Cognitive acceleration: Science and other entrances to formal operations

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Based on Piaget's theory and using Vygotsky's ideas a long term experiment aiming at development and formation of formal operation las a specific kind of learning strategiesl through science education was carried out. Principles and results of that experiment are shown and compered with other investigations. It is argued that the concept of cognitive acceleration through instruction may be successful in other sublect matters, too (e.g. in history, but not in foreign Ianguage).

Koonitive Akzeleration: Naturwissenschaft und andere Zugänge zu formalen Operationen
Ausgehend von Piagets Konzeption und unter Einbeziehung von Wygotskis Konzeption wurde ein langfristiges Experiment im naturwissenschaftlichen Unterricht zur Entwicklung und Ausbildung formaler Operationen (als spezifische Lernstrategie) durchgeführt. Prinzipien und Ergebnisse des Experiments werden dargestellt und mit anderen Untersuchungen verglichen. Es wird gezeigt, daß das Konzept der kognitiven Akzeleration durch Unterrichtsgestaltung auch in anderen Fächern (z.B. Geschichte, nicht aber Fremdsprache) Erfolg verspricht.

Definitions

I am not sure if this paper can properly be described as contributing to the debate on learning strategies; If the term “learning strategies” is restricted to conscious procedures which students learn in order to help them learn more efficiently, then it cannot. But if we include unconscious processing mechanisms which develop partly as a result of maturation, but over which we as teachers may have some influence, then this paper is relevant to the symposium.

Our work for some years has been concerned with the development of formal operational thinking in adolescents. Initially (Shayer & Adey, 1981; Shayer, Kuchemann & Wylam, 1976, Shayer & Wylam, 1978) the main focus was to measure and describe the incidence of formal operations in the school population, and there was an implication that curriculum materialsshould be “matched” to the qualitiy of cognitive processing available in the students. Since 1980 however, we have taken seriously Vygotsky's dictum that “the only good learning is that which is in advance of development” (Vygotski, 1978) and we have become more interested in the promotion of formal thinking. Even to talk of “promoting” formal operations is to imply that cognitive development occurs under the influence of more than maturation and genetic potential, and this brings into question the rather problematic relation between learning and development to which Vygotsky gave some attention.

To conclude this preamble, I take “formation” to mean something more fundamental and generalisable than “learning”, and yet more amenable to the influence of teachers than “development” used in a purely maturational sense. And I include in “learning strategies” general proceccing capabilities of the mind which assist in the learning of, at least, a wide range of different topics within one domain and, at most, all sorts of academic learning. With these defintions, what I have to say will be about “formation of learning strategies”.

Cognitive acceleration throuoh science education

Our work on Cognitive Acceleration through Science Education (CASE) has been described elsewhere (Adey & Shayer, 1990; Shayer & Adey, 1992a, 1992b, 1993) and here I will provide only a summary of the main features and results. A set of 30 activities was developed which incorporated the following features:

- Concrete preoaration: the provision of vocabulary and clarification of the terms of the problem.
- Cognitive conflict: a problem which cannot quite be solved by the learner using his/her current level of thinking
- Opportunities for meetacognition. Pupils reflect on how they solved the problem.
- Bridging: Other examples are explored where the same formal schema may be useful.

Teachers used these activities to replace regular science lessons with 11 - 14 years olds at the rate of one every two weeks over a two year period. Pupils made significantly greater gains in cognitive development (perhaps in the context of this symposium I should say “cognitive formation”) than controls. Most important from the point of view of generalisability of what was “developed”, “formed”, or “learned”, was the finding that up to three years after the end of the intervention programme students who had experienced the CASE activities performed significantly better on nationally set examinations in science, mathematics, and also in English. Whatever changes had taken place in the experimental students they appeared to be permanent and transferable to domains far removed from the science context in which the activities had been encountered.

