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FOREWORD

Thinking in Science – Thinking in General?

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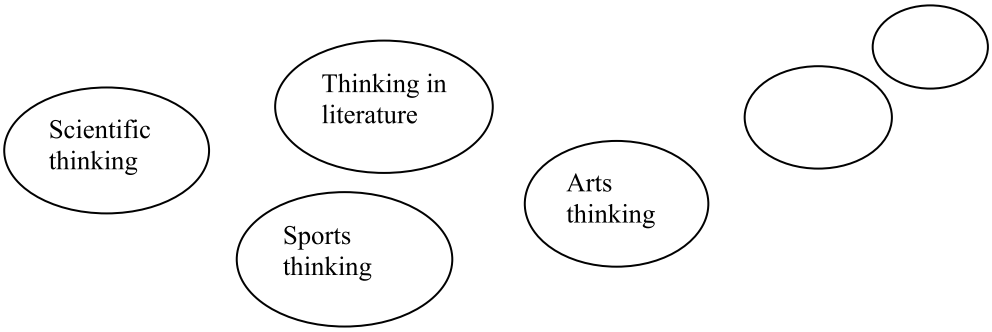
Introduction

In science we pay attention to some particular types of thinking, such as deductive and inductive logic, establishing causality through experimentation, analysis, and categorisation. There may be other types of thinking which we believe to be more typical of other fields such as literature (e.g. characterisation, sense of audience), art (e.g. form and composition, originality), or sport (e.g. whole-game strategies, anticipation) but which do not play such as large part in science. So can we represent thinking in different domains as completely independent of one another, as represented in figure 1?

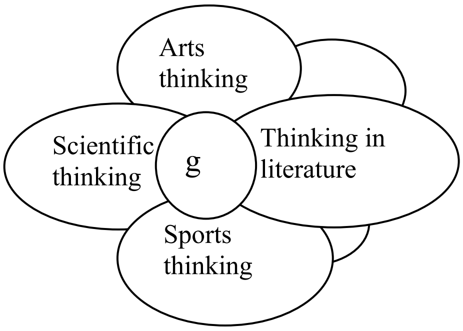
Fig 1: Separate types of thinking.



A Model of Thinking

Intuitively such a total separation of different types of thinking does not seem plausible and in fact the psychological evidence is clear (Anderson, 1992; Carroll, 1993) that there is always a significant correlation between higher level thinking across all different subject domains. Notwithstanding claims for completely independent 'multiple intelligences', all of the evidence points to the existence of one general intellectual processing mechanism (general intelligence, or 'g'), which is supplemented by a range of specialised abilities such as verbal, quantitative, and spatial (Demetriou, Gustafsson, Efklides, & Plastidou, 1992) . In the terms outlined above, this might be represented more like figure 2:

Fig 2: A general plus specialised model of thinking.



Here, while each domain does have its special characteristics, all are underpinned by a general processing mechanism.

This model of thinking abilities raises an intriguing question: If we could, within our science teaching, improve our students' ability to use higher order thinking skills, would this transfer to other domains and to their daily lives? Would they approach all sorts of problems in a more intelligent manner? In the Cognitive Acceleration projects initiated at King's College London in the 1980s we have explored these questions, and now we believe that we can answer a clear "yes": stimulating higher order thinking in science improves students' general intellectual ability across the board. This may seem somewhat surprising, since the literature (for example Detterman & Sternberg, 1993) on 'transfer' (the transfer of a mental ability developed in one context into a completely new context) suggests that it is very rare. Nevertheless, I propose to use the opportunity of this foreword to Volume 7 Issue 2 of APFSLT for a plea to use science teaching as much as an opportunity for the development of our students' general thinking ability as for the development of specific conceptual understanding in science. Firstly I will say something about principles of cognitive stimulation derived from cognitive psychology, then a little about how these principles may be interpreted as a teaching method and curriculum materials, and finally refer to some evidence for the effects of this approach.

The Three Central Principles

Cognitive Acceleration through Science Education (CASE) draws on Piaget and the neo-Piagetians, and on Vygotsky and his intellectual followers. From these sources we explicated a series of principles which would guide a pedagogy aimed at promoting higher level thinking (in Piagetian terms, formal operations). The central three of these principles are:

1. **Cognitive Conflict**. Piaget suggested that one of the mechanisms by which cognition develops is through a challenge to existing cognitive structures by experiences which make demands somewhat beyond the child's current processing capability. The same idea is encompassed by Vygotsky's Zone of Proximal Development ("The only good learning is that which is advance of development"). CASE activities are designed to provide such challenge, in scientific contexts, on a slope of increasing difficulty such that, at some point, students of different abilities all encounter cognitive conflict.

2. **Social Construction**. Both Piaget and Vygotsky stressed the role of social interaction in cognitive development, although it is Vygotsky's claim that "ideas appear first in the social space and then become internalised by the individual" that is best remembered. CASE pedagogy emphasises the importance of collaborative learning in the class, with groups of students interacting with one another, positive argument and critical questioning encouraged, and every student's contribution valued.
3. **Metacognition**. Another notion central to the Piagetian model of cognitive development, especially for the emergence of formal operations, is 'reflective abstraction', the idea that the individual reaches a higher level of thinking by reflecting on their own thinking. The Vygotskyan notion that language acts as a mediator of learning also suggests that putting thoughts into words (the conscious explication of thought) is a powerful driver of cognitive development. CASE teachers encourage their students to explain what they are thinking, what they find difficult, what they have learned, what mistakes they have made and how they corrected them.

