INNODATA MONOGRAPHS – 2

THE SCIENCE *OF* THINKING, AND SCIENCE *FOR* THINKING: A DESCRIPTION OF COGNITIVE ACCELERATION THROUGH SCIENCE EDUCATION (CASE)

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Foreword

Cognitive Acceleration through Science Education (CASE) is an innovative teaching approach elaborated out of research into cognitive development based largely on the work of Piaget and also incorporating fundamental tenets of Vygotsky's theories of learning. The programme aims to improve children's thinking processes by accelerating progress towards higher-order thinking skills or what Piaget termed 'formal operations'. CASE focuses on enhancing pupils' capabilities in understanding science concepts, science being an area in the curriculum that has always presented particular difficulties for the majority of pupils. Rather than being intended as an alternative science curriculum, CASE is designed to be an intervention programme in the existing curriculum, and originally targeted pupils between the ages of 11 and 14 years.

To date in the United Kingdom, the programme has proved highly successful in increasing pupils' capacities for understanding science and in developing their general thought processes, and is now widely applied in schools throughout the country. Similar programmes are being developed with different age groups and in other subject areas—mathematics and English—and the programme is being experimented with in some other countries.

Introduction

CASE is designed as an intervention in the science curriculum of students aged about 11 to 14 years. It had its origins in work done in the 1970s at Chelsea College in London, which showed that many of the concepts included in science curricula in the United Kingdom (and throughout the world) actually made demands beyond the current intellectual capability of the students. In the United Kingdom, this problem was highlighted with the end of the selective school system, when for the first time teachers in grammar schools, which had selected only the top 20% of the ability range, encountered the full range of students in the population. In the United States the problem showed up as the revelation that many college freshmen had a very uncertain grasp of fundamental concepts in science which supposedly had been part of their high school curricula (Renner et al., 1976). In perhaps the majority of countries in the world, where secondary education was available only to a minority, the difficulty of science concepts tended to be masked by the rote learning of definitions, which avoided the problems of trying to teach for real understanding.

The team at Chelsea College, led by Professor Michael Shayer, took a scientific approach to the problem of difficulty in science. On the one hand, we needed an accurate description of the intellectual profile of the school population, and on the other hand, we needed a way of measuring and describing the level of difficulty of science concepts. The theory of cognitive development which had been elaborated by the Swiss psychologist Jean Piaget provided us with just the sort of description we needed. Drawing on the Genevan's descriptions of types of thinking available at different stages, we (1) developed an instrument with which curriculum materials could be analysed for the cognitive demands that they made, and (2) developed group tests of cognitive development (Shayer et al., 1978), using them in a very large-scale survey to establish the levels of thinking of children at different ages in the school population of England and Wales. This work has been fully described elsewhere (Shayer & Adey, 1981), and here I need say only that a significant mismatch between the demands of the curriculum and the type of thinking available in the population was established.

With regard to this mismatch, there are in principle two possible approaches to a solution: make the science curriculum easier, or increase the intellectual capability of the students. While the former would be relatively easy, it would inevitably engender academic and political difficulties, and in any case might be seen as a defeatist solution. Although the prospect of increasing all students' ability to think may appear daunting, this was precisely the aim of the CASE project, initiated in 1982.

The underlying psychology

By ‘cognitive acceleration’ we mean the process of accelerating students’ ‘natural’ development process through different stages of thinking ability, towards the type of abstract, logical and multivariate thinking which Piaget describes as ‘formal operations’. Formal operational thinking is characterized by the ability to hold a number of variables in mind at once—for example, to be able to weigh up two sides of an argument, to consider even-handedly the advantages and disadvantages of a particular course of action, or to be able to see both the separate and combined effects of a number of input variables (for example, sunlight, carbon dioxide, water) on an outcome (the production of glucose). Piaget had suggested that this type of thinking becomes available to children as a process of natural intellectual development around the ages of 14 or 15 years. However, our Chelsea survey showed that only 30% of 16-year-olds were capable of such thinking, and this conclusion was supported by work with college freshmen in the United States, and parallel (but smaller-scale) surveys in other parts of the world.

In the late 1970s, it was not at all certain that the type of intellectual development described by Piaget and Inhelder could be influenced by any sort of educational process. A review of the literature that I conducted at the time led to the pessimistic conclusion that acceleration studies had so far shown little success. However, each of the previous studies had adopted a rather short-term and direct instructional approach, as if the mind’s ability to process information could be changed by learning a new set of rules. We believed that such approaches were flawed since the mind’s processing ability grows slowly, in response to demand placed upon it by challenging problems. This gives us the first of the five ‘pillars’ of CASE theory, *cognitive conflict*. This occurs when a student encounters a problem which she cannot easily solve for herself, but which, with carefully structured help from an adult or more able peer, she can solve, or at least gain in understanding the nature of, so that a solution is more likely to become available later. (Cognitive conflict and the other ‘pillars’ will be illustrated with specific examples in the section entitled ‘Planning and implementation’).

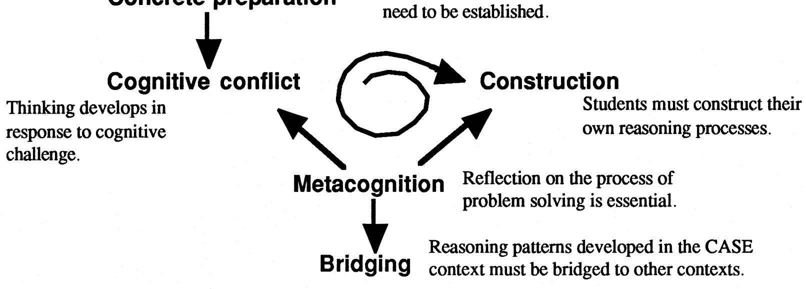
The principle of cognitive conflict is also encapsulated within the idea of a ‘zone of proximal development’ (ZPD) developed by the Russian psychologist Lev Vygotsky (1978). The ZPD is the difference between what a child can do unaided, and what he can do with the help of an adult. Vygotsky says: ‘the only good learning is that which is in advance of development’. In other words, learning tasks that are well within the child’s capability do not provide the challenge that stimulates cognitive growth. The emphasis here is on the student's own construction of higher-level modes of thinking. The teacher can provide the appropriate experiences and lead, through careful questioning, but cannot put higher-level thinking capability directly into the student's mind. The student must construct this for himself, and this is bound to be a slow process. This provides the second pillar of CASE theory, the idea of *construction*. Cognitively stimulating experiences are those which take place within the ZPD or 'construction zone'.