What was the mechanism by which this long term far transfer was achieved? Our own hypotheses marry Piagetian ideas of the develppment of formal operational thinking with Vygotskyan notions of social metacognition. The Piagetian arguments are that formal operations are qualitatively different from concrete operations, that they provide a higher level access to all sorts of learning (they are domain general), and that they cannot be taught directly but with well-structured experiences of cognitive conflict students are put in the position where they must construct formal schema for themselves. This depends, of course, on an adequate level of maturity having been attained but we contend that maturity alone, without the right kind of cognitive stimulation, will not engender formal thinking in students. Once the formal capability is established it becomes a permanent feature of the students' cognitive equipment, available to be applied to all sorts of academic learning.

The Vygotskyan element is partly concerned with the construction process: the construction of formal schema is encouraged by the arguments, justifications and explanations which take place when students discuss results and meanings amongst themselves and with the guidance of a careful teacher who encourages the student's own constructions rather than tries to impose his of her own “knowledge”. But it is possible also that the very process of sociaconstruction is learned, maybe unconsciously, by students as being a productive and enjoyable strategy which can be used in many learning contexts.

Alternative hypotheses have been put forward to explain our results. Some have claimed that all the CASE experience did was to boost students' confidence in their own ability. I would like to see the notion of “confidence” operationalised more effectively before that becomes a testable hypothesis. Others have claimed that the discussion which takes place in CASE lessons itself directly develops language skills, and our apparent “transfer” was no more than the parallel development of separate scientific and language abilities, not connected as we suppose through a deeper level of general cognitive processing.

One way of testing our model of a central cognitive processor which is amenable to educational influence would be to see whether similar effects could be achieved by cognitive acceleration programmes delivered through completely different domain contexts. For example, could a programme which employed the same feature of concrete preparation, cbgnitive conflict, metacognition, and bridging but set in the context of history, delivered by history teachers, produce a long term effect on students' achievement in science? If it could, that would provide strong support for the notion of an educable central processor.

In this paper I would like to explore the potentialities for cognitive intervention through the “doors” of other domains. First, perhaps, I should make clear that I am not assuming that some academic domain context is absolutely essential for the delivery of a cognitive stimulation programme. There is evidence that context free intervention methods such as Feuerstein's Instrumental Enrichment (SHAYER & BEASLEY, 1987) and Lipman's Philosophy for Children (LIPMAN, SHARP & OScANYAN, 1980) can produce growth in fluid intelligence measures and also in academic achievement, but there are practical difficulties in fitting such schemes into real school timetables and so I propose to focus here on the potentialities of domains defined by normal school curricula for the development of higher level thinking (“the formation of learning strategies”).

Characterising higher level thinking

If the potential of other subjects to act as hosts to cognitive acceleration programmes is to be considered, it is necessary first to discuss at what level of generality higher level thinking may be described. We have clear examples of the schemata of formal operations provided in science contexts by Inhelder and Piaget (1958). These include control and exclusion of variables, ratio and proportionality, compensation and equilibrium, probability, correlation, and formal modelling. Inhelder's experimental situations place all of these in contexts which any science teacher would recognise and feel at home with.

Two questions arise:

- Is formal operational thinking an account of higher level thinking restricted only to science?

and

- Are those particular schemata applicable to other domains?

It will already be clear that my answer to the first question is “No” although I am conscious that many psychologists (e.g. Kuhn, Amsel& O‘Loughlin, 1988; Resnick, 1987) would disagree with me. To the second question I would answer a qualified “they probably cannot simply be mapped on to the type of thinking characteristic of other domains of knowledge”. In the CASE project we used the schemata listed above as the contexts in which activities were set. If other subject areas are to be used as vehicles for cognitive stimulation it will be necessary to identify, characterise, and exemplify equivalent schemata of higher level thinking in those domains. Only after these have been developed can the principles of concrete preparation, cognitive conflict, metacognition, and bridging be applied in the design of activities for the promotion of higher level thinking in that domain.