A New Pedagogy

It can be seen that these principles lead to a pedagogy which is distinctly different from normal high quality teaching for conceptual development (which tends to have behavioural objectives achievable in one lesson, focuses on individual achievement, and tries to ensure ready accessibility). For this reason, in CASE we always recommend setting aside special time for CASE activities, distinct from normal science curriculum time. This is to help teachers make the clear distinction between the two types of good teaching – on the one hand good traditional instruction for concept development and on the other cognitive intervention for general cognitive development. The latter is seen to have a far deeper and longer lasting effect, albeit at the cost of 'delivery' of specific curriculum content.

Although these central principles (which we sometimes call 'pillars') of teaching for higher order thinking were the basis for the design of the original published CASE materials, Thinking Science (Adey, Shayer, & Yates, 2001), we never supposed that the printed materials – even enhanced with videos and powerpoints – could ever by themselves do the job of changing teaching practice. Teaching for cognitive stimulation is a different kind of teaching, and this necessarily requires an effective programme of professional development for teachers (Adey, Hewitt, Hewitt, & Landau, 2004).

Essentially teachers need to understand some of the underlying theory and to develop the practice of generating well-managed difficulty, of orchestrating high quality discussion between students, and of encouraging students to reflect on their own learning. This is a rather radical departure as one often is not able to point, after one lesson, to the "material covered", one's students sometimes leave the classroom a bit confused, they certainly have no notes of what has been achieved, and the school Principal has to accept that in these lessons a certain amount of productive argument and discussion is essential.

But for those many schools all over the world who have taken on the CASE methodology, the academic rewards are quite gratifying. In spite of apparently 'losing' valuable curriculum time to thinking lessons, the sacrifice pays off. We have shown over and over again (Adey & Shayer, 1993, 1994; Shayer, 1999; Shayer & Adey, 1993) that when properly implemented, a CASE intervention in (UK) Years 7 and 8 (Hong Kong S1 and S2, US grades 6 & 7) leads, in comparison with matched control groups, to (a), at the end of the two year intervention, greater gains in cognitive development; (b), one year later, greater achievement in science tests; and (c), two years later again, significantly higher grades in nationally set and marked measures of achievement – not only in science, but also in maths and English. That is the long term far transfer which justifies the claim made at the beginning of this paper: that work on developing students' higher level thinking in science actually increases their general intelligence across the board.

Concluding Remarks

One may reasonably ask, if we are interested in the development of general intelligence, why go through science rather than any other subject domain? Are we making claims for some special status of science as a vehicle for the development of thinking, as used to be claimed for Latin? No, not really. The reason we went through science initially was simply that Michael Shayer, Carolyn Yates and myself were all science teachers and we thought we knew a little more about that domain than any other. But also the schemata of formal operations described by Inhelder & Piaget (1958) (control and exclusion of variables, proportionality, classification systems, equilibrium, and the others) have a very science-y look to them. Nevertheless, there are now Cognitive Acceleration materials set in mathematics, technology, and the arts, and at primary level also. In principle there is no reason why such an approach should not be taken through any subject domain.

But this is a Forum for Science Learning, and in this journal I make no apology for promoting the idea that science teaching can teach much more than science; science in schools provides a rich environment for encouraging our students to develop their general thinking power, which can then be applied across all of their learning. I believe this to be a wonderful opportunity for all science teachers, provided they are prepared to 'raise their game' to meet the new challenges of teaching for cognitive acceleration. Apart from anything else, it is a lot of fun!

References

Adey, P., Hewitt, G., Hewitt, J., & Landau, N. (2004). *The Professional Development of Teachers: Practice and Theory*. Dordrecht: Kluwer Academic.

Adey, P., & Shayer, M. (1993). An exploration of long-term far-transfer effects following an extended intervention programme in the high school science curriculum. *Cognition and Instruction, 11*(1), 1 - 29.

Adey, P., & Shayer, M. (1994). *Really Raising Standards: cognitive intervention and academic achievement*. London: Routledge.

Adey, P., Shayer, M., & Yates, C. (2001). *Thinking Science: The curriculum materials of the CASE project* (3rd ed.). London: Nelson Thornes.

Anderson, M. (1992). *Intelligence and development: a cognitive theory*. London: Blackwell.

Carroll, J. B. (1993). *Human Cognitive Abilities*. Cambridge UK: Cambridge University Press.

Demetriou, A., Gustafsson, J.-E., Efklides, A., & Plastidou, M. (1992). Structural systems in developing cognition, science, and education. In A. Demetriou, M. Shayer & A. Efklides (Eds.), *Neo-Piagetian theories of cognitive development*. London: Routledge.

Detterman, D. K., & Sternberg, R. J. (Eds.). (1993). *Transfer on Trial*. New York: Academic Press.

Inhelder, B., & Piaget, J. (1958). *The Growth of Logical Thinking*. London: Routledge Kegan Paul.

Shayer, M. (1999). *GCSE 1999: Added-value from schools adopting the CASE Intervention*. London: Centre for the Advancement of Thinking.

Shayer, M., & Adey, P. (1993). Accelerating the development of formal operational thinking in high school pupils, IV: Three years on after a two-year intervention. *Journal of Research in Science Teaching, 30*(4), 351-366.