The third pillar of CASE theory is the encouragement of *metacognition*. Metacognition means simply 'thinking about your own thinking', although as an extremely fashionable notion in cognitive psychology the word has been used in many different ways (Brown, 1987). We can help ourselves to develop higher-level thinking only if we take some control of our thinking, that is become conscious of ourselves as thinkers. In CASE, students are encouraged to take time to reflect on how they solved a problem, what they found difficult about it, what sort of reasoning they used, how they sought help and what sort of help they needed. This is time-consuming and quite difficult to do, and teachers and students need a lot of help and encouragement initially to become more metacognitive in their approach.

There are just two more pillars of CASE theory. One is the idea of *concrete preparation*. You cannot simply present students with a difficult problem and expect the cognitive conflict to do the work of cognitive acceleration. There must be a phase of preparation in which the language of the problem is introduced, along with any apparatus to be used and a context in which the problem is set. The aim is to ensure that the difficulties encountered are just intellectual, and as far as possible are not compounded by problems of language or context. The final pillar is *bridging*, the linking of ways of thinking developed in the particular context of the CASE activity to other contexts within science, mathematics or other parts of the curriculum and to experiences in real life. If it is to become generally available, reasoning developed within a special context must be abstracted, and the student shown how it can be used as a general thinking tool.

Figure 1 illustrates the relationship of these five pillars to one another.

FIGURE 1. The 'five pillars of CASE wisdom'



The relationship of cognitive conflict to construction, shown in Figure 1 by a spiral arrow, is not straightforward. When we are presented with a problem with any sort of difficulty in thinking to which we cannot readily produce a solution, it is in the general nature of humankind to seek simple solutions. We 'short-circuit' a full analysis of the problem in order to reach an accommodation that will meet the immediate needs of the situation. Students on their own will rarely seek full understanding of a situation but will tend to settle for the minimum solution that will meet the immediate demands of the problem in question. For example, faced with the problem of determining what factors cause iron to rust and finding that nails in water rust faster than dry nails, the student will be content with the solution 'rust is caused by water' without delving more deeply into the possible effects of air as well. Thus cognitive conflict by itself does not automatically lead to reconstruction of concepts or to reaching a full understanding. The cognitive conflict must be maintained and this can only be done by the teacher through close questioning. This gives a hint about the nature of the pedagogy required for cognitive acceleration, which will be described in the section on professional development below.

The 'five pillars' provide a foundation for the pedagogy of cognitive acceleration, but by themselves they specify nothing about the subject matter context. Teaching methods based on the Piaget–Vygotsky foundation outlined above could be developed in any subject matter. So why did we choose to work through science rather than, say, mathematics, history or English? There was a pragmatic element to the answer—the early Chelsea work that led to the CASE project was science-based and both Michael Shayer and I had science backgrounds. But there was also a good theoretical reason for at least starting the work in science even though it expanded later into other subject areas. The original detailed description of formal operations provided by Inhelder and Piaget (1958) is characterized by a set of mental 'schemas': control of variables, ratio and proportionality, compensation, equilibrium, correlation, probability, and the use of formal models. These schemas are immediately recognizable by scientists and science teachers as descriptive of important types of relationships between variables, and they are the stuff of experimental design and the elucidation of general patterns of behaviour in the natural world. Formal operations are certainly not limited to science, but are a quite general way of processing data in any intellectual field, and the schemas of formal operations can be interpreted in the context of any academic subject area. Nevertheless, their application to science, and to some extent to mathematics, is fairly straightforward, and so science presented itself as a most obvious gateway to the development of high-level thinking.

The complete underlying theoretical model of the CASE project can be conceived of as the 'five pillars of CASE wisdom' (Figure 1) set in the context of the schemas of formal operations described by Inhelder and Piaget.

Risks

The potential risks associated with the implementation of the CASE project are partly theoretical and partly practical.

At the theoretical level there is some controversy about the validity and the generalizability of the Piagetian model of cognitive development. It has been suggested that it may be possible for an individual to be capable of formal operational thinking in one context but not in another. This idea arises from a misunderstanding of the notion of operational thinking. Piaget is very clear that mental operations need to be performed on some 'raw material' in the form of knowledge or information. One cannot expect a person, however mature and intelligent, to immediately display high-level thinking in a field with which she is unfamiliar. One *may* expect her to take a formal operational approach to the process of acquiring knowledge in a new field. Expert performance depends both on a high level of processing ability and on a foundation of experience in the field in which expertise is being demonstrated (Larkin, et al., 1980). Raising levels of processing ability does not in itself create experts in every field, but it does permit individuals to acquire expertise more readily. In the end, the results of our evaluation (to be described below in the section entitled 'Trials and evaluation') provide strong evidence for the generality of formal operations.

Practically, implementing the CASE programme involves teachers in using special lesson activities instead of some of their normal science curriculum lessons. This presents two problems. The first is that the CASE activities do not appear specifically in the National Curriculum, and so school Heads and teachers need to be convinced that their students will benefit if they 'give up' some of their normal curriculum activities. This will be a problem recognized by anyone who has tried to introduce innovative methods in any country that has a well-defined National Curriculum. A specified curriculum can act as much as a cage, trapping the educational system in a stagnant annual repetition of the same material, as a support for teachers uncertain of what they should teach and in what order (Adey, 1984). It must be said also that educators sometimes use the curriculum as an excuse to block innovation: 'we would like to try it, but we don't have time to deviate from the curriculum'.