My colleague Michael Shayer has claimed (Shayer, 1988) that to design an intervention in a domain other than science will require a considerable preliminary analysis and validation of the “abstract descriptors” of that domain in the same detail and with similar richness of examples as has already been done for science (Inhelder & Piaget, 1958; Shayer & Adey, 1981). He specifies a set of steps which include stating the objectives of the domain, grouping those objectives under 5 to 10 abstract descriptors which describe the main underlying kinds of performance and understanding teachers are looking for in distinguishing between good and not-so-good students, analysing these descriptors in terms of levels of cognitive development, and empirically validating the detailed descriptions produced. Only an experienced subject teaching specialist can do this - a psychologist's good guess would never be good enough.

English

We do have at least one good example of this process being applied - in this case to the English language curriculum. Esther Fusco (Fusco, 1983) took four descriptors - Classification, Correlations, Proportional Reasoning and Causality - from Shayer and Adey's

(1981) science curriculum analysis taxonomy and translated their definition and instances into the context of English comprehension. In addition four more descriptors - Seriation, Frames of reference, Spatial I temporal relationships, and Formal logic - were defined from Fusco's experience as an English teacher and her reading of Piaget as more particularly relevant to English. For each of these descriptors Fusco considered what would count as performance at early concrete, late concrete, early formal, and late formal operational levels and provided literature-specific descriptions of expected performance. For example, proportional reasoning is interpreted as different levels of analogical reasoning and one of the six descriptors for late concrete is “Analyses simple comparative propositional relationships, instanced by good/evil in The Lion. the Witch and the Wardrobe”. At the early formal level comes “Compares relationships that are implicitly stated, and explains reciprocal events in a story” (instanced from Tom Sawyer and Anne Frank's Diarv of a Young Girl). Fusco showed that it was possible to use this taxonomy so that experienced English teachers could (a) produce satisfactory agreement in assessments of the level of demand of specific texts, and (b) produce reliable assessments of the levels of understanding of the texts shown by different students.

The important principle shown here is that although the developmental model drawn from Piaget is general, it requires to be “read in” to the context of the school subject and its reliable use depends on the subject specialist's expertise.

The task of designing a cognitive intervention programme in an English context remains to be done. As with development of the analysis tool it will require someone with subject expertise and the ability to identify the nature of cognitive conflict within~the literary domain.

Mathematics

On the face of it the schemata we used in science seem to have close parallels in mathematics. Certainly proportionality, compensation (inverse proportionality),correlation, and probability should be directly applicable. But in mathematics here appears to be a dimension, which may be interpreted as the equivalent of formal modelling but has a strong metacognitive element, concerned with the pupil's awareness of what sort of operation to perform on a problem. Shayer found that many children entering secondary school performed in mathematics problems well below what might be expected from their Piagetian level. He ascribes this to a failure in instruction in primary schools where drill in the “four operations” takes precedence over standing outside a problem and considering what. sort of operation is going to be most profitable here.

“The distinction is between mathematics as a descriptive language (concrete operational), for which their primary schools had prepared the children well, and the process of reflecting on the rules of that language, or reflecting on which mathematical model might be an appropriate one to use. Ask the children how to find out how many apples you need to give 20 children 3 apples each, and they readily supply 'three times twenty'. Ask them how much bigger 60 is than 20, and they answer either '60 minus 20' - a wrong model - or more often 'I was never any good at that kind of maths'.”(Shayer in (Adey & Shayer, 1994) Ch. 8)

Michael Shayer has recently been awarded funding to investigate possibilities of cognitive acceleration in mathematics, and will now be able to act on his own advice: “Development of the intervention art for secondary mathematics may require a judicious blend of the construction and metacognition parameters.”

