look for contradictions in interpreting a descriptive account. Tends to pick on one feature only.	Imposes a consistent interpretation, but builds it around one feature of the account. Nominal scale level of interpretation.	Takes several aspects of described situation into account, but separately, and in imposing cause – effects stays within the descriptions, and mostly re-describes it. Ordinal[5] scale level of interpretation. (Examine whether a concrete model (1.4, 2A and 2B) is provided.)	Extended describer level. Still stays largely within the descriptive account, but considers more than one aspect at once (trees removed; rain on soil; soil washed away).	Explainer thinking. Not only are all the relevant features of the description accounted for, but hypotheses are tested against the data and, when necessary, inferences made imaginatively using outside ideas and data. (Examine whether a formal model (1.4, 3A and 3B) is provided as an interpretation.)

[4] Association: co-incidence in time or place serving as basis for prediction.
[5] Ordinal scale: a scale which has order, as in the order of ages of a set of siblings, but there is no regular relationship beween the values.

Curriculum Analysis Taxonomy 2: The development of different 'schemas' required for the understanding of the sciences.

Function	*2A early concrete*	*2b late concrete*	*3A early formal*	*3B late formal*
2.1 Conservation	Accepts that the amount of substance does not change, but still believes that weight and volume do, except in the very simplest situations, e.g. accepts volume constant when liquid poured to different shaped vessel, but volume of water displaced does not equal volume of displacing body. Conserves number and length.	Conservation of weight even when the dimensions of the body are changed. Volume conserved if body can be seen, but not if it dissolves.	All conservations. Now understands how the volume of odd-shaped objects can be determined by displacement. Notion of pure substance, which is conserved even when mixed with other (pure) substances. Realises that the volume of liquid displaced by a body does *not* depend on its weight.	
2.2 Proportionality	Can double or halve the quantity of two related sets, e.g. if 2 oranges cost 4p 1 orange costs 2p.	Has not arrived at metric proportions.[1] Can make inferences from data involving constant ratio as long as ratio is a small whole number, e.g. if 2 sweets cost 5p, 6 will cost 15p. Thus, can scale up by factors of two or three, and partition using simple whole numbers.	Can make inferences where a ratio of simple whole numbers is involved, e.g. if a 2 kg box costs 12p and a 3 kg box costs 15p, which is the better buy? Can handle, as functional relationships, ratio variables such as density as weight/volume; current/voltage, and gas volume changes with temperature and pressure: $n_1v_1 = n_2v_2$ in chemical volumetric work.	Can formulate and quantify relationships between different ratio concepts mentioned under 3A descriptions, e.g. in investigating the shadows cast by different sized rings, 'the ratio between the ring sizes and the distances has to be the same'. Thinking in terms of direct or inverse relations between ratio variables (e.g. moles/litre, or mass/atomic mass) knows how to model the relationships mathematically. See 2.4 (3B). In volumetric work can handle computation in terms of V_2/V_1, *therefore* C_1/C_2.

[1] Metric proportions. The equivalence of two numerical ratios e.g. 2/6=7/21

Function	*2A early concrete*	*2b late concrete*	*3A early formal*	*3B late formal*
2.3 Equilibria of systems	See 1.3 (2A) Observations ordered in terms of one property.	Relationships between variables only conceptualised two at a time, with the relationship linear (direct or inverse). (Single variables like force not compound variables such as pressure.)	Where there are two independent variables related to each other at equilibrium, will discover this relationship, provided the ratios are simple whole numbers e.g. 3/2; 1/4; 3/4, etc. e.g. $W_1/W_2 = L_2/L_1$, in a balance, or $h_1/h_2 = a_2/a_1$ in hydraulic press, without grasping the internal law of the whole system.	Can compare any ratio in two independent variables' equilibria by treating them as a proportion. When there are 3 or more variables related to each other at equilibrium, can conceptualise the relationship of the third to the other two, and thus arrive at a general law for the system, and can discuss the reciprocal relation of the first two variables e.g. in the case of the inclined plane. Relates the truck weight and hanging weight variables by equating them to the ratio of the vertical rise and fall of each. Can provide an *explanation* for a relation established at 3A level, e.g. $h_1/h_2 = a_2/a_1$, because pressure produced by each arm is the same – leading to view of the whole system.
2.4 Mathematical operations	Number is now distinguished effectively from size, shape, appearance. Number as a series, but confined to the numbers which can be given a conceivable concrete realisation.	Can work with single operations (e.g. addition, subtraction, division and multiplication) but the system of numbers must have *closure*; i.e. the operation must be unambiguous and the result of the operation must be within the set, e.g. 5 + 4 = x can be solved, but ? – 7 = 7 – 3 or 5 ÷ 4 cannot.	Concrete generalisation. Can work with the relationship V = *lbh* or $W_1H_1 = W_2H_2$ but only by treating each step as a definite operation on definite numbers. Begins to accept lack of closure, e.g. can solve ? – 7 = 7 – 3 by a series of operations to each side of the relation.	Can properly conceive of a *variable*, and begins to work with the explicit rules of a system so as to develop proof strategies. See 1.3 (3B). Rather than needing a formula where several variables are involved, can analyse the set of relations required by the model so as to sequence correctly a series of simple computations e.g. with a 'hydrogen-oxygen' model, realises the weight changes relating to H and O separately must be computed before weights of other compounds can be computed. Before a density calculation can be set up the relevant weight and volume changes must be found.