The second practical problem is that the type of teaching required for cognitive acceleration is significantly different from normal good instructional practice, and so the effective introduction of CASE requires a programme of professional development for the teachers involved. We will return to these problems, and ways in which they are solved.

Planning and implementation

FUNDING THE INITIATIVE

The initial funding for the development of CASE came from two research grants awarded by the Economic and Social Research Council in the United Kingdom. In 1981 a modest grant enabled Michael Shayer to draft about six activities and test them in one school. These established the use of the schemas of formal operations (see the section entitled ‘The underlying psychology’) and cognitive conflict, and started an exploration of the practicality of introducing new sorts of activities into the regular school curriculum. Initial results were encouraging. On the basis of this pilot, Shayer applied for, and in 1984 obtained, a much more substantial grant enabling the employment of Philip Adey and Carolyn Yates full-time for three years to develop and evaluate a full-scale CASE programme in a number of schools.

DEVELOPING THE ACTIVITIES

I cannot claim that in 1984 we had fully articulated the theoretical model outlined above. The schemas of formal operations were established as the framework within which activities would be structured; the ‘pillar’ of cognitive conflict was recognized as central to the process of cognitive acceleration; and constructivism had always been a main pillar of Piaget’s account of cognitive development. The need for concrete preparation was a pragmatic necessity that arose out of our experience as teachers, and bridging likewise seemed of obvious importance if the schemas were to be generalized. But our elaboration of the importance of metacognition grew throughout the project, from being implicit in the type of questioning that we promoted, to becoming an explicit and very important part of the CASE method. This gradual evolution of the ‘pillars’ CASE as a complete theoretical structure underpinning the design and delivery of activities has since become a significant element in the development of teachers, to be described later.

Target population

In line with the origin of CASE as described above, we were concerned with a broad range of ability, i.e. the majority of the student population for whom science appeared to be rather difficult. In terms of ability, our target was the middle 80% to 90% of students. It is important to be clear about this, since the experience of cognitive conflict will depend on an individual's ability. What provides an interesting and productive puzzle for one individual may appear trivial to a more able child and incomprehensible to a less able peer. While careful design of activities and flexible pedagogy can provide a wide range of levels of conflict within a particular activity, we considered it impracticable to include within our target population either the exceptionally able child, who would already be using formal operations by the age of 11 years, or children with serious learning difficulties, who at 11 might still be pre-operational.

In terms of ages, we targeted the 11–14 range. The main reason is that for the great majority of students this is the age of preparation for formal operational thinking. There is some evidence (Epstein, 1990) that there are brain-growth spurts at about 11 in girls and 12 in boys which may be part of a physiological maturation programme evolved to prepare adolescents for the intellectual demands of adulthood. Our survey of the population referred to in the Introduction showed that only a small proportion of children actually attained the ages of cognitive development described by Piaget in his 'epistemic subject'. The population survey may be read as an indication of a deficit in the quality of stimulation provided for the majority of children at home and in school. On the basis of this reading, such a deficit should be remediable by providing appropriately designed stimulation at the right ages.

There is a pragmatic reason also for choosing 11–14 years as the age of operation of CASE. In the United Kingdom, 11+ is the age of transfer from primary school, where there are class teachers who teach all subjects, to secondary school, where there are specialist subject teachers. An intervention set within a science context would require science teachers who already understood—implicitly if not explicitly—the nature of the scientific reasoning patterns which form the context of the intervention.

DRAFTING THE ACTIVITIES

Armed with the main features of a theoretical model, with the schema of formal operations and with our experience as science teachers, the CASE authors (initially Michael Shayer, then joined by myself and Carolyn Yates) started to draft activities we thought would be appropriate for our target population. We discussed the form and practicalities of the activities amongst ourselves and with other academics and teachers. We ourselves taught each of the drafted activities to classes in London comprehensive schools that represented the age and ability range of our target population, and the kind of social and ethnic mix typical of inner-city schools in the United Kingdom. After a year of the funded project we had a bank of some twenty activities ready for a wider trial.

Before describing this, however, I will give some examples of CASE activities and how they are related to the theoretical model.

WHAT THE CASE ACTIVITIES LOOK LIKE

To show how these general principles are worked out in practice, three activities will be described in some detail. These are all drawn from the published Thinking Science curriculum materials, available in English (second edition), German, American and Welsh versions (Adey, Shayer & Yates, 1992, 1993, 1995). These materials contain about thirty activities described in terms of student worksheets and workcards, teachers' notes, and notes for technicians about the apparatus requirements.

TS3, Tubes. This is the third activity in the programme. In the previous activities, the ideas of variable, values of variables, and relationships have been introduced. Students have a box of small tubes. Questioning in a whole class discussion ensures that they identify the variables and values: length of tube (short, medium, long); width of tube (wide or narrow); and the material of the tube (glass or plastic). This is the concrete preparation phase of the activity, familiarizing students with the basic ideas they are going to manipulate and the practical apparatus they are to use. Then they are asked to blow across the tubes, and listen to the note produced. The question is this: what affects the note that you get? They have some free exploration time and are asked, if they think they know what affects the note, to explain to the teacher or to another student what they think and why they think it. There is often a need, after some minutes, to call the class together and suggest that they take tubes just two at a time.

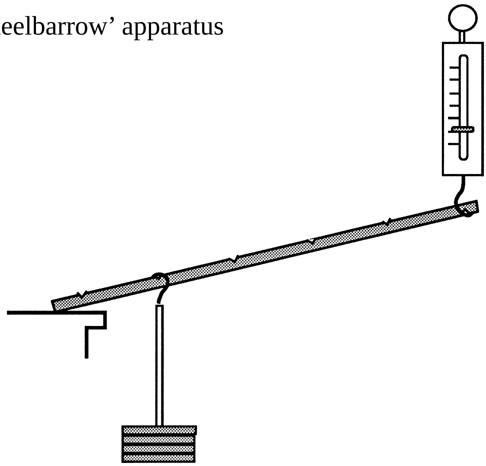
This is the phase of cognitive conflict and construction. A child may come up with the claim that the width of tube affects the note. 'Show me', says the teacher. The student demonstrates with two tubes of different width that produce different notes. Looking at the tubes, teacher points out that they also have different lengths. 'How do you know whether it is the length or the width that affects the note?' Here the teacher is establishing some cognitive conflict, challenging the student to take account of a variable that she had not yet noticed. Typically, a child might answer 'both width and length affect the note'. She does this as it seems a simple way to resolve the conflict, but the teacher perseveres with the questioning, saying finally 'go and choose another pair of tubes, but this time try to find a pair that will give us a clear answer'. Note that the teacher does not direct the student to choose two tubes in which only one variable has altered. The whole point is that the student must construct for herself this strategy for control of variables.