History

It is tempting for scientists to view history as a rather inexact scientific enterprise: the collection of evidence, attribution of cause and effect, and the building of general models of the way that events occur. If we were to do this it would be easy enough to apply our scientific versions of formal thinking to the historical domain but the reality is that history has its own characteristic qualities quite distinct from scientific thinking. In particular, historians are more inclined to see their job as one of interpretation of events in the light of the conditions obtaining at the time, rather than trying to draw general conclusions about what might happen at another time and another place. The “evidence” for history is not given, it is selected by the researcher. It will not speak for itself but must be interpreted in the light of the historian's understanding of the conditions of the past that produced it. History must employ a range of interpretations and explanations, and historical events cannot be understood without reference to the motives and beliefs of the participants.

In interpreting history, some characteristics of formal operations are the ability to form hypotheses, to see more than one point of view, to interpret a behaviour in the light of the conditions obtaining at the time (rather than apply today's values to medieval government), and to accept lack of closure. Ultimately it is to recognise the prejudice of one's own interpretation. Significant work has already been done in the analysis of historical understanding, from the pioneering work of Peel (1967) and Hallam (1967), through to more recent work by Dickinson and Lee (Dickinson & Lee, 1978). The last-named have paid close attention to the problem of reading the schemata of formal operations developed in science into a historical context. They rightly point to the difference between concepts in science and concepts in history, to the absence of general laws in history, and to the absence of “variables” which could in any sense be controlled. However, I believe that by focussing on the physical manipulations characteristic of the Inhelder and Piaget experiments, Dickinson and Lee get too close to the data and fail to see the overriding general characteristics of concrete and formal operations.

This returns us to the question of what level of description is appropriate if we are to seek Piagetian descriptions of thinking which are domain-free. The level of “control of variables” is too fine-grained and so domain specific. It makes no useful sense to describe the causes of the American Civil War as (1) Northern industrialisation, (2) State's rights and (3) Slavery, and then to imagine that if (1) and (2) were held constant, we could tell whether (3) alone would have been enough to cause the war! On the other hand, the most abstract level of the Piagetian account of the development of formal operations, which appeals to an idiosyncratic form of propositional logic, is very difficult to apply to real cases. Many claim that this level does not “work”, and although Shayer has defended it theoretically (Shayer, 1972) and (Bond, 1990) has demonstrated it empirically, we have actually found it neither necessary nor useful to resort to propositional calculus in analysing levels of thinking.

I believe that Dickinson and Lee themselves provide an excellent example of the intermediate level of generality at which the qualitative difference between levels of cognitive development can be described in a manner applicable across many domains. They describe a test they gave to students aged 12 to 18 in which a description of a First World War naval battle is provided, and questions asked about possible motives of one of the fleet commanders for the actions he took. Students' answers are classified into four levels (this is after the application of Piaget to history has been discounted):

Examples of the lowest level (I) answers include pupils who are simply confused by the actions or misconstrue the data in elementary ways. Although they can often firid in the text answers to specific questions of fact, such pupils seemed incapable of holding enough of the information in their mind at once to operate effectively on it to make any sort of relationships between the different facts.

Level II answers failed to distinguish between the historians's viewpoint and that of the commander, and employed personal projections and prejudices unjustified by the evidence given. They often assumed that the commander knew what the pupil knew - for example how many submarines the enemy had on station. In other words, mental operations were performed on the concrete data provided, but the operations were clouded by egocentricity and a desire to close to an answer even when the data to provide an answer was not available. This is characteristic of conrete operations.

At level Ill the historians's and the commander's viewpoints and knowledge are distinguished, demonstrating the abandonment of an egocentric position by the student and the adoption of amore disinterested overview, characteristic of formal operations. However, such students still seemed unable to place the battle in a wider context and so see the actual world in terms of many possible worlds. This shows when the student is asked what alternative actions the commander might have taken. Suggestions are confused, uncertain, and sometimes self-contradictory.

Only at Level IV are these contradictions resolved, and this is achieved by “subjects seeing the rival considerations which demanded Jellicoe's attention in the wider context, and integrating them successfully.” (Dickinson and Lee 1978 p.103).

By adding very little gloss to their account, I believe I have shown their levels I - IV to be clear descriptions of early concrete, late concrete, early formal and late formal operational thinking, but let us look at the percentage of students at each age who achieved each of Dickinson and Lee's levels of historical thinking, and compare it with data Shayer et al. obtained for levels of cognitive development in the British school population.