Function	*2A early concrete*	*2b late concrete*	*3A early formal*	*3B late formal*
2.5 Control of variables	Can reject a proposed experimental test where a factor whose effect is intuitively obvious is un-controlled, at the level of 'that's not fair', but fails to separate variables and so eliminate one. 'Fairness' may also be applied in the sense of giving every factor an equal chance, e.g. 'slower runner should be given shorter distance'.	Will usually vary more than one factor in each experiment, and often varies other factors to test the effect of a given one.	Sees the need to vary one factor at a time and can suggest experimental tests to control for factors explicitly named. May fail to control factors that are not perceptually obvious. Fails to develop a strategy based on a feeling of the system as a whole. May not see the point of having an experiment without a factor present to see if it is a variable.	Sets up suitable experiments to economically control factors and eliminate ones that are not effective, and can apply 'all other things equal' strategy to multivariable problems. More sophisticated biological experiments possible including interaction effects. Appreciates the impossibility of controlling natural variation, and so the need for proper sampling.
2.6 Exclusion of variables	In analysis of a multivariate problem (e.g. pendulum, flexibility of rods of different materials, shape, etc.) has no strategy for excluding interfering variables. May attempt to order the effects of factors and may arrive at the direction of the effects if they are intuitively obvious, e.g. 'longer rods bend more'.	Will order the effects of a given factor, but fails to exclude the interference of the other factors because he is trying to impose bivariate thinking. Thus, often arrives at correct effect of a factor by invalid arguments. Unlikely to arrive at correct effect where it is contrary to intuition or where the factor makes no difference.	Will correctly arrive at the effect of a factor from experiments in which he/she has controlled for the other factors, but will often fail to exclude the effect of other factors when asked to select, from a group of experiments, those required to show the effect of each factor. Thus, when two factors have been changed, and an effect is noticed, is likely to attribute change to the combination of both.	Because of an implicit knowledge of the different effects which may be caused by the combinations of the variables that are possible, will select economically from a variety of experiments those required to show the effect or non-effect of each in turn.
2.7 Probabilistic thinking	No notions of probability.	Given 3 red objects and 3 yellow objects mixed up in bag, realises that there is a 50/50 chance of drawing a red one.	Given other ratios of objects will count the numbers of the given type (*n*) and the number of all objects (*N*) and express the chance of selection as a fraction *n*/*N*.	

Function	*2A early concrete*	*2b late concrete*	*3A early formal*	*3B late formal*
2.8 Correlational Reasoning		No systematic method of estimating the strength of a relationship except to look to see if the confirming cases are bigger in number than all the rest.	Begins to look at the ratio of confirming to disconfirming cases, but tends to look only at the probability of two of the four cases, e.g. for blue or brown eyes and light or dark hair will compare the ratio of those with blue eyes and blond hair to those with blue and dark.	Realises that the opposite pairs are as important as each other. Thus, takes the brown eyes/dark hair set together with the blue eyes/fair hair set, and compares it with the sum of the two disconfirming cases (brown/fair and blue/dark).
2.9 Measurement Skills	Makes measurements by comparing beginning and ending of object/journey with rule in simple whole numbers.	Bar diagrams, histograms, idea of *mean* as the centre of a histogram, and variation as its breadth. Graphical relationships of first order equations. Interpretation of graphs where there is a 1:1 correspondence with the object modelled, e.g. height/time relationship for the growth of a plant.	Interpretation of higher order graphical relations, and use of problem-solving algorithms, e.g. $P_1V_1 = P_2V_2$ for gas pressure calculations. Can make interpretations which involve relations *between* variables in a graph, e.g. in a distance/time graph will see that a vertical section means 'standing still' and that a horizontal section is impossible.	Interpretation of higher order graphical relations in terms of *rates* (instantaneous slopes) and reciprocal relationships; conceptualisation of relationships between variables, e.g. in $V = lbh$, if l rises (V constant), b and/or h must drop proportionally.

[1] Metric proportions. The equivalence of two numerical ratios e.g. 2/6=7/21