In a comprehensive mixed-ability class of 12-year-olds, it is possible that there will be one or two children who find the whole task so easy that they do not experience much cognitive conflict. For these the teacher may suggest a higher-level task, such as looking for interaction between variables. There may be one or two others who, at the end of the sixty- or seventy-minute lesson, remain quite confused by the whole exercise and still fail to see the point of controlling variables. The great majority, however, will have experienced (through interaction with the apparatus, worksheet questions, the teacher and with other students) sufficient conflict to have constructed for themselves at least the beginning of a control of variables strategy. The full development of this into an internalized, unconscious schema which is 'naturally' brought to bear on all experimental situations will still take some time, but essential groundwork has been laid and previous concrete change-everything-and-see-what-happens schemas will have been severely shaken, if not broken up altogether. Even for the least able students who remain confused at the end of the activity there will have been a struggling with the problem and some doubts cast on the ineffective concrete strategy. Even a slight sense of unease at the way in which experimental questions are approached is of value. It is the cognitive struggle that is critical in the promotion of cognitive development; and so the objective has been reached if every child experiences some cognitive conflict and goes some way towards finding a resolution satisfactory to herself or himself. This is likely to be an end point that differs for each student, according to their ability and their personality.

For a second example, consider **TS8, The Wheelbarrow**, which is concerned with the reasoning pattern of proportionality. Before this activity, students have explored ideas of scaling by looking at pictures of embryos drawn to different scales, and by using maps of the school environs to estimate real distances. The word 'ratio' has been introduced. The apparatus for TS8 consists of a stick about 8 mm in diameter and just over 60 cm long. It is notched in two places so that a mass hanger and a Newton spring balance can be attached, as shown in Figure 2. The concrete preparation consists of a discussion with the whole class about the advantages of using a wheelbarrow to carry loads, and introduction of the apparatus, also shown by illustrations on the worksheet which draw clear parallels between this apparatus and the application of lift and load forces in a wheelbarrow.

Working in groups, students record and tabulate the lift as successive loads are added. This itself is not intellectually demanding, but for each pair the ratio of lift to load is to be calculated. Here the teacher will bridge back to previous ratio work, ask questions about the meaning of ratio, and insist that each of the 'answers' produced on calculators for the ratio is given meaning in terms of what it implies about the load that can be carried with a moderate lift in the

FIGURE 2. The 'wheelbarrow' apparatus



wheelbarrow. This is a time-consuming process. With about six pairs of values completed, the teacher discusses with the class what patterns seem to be emerging. By asking different groups to report, it is established that there seems to be a constant ratio of lift to load (typically 1:3). Now the level of cognitive conflict increases, as students are asked to work out what the lift would be for some loads they have not tried. In a well-conducted CASE class there is some metacognitive discussion here about how they might go about this problem, with suggestions of approaches being discussed and critically compared around the classroom. Although an additive strategy ('for every extra 3N load, you add 1N lift') may appear satisfactory, the teacher through questioning aims to lead students to see that for large numbers this is inefficient and that a 'three-times' (true ratio) strategy is more general and powerful. Obviously, the extent to which this is successful depends on the ability of the particular class and on the time available, but as with the previous example, the least that is to be achieved is a realization that there is some multiplicative approach to such problems which is available. Repeated exposure to this type of proportional thinking slowly builds it into the students' repertoire as an operational schema.

TS 18, Treatments and Effects, which is taught in the second year of the programme, provides a final example. This is set in the context of the schema of correlation. The concrete preparation concerns two researchers who are testing the effect of a new fertilizer on the growth of carrots. Each has a treatment and non-treatment set of carrot plants and counts the number of plants in each set, which show increased yield over a standard. The data are presented to the whole class as two 2 × 2 tables (treated/untreated and shows effect/no effect) and the discussion emphasizes that the data from the untreated carrots are as important as those from the treated carrots (concrete operators tend to look only at treated carrots, to see if many show increased yield). Each group of students is now given a set of twenty cards. Each set of cards shows one organism (rose, wheat, cow, pig or sheep), and also shows whether or not the organism has received some treatment (e.g. fertilizer, pills to make more milk, etc.) and whether the animal or plant demonstrates an effect (by growing more, producing more milk, meat, etc.). Students first sort the cards into four piles according to whether they have: A, not been treated and not shown an effect; B, not been treated but shown an effect anyway; C, been treated but not shown an effect; and D, been treated and shown an effect.

Students then address the question of whether any effect seen is likely to be the result of the treatment or not. For example, if the treatment causes the effect, in which of the four piles A, B, C and D would you expect to find large numbers? Discussion in groups leads to the conclusion that you would expect piles A and D to be large, and B and C to be small. In the discussion of these results the terms ‘positive correlation’, ‘negative correlation’ and ‘no correlation’ are introduced to help students think about what sorts of relationships exist between treatments and effects. This activity models at a simple level the type of experimental evaluation of treatments which is at the heart of much medical, agricultural and other research. Without an understanding of correlation and associated probabilistic relationships, the majority of popular science reports in newspapers are incomprehensible. This type of activity lays the groundwork for important understandings in scientific investigation as well as contributing to general cognitive growth.