	Age:	12:9		16:0	
Piaget stage	D & L level	Shayer	D & L	Shayer	D & L
early concrete	I	99	100	100	100
late concrete	II	70	84	88	98
early formal	III	14	23	32	55
late formal	IV	2	2	13	10

Dickinson and Lee's sample was drawn from one selective and one comprehensive school, so the proportion at the higher stages would be expected to be higher than that of Shayer's truly representative sample. Of course this parallel does not “prove” that Dickinson and Lee's levels are isomorphous with Piagetian stages, but combined with the analysis of characteristics of the levels which they give it is difficult to escape the conclusion of a close relationship.

The extent of work already completed in history makes it a promising candidate for further studies in cognitive acceleration and it is not difficult to imagine the form than an intervention programme might take. Conflict may be provoked by asking students to offe(interpretations of the actions of a historical figure, and then progressively feeding them more data which their tentative hypotheses must be accommodated. There is plenty of opportunity for metacognition in terms of “But what did you make of ...?” “Put yourself in the shoes of. This last, in. particular, is the basis of empathy which has become such an important element in modern history courses. History taught as interpretation rather than as the learning of facts is a fertile field for the sort of inter-pupil discussion which gives many opportunities for metacognitive reflection on student's own thought processes.

Foreign language learning

I would not want to complete this paper leaving the impression that I believe all academic studies have the potential of offering opportunities for cognitive acceleration, so I will conclude with one example where I see few such opportunities - the learning of a foreign language. Biggs and Collis‘ (1982) attempt to apply their SOLO taxonomy, isomorphous with Piaget's developmental stages, to the translation of phrases from French to English but their cognitive structural analyses of examples are not convincing. It is notable that unlike other sections of their subject-by-subject analysis, there are no literature references to the psychology of foreign language learning.

Traditional methods of lQarning a second language involve the learning of rules of grammar and structure and the memorisation of vocabulary. The analytical aspect of such an approach might well be enhanced by the availability of formal operations with their associated to ability abstract generalisations from specific examples and so consciously to build rules of production. This is the meta-linguistic approach requiring consciousness of language structures. It is a hard road to second language acquisition but one which commonly is taken by many who find themselves, as adults, living in a country whose native language is not their own. But there is another route to second language learning which is far more closely related to the method by which we learn our first language: the activation of an innate language processing mechanism in the context of a particular new Ianguage. This is the basis of the communicative approach to second language learning. Its relationship to first language learning has been demonstrated by Newport (1991) and her coworkers who showed the long-term quality of English as an acquired second language of Koreans working in a university environment in the United States dropped off sharply as a function of the age at which the subjects started to learn English, flattening out to a minimum from about 17 years onwards. It appears that second language learning, far from being assisted by the development of higher order thinking as the metalinguistic method might require, actually requires certain elementary structure to be active and not to have been overtaken by more complex methods of processing. Added to the probable requirement for a psycho-motor skill of encoding a series of sounds and reproducing them accurately, it appears that the teaching of foreign languages is not an area of the school curriculum which lends itself easily to cognitive interventionist methods.

It is however an area which lends itself to experimentation with efficient instruction. Programmes such as “Accelerated Learning” (Rose, 1985) make much of the fact that their methods are based on latest research “on the brain and human develoment”, but inspection of their materials shows that they have made excellent use of what we know about instruction but none at all of interventionist methods. It is noteworthy that it is in the area of modern language learning that Accelerated Learning has made its most obvious commercial impact.

Conclusion

I believe that there are both psychological theoretical reasons and educational practical reasons why we should study the possibilities of exploring the formation of higher level thinking, conveniently described as formal operational thinking, through many domains of the academic curriculurn. Considerable work is required to operationalise this intention, but the potential benefits in terms of a genuinely educated (not just skilled) population would be incalculable.

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