It is important to note that in none of these ‘thinking science’ lessons do students complete neat notes of ‘conclusions reached’ or ‘knowledge captured’. There may be no written product at all, as the worksheets are used just to record data that form the raw material for thinking about relationships. Some CASE teachers actually encourage students to throw away their worksheets at the end of the lesson, so as to emphasize that the real product of these lessons is changes, maybe small but nevertheless real, in the way that students think. This again highlights a difference between the CASE intervention activities and the regular science curriculum, a difference that some teachers initially find hard to accept.

Fitting it into the curriculum

CASE does not offer a complete alternative science curriculum. Indeed, the pedagogic difficulty of managing intervention lessons and the fact that no science content is explicitly covered make it unsuitable as a substitute for regular science teaching. Furthermore, while the uncertainty with which students are sometimes left at the end of CASE lessons is productive in moderate amounts, it might well become demotivating if it were a permanent feature of science lessons. CASE is described as an ‘intervention’ because it is a process of intervention in ‘normal’ cognitive development, and also because it is an intervention in the regular science curriculum. CASE activities are taught instead of regular science activities once every two weeks. In a thirty-seven-week school year, after allowing for open days, sport days, examinations and so on, this means that about fifteen or sixteen CASE activities can be taught in one year, or thirty-two over the two-year period of the intervention.

Such a schedule can represent 20% of the time allocated to science, and teachers sometimes say ‘it sounds like a good idea but we do not have the time for it’. Their position is understandable, but the reality is that very little time is actually ‘lost’ to the curriculum content material. This is partly because CASE already covers some of the process objectives of the curriculum, but mostly because as the students’ thinking develops so they are able to understand and make sense of the regular curriculum material more efficiently, in less time. Luckily, we have very good evidence to support this claim, and this evidence generally persuades teachers that the risk of ‘losing’ so much curriculum time is worth taking, at least on a trial basis.

Trials and evaluation

The effect of the CASE intervention on students' cognitive development and academic achievement determined from our original research project has now been widely reported—see, for example, Adey and Shayer (1993, 1994); and Shayer and Adey (1992*a*, 1992*b*). A summary of that work will be given here before more recent evidence is considered.

THE 1984–87 EXPERIMENT

Originally, we chose ten schools representing widely different social and geographical environments in England to test the materials which we had ourselves already used in two London comprehensive schools. The results to be described here are for the ten experimental classes in seven schools that continued with the programme, more or less as intended, for a period of two years. In each of these schools, one or two classes were designated as 'experimental', and from September 1985 started to use the Thinking Science activities as described above once every two weeks for two years. Four of the experimental classes were United Kingdom Year 7 (United States grade 6) classes, with children aged about 11+ years, and six of the experimental classes were Year 8 (United States grade 7), with children aged about 12+ years. In each school parallel 'control' classes were identified and these were matched with the experimental classes for age and ability. The control classes were taught their regular science curriculum without loss of time for the CASE intervention.

All classes—experimental and control—were given a pre-test of cognitive development to act as a baseline for measuring any subsequent growth and to make allowance for any initial differences between experimental and control groups. At the end of the two-year intervention period, all classes were given post-tests of cognitive development, and also a test of science achievement. This was the end of the intervention programme (and of the funded research), but one year later we revisited the schools to collect information on all of the students' science achievement. One further year later, in July 1989, those classes that had started the CASE intervention in their Year 8 took their General Certificate of Secondary Education (GCSE) examinations. This is the national public examination taken at 16 years by all students in schools in England and Wales. For all of the students who had previously been in classes designated as experimental and control we collected the grades attained in science, mathematics and English. One year on again (July 1990), those who had started in Year 7 sat their GCSEs and again we collected their grades. We thus had the data which allowed us to compare over a long period (a) cognitive growth and (b) academic achievement of initially matched students, some of whom had experienced the CASE intervention and some of whom had simply followed their regular science courses.

In order to allow for individual differences in starting cognitive levels, all data were processed by (i) finding the regression line for each post-measurement on pre-cognitive measures for the control groups; (ii) using these regression lines to predict the value of the post-measures for each experimental child as if s/he were no different from a control child; and (iii) subtracting the predicted post-measure from the actual post-measure obtained. This difference is the residualized gain score (r.g. score). For any group of students the mean r.g. score is a measure of the extent to which their development or learning has been different from that of the initially matched control group.

For convenience of comparisons, all results will be reported in terms of r.g. scores. Note that r.g. scores build in comparison to controls and that by definition the mean r.g. score of a control group must be zero. Results for four groups will be considered: boys who started the intervention at the beginning of Year 7 ('11+ boys'), boys who started the intervention at the beginning of Year 8 ('12+ boys') and the corresponding girls' groups. Table 1 summarizes for each group the number of students, mean r.g. score, standard deviation, and (where significant) the significance level and effect size in standard deviation units, for the immediate post-test of cognitive development and then delayed science achievement and GCSE grades obtained up to three years after the end of the intervention.

Attention should be drawn to a number of features of these results, some of which are obvious and some of which are not clear from the raw figures:

- The immediate effects seem to be rather limited, but (1) more recent immediate effects obtained on cognitive development have been much larger (see below), and (2) there is a strong correlation on an individual student basis between cognitive gains over the two-year intervention programme and subsequent gains in GCSE scores.
- In spite of the moderate immediate effects, there is a long-term, and apparently growing, effect of the intervention on students' academic achievement. In principle, this is what might be expected from an intervention programme which increases students' general thinking capability. The effect of the raised cognitive levels will be, starting at the end of the intervention, to improve students' ability to benefit from normal classroom instruction. Such improvement is likely to be cumulative as better understood conceptual learning provides a sounder platform for further learning, and so on.

TABLE 1. Residualized gain scores on successive tests after completion of two-year CASE intervention, based on pre-cognitive tests, September 1984

		Group	Number	Mean gain	Standard deviation	Signifi-cance, p<	Effect size (s.d.)
Immediate post-cognitive test, July 1987		11+ boys	29	-0.21	0.95	-	-
		11+ girls	27	0.08	1.10	-	-
		12+ boys	65	0.70	1.00	.001	0.75
		12+ girls	52	0.03	0.98	-	-
One year delayed science achievement, July 1988		11+ boys	37	2.72	15.45	-	-
		11+ girls	31	7.02	12.76	.020	0.60
		12+ boys	41	10.46	16.60	.005	0.72
		12+ girls	36	4.18	14.41	-	-
GCSE 1989	– Science	12+ boys	48	1.03	1.34	.005	0.96
		12+ girls	45	0.19	1.38	-	-
	– Maths	12+ boys	56	0.55	1.23	.005	0.50
		12+ girls	54	0.14	1.27	-	-
	– English	12+ boys	56	0.38	1.27	.050	0.32
		12+ girls	57	0.41	0.96	.010	0.44
GCSE 1990	– Science	11+ boys	35	-0.23	1.46	-	-
		11+ girls	29	0.67	1.36	.025	0.67
	– Maths	11+ boys	33	-0.21	1.59	-	-
		11+ girls	29	0.94	1.26	.005	0.72
	– English	11+ boys	36	0.26	1.65	-	-
		11+ girls	27	0.74	1.32	.025	0.69

- There is a strong ‘far transfer’ effect. That is, an intervention programme delivered by science teachers through activities with a strong scientific context has produced effects on students’ achievement in mathematics and in English literature. This is a rare effect in the psychological literature, perhaps because few studies have taken such a long-term view of experimentation and measurement as we have in the CASE project. Such transfer implies that the CASE intervention has tapped into and influenced a deep-seated function of the mind, which has a broad effect on students’ intellectual functioning.
- There seems to be an age/gender interaction effect, in that the intervention is most effective with younger girls and with older boys. Although this notion fits neatly with a model of a cognitive window of opportunity for the promotion of formal operations, which in line with their generally earlier maturity at this age comes earlier for girls than it does for boys, we must be very careful before drawing such a conclusion. For one thing, the 11+ group was actually more able overall than the 12+ group, both age groups starting the intervention at about the same mean level of cognitive development. For another, more recent data do not show anything like the same gender effect.
- The distribution of gains within any group (not shown here, but see Adey and Shayer, 1994) is often bimodal. That is, some of the students make very large gains, around two standard deviations, whilst others make gains little

more than the controls. We do not know why this is, but it may possibly be due to the ‘fit’ of the Thinking Science methods with different motivational styles of individual students (Leo & Galloway, 1995).

MORE RECENT RESULTS

Results reported so far were from the original research experiment, in which we were able to measure effects on particular experimental classes against the results of well-matched control classes in the same schools, with the same teachers. The disadvantages, however, were that the numbers were relatively small because we were only able to collect data from one or two classes in each school; we ourselves were still in the process of inventing the method for training the teachers; and the teachers themselves were working on the project in isolation within their schools.

Following the publication of the long-term effects on GCSE scores in May 1991, there was a great demand from schools for the materials and methods that would enable them to replicate the results. Since then, we have been running a series of two-year in-service teacher education courses to introduce the methods. This professional training will be described in more detail in the section entitled ‘CASE and the professional development of teachers’. Although we are now collecting many new data, an important difference between this and the original experiment is that since we now have a method which we believe works, we cannot ethically deny it to any class just to provide an experimental control. One way of analysing new data is to compare gains made by CASE schools with the national norms established in the Chelsea survey (see above). From the first cohort of schools participating in the CASE training programme, we were able to collect pre- and post-test data on levels of cognitive development for sixty-three classes in eight schools. Some of these classes made a Year 7 (11+) start on the intervention, some a Year 8 (12+) start, and one school started the intervention in both years. A summary of the effect sizes of the school mean residualized gain scores compared with national norms is given in Table 2.

TABLE 2. Effect sizes of cognitive development: residualized gain scores in eight schools which participated in CASE training, 1991–93

School	Start age	Effect size (s units)	School	Start age	Effect size (s units)
1	11+	0.67	5	12+	0.80
1	12+	0.76	6	11+	1.00
2	11+	0.69	7	12+	0.29
3	11+	1.12	8	12+	1.26*
4	11+	1.12			

* By comparison with previous Year 9 group, questionable.

We have actually studied the effect size obtained in each of the sixty-three classes. In one class, there was a significant negative effect, possibly due to some error in the administration of the pre-test. In four others there were insignificant negative effects. In three classes there were positive effects of less than 0.3s. In all of the remaining fifty-five classes there were significant positive effects of the CASE intervention on children's rate of cognitive development. As we have shown previously, cognitive gains attained over the intervention period are related to subsequent academic gains.

In 1995 and 1996 we were able to collect data on the academic achievement of CASE schools, compared with non-CASE schools, for the 'Key Stage 3 National Curriculum Test' (KS3 NCT) as well as for GCSE grades of students who had used CASE in 1991–93. I will present the KS3 results first. In the United Kingdom, the Government has instituted a series of nationally moderated tests to be given in various subject areas at the end of each 'Key Stage' of education, which means at the ends of Years 2, 6 and 9 when children are about 7, 11 and 14 years old respectively. For schools that use Thinking Science in Years 7 and 8, the KS3 NCT given at the end of Year 9 provides a convenient measure of academic achievement one year after the end of the intervention.

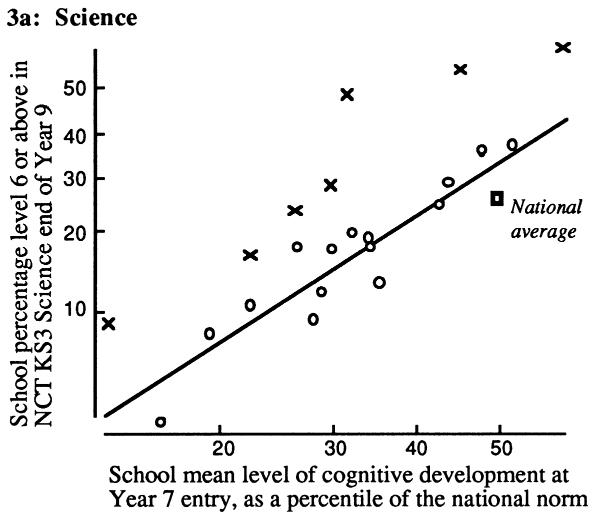
In Figures 3a, 3b and 3c each point represents one school. The horizontal x-axis is the mean score of the school's students at the beginning of Year 7 (secondary school entry) on measures of levels of cognitive development, expressed as a percentile of the national average. This is a measure of the school's intake ability, which is a reflection of factors such as the socio-economic conditions in the school's environs and whether there are selective schools in the area which cream off the more able students. It so happens that almost all of the schools for which we have data at present are in the lower half of the intake ability range. The vertical y-axis is a measure of success in the KS3 NCT. These tests are scored for National Curriculum levels, which fall on a range from 1 to 10 (or more recently 1 to '8 and over'). The percentage of students attaining levels 6 and above at Key Stage 3 is commonly taken as a measure of the success of the school. In order to make the plot linear, all scores have been transformed into logits: ln(%100%). This is why the axis scales are not equal-interval.

In each figure, the regression line has been drawn through the points of the control (non-CASE) schools only. It shows, not surprisingly, that success in the Key Stage 3 tests is closely related to the intake ability of the school's pupils. What is striking is that for almost all of the data we have so far, CASE schools fall above—often far above—the regression line for control schools. This means that whatever the intake level of the school, CASE schools are adding significantly more academic value to their students than non-CASE schools. Even in English, where points are more widely distributed because of the lower reliability of the assessments, every CASE school falls above the mean for non-CASE schools. The effect is equivalent to an addition of about thirty percentile points to school mean academic achievements.

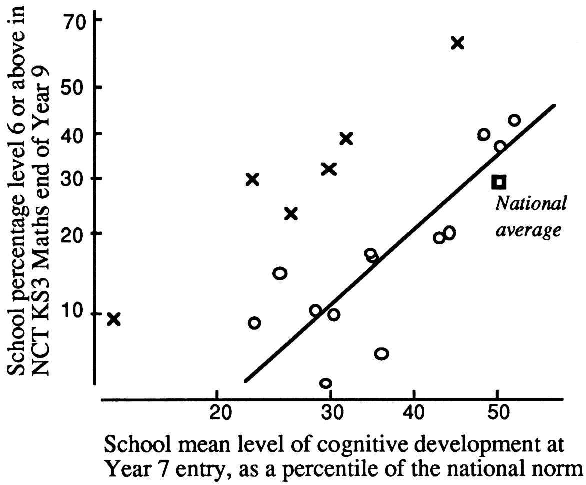
The 1995 GCSE results for students who used CASE three years previously follow a similar pattern, although there are fewer schools for which we have data at present. The pattern is analysed in exactly the same way as the KS3 data, except that the measure used for a school's mean success at GCSE is the percentage of students attaining grades A, B or C at GCSE, on a scale which runs from A to G plus 'fail'. Grades A–C are generally considered a 'good' pass at GCSE and a basis for continuing education in that subject area. Figures 4a–c summarize the results for the 1995 GCSE.

It seems clear that the CASE intervention has systematically added greater academic value to students of a given starting cognitive level than is normal for non-CASE schools, and that the effect on student thinking transfers beyond the science context in which the cognitive intervention programme is delivered. The precise nature of this effect is not absolutely certain, and we will discuss further the relationship of the underlying theoretical hypotheses to the results obtained in the last section.

FIGURE 3. The relationship between school entry cognitive levels and NCT KS3 test performance at the end of Year 9 for CASE (x) and non-CASE (o) schools



3b: Mathematics



3c: English

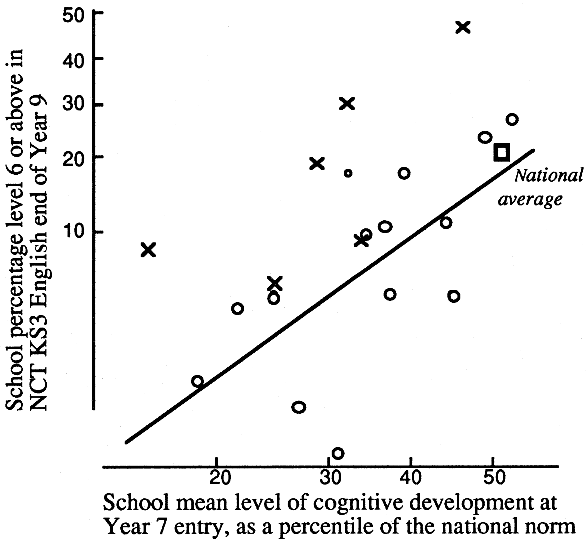
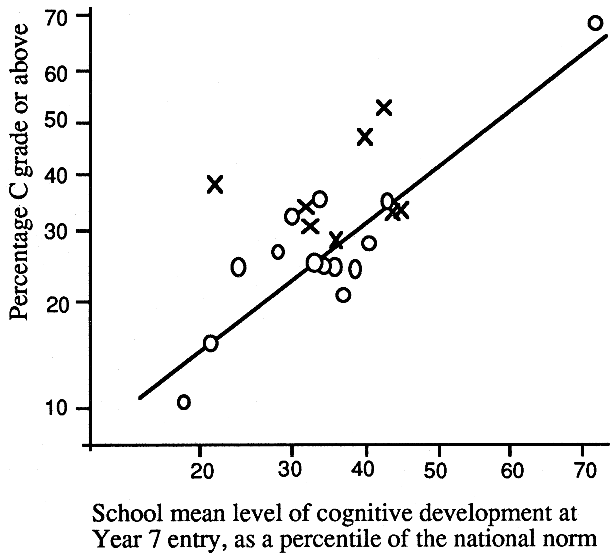
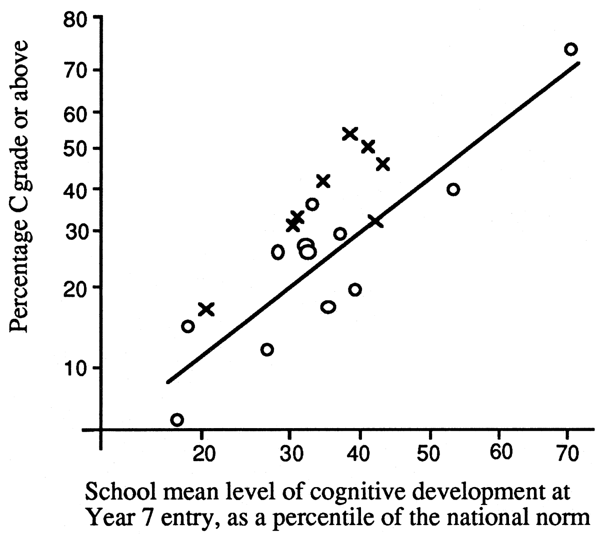


FIGURE 4. The relationship between school entry cognitive levels and GCSE examination performance at the end of Year 11 for CASE (x) and non-CASE (o) schools

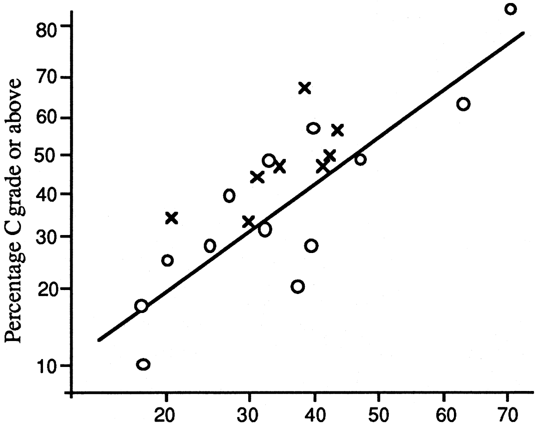
4a: GCSE Science, 1995



4b: GCSE Mathematics, 1995



4c: GCSE English, 1995



School mean level of cognitive development at Year 7 entry, as a percentile of the national norm

CASE and the professional development of teachers

It will be very clear from what has been written above about the nature of the CASE intervention that teaching children to think is a subtle, complex process which cannot be reduced to a set of specific activities for teachers to follow. The reason that there can be no such thing as a 'teacher-proof curriculum' is that the process of teaching is an essentially human social enterprise involving myriad types of interaction between teacher and pupils. For teaching to be effective, each teacher has to find her or his own way of working with the great variety of personalities and intelligences which they meet every day.

If these principles are true for teaching in general, they are even more important when applied to teaching for the development of reasoning. We have to consider what the teacher of thinking needs to be able to do, what normal training and experience have prepared them for, and how the gap between the two might be closed. Although pre-service training will be considered briefly, attention will be focused on in-service education of practising teachers and the particular programme developed for CASE.

WHAT IS NEEDED?

What are teachers of thinking required to do? Teaching for the development of reasoning in children is the antithesis of teaching for the recall of factual content. The development of critical thinking, or higher-level reasoning, in children requires by definition that children be given an opportunity to exercise their own minds, to engage in critical appraisal, to risk opinions in a sympathetic atmosphere and then have the opinions challenged in a rational but respectful manner. This means the creation in the classroom of a very special sort of atmosphere which is intellectually rigorous but at the same time friendly and safe—in the sense that all children should feel confident in taking cognitive risks. To create such an atmosphere, the teacher needs to have:

- clear objectives in terms of the type of reasoning being developed in a particular thinking lesson;
- some familiarity with the underlying theory of cognitive acceleration;
- an intimate understanding of the range of reasoning and arguments displayed by his or her pupils, if not of the particular levels of argument employed by each individual pupil;
- mastery of a range of techniques such as asking leading questions, suspending judgement, setting challenges appropriate to particular children,

and the ability to interpret children's utterances in terms of the type of thinking they are using.

The 'needs list' may be seen as something of a specialization of the requirements placed on any teacher, rather than as a radically different type of teaching. It is, or at least should be, part of every good teacher's repertoire to be clear about objectives, familiar with teaching materials, sensitive to children's needs, and in command of questioning and other techniques. But for the development of reasoning in children, each of these requirements is raised to a higher degree, or applied to rather particular methods and materials different from the normal content-oriented curriculum.

PRE-SERVICE TEACHER EDUCATION

Is it realistic to expect the development of such specialized skills during pre-service training of teachers? The pre-service training of both primary and secondary teachers already has a very full curriculum of content upgrading, pedagogic and managerial classroom techniques, confidence building, and some basic learning theory and consideration of the aims of education. Whether the education component of a course is concentrated in a one-year professional programme or whether it is infused across a longer period of a higher education course, it cannot aim to do more than to provide teachers with basic skills and confidence and to act as a selection process to filter out the least suitable people from the profession. The effective teaching of thinking requires a level of skill and experience which is, by its nature, beyond the possibility of inclusion in normal pre-service teacher education programmes. There may be occasional 'natural' teachers who, possibly through their own experience as pupils or in their families, have developed to an unusual degree the ability to help others to develop their thinking, but we are concerned here with the majority of student teachers who do not immediately exhibit such exceptional skills.

Certainly, it is sensible to include reference to teaching for cognitive acceleration in pre-service courses, if only to alert students to future possibilities, but one should not expect too much of the effects of such introductory sessions on the student teachers' classroom practice. In our own pre-service one-year postgraduate professional course for science teachers at King's College London, we devote one day to the Thinking Science methods and materials. Each year the reaction of students ranges widely from those who think it is the best session of the whole year, and who say 'Why didn't you tell us this before? Why isn't all teaching like this?' to those who view it as theoretical mumbo-jumbo which has no bearing on their major concerns of classroom management and the teaching of content.

We cannot realistically expect to develop teachers of thinking in pre-service courses, but we can sow the seeds of curiosity and indicate what possibilities lie ahead for those interested. It takes a few years of practice for classroom management skills and pedagogical content knowledge to become well established, before the time is ripe for the further professional development of teachers to upgrade their understanding and skills to the level required for the effective stimulation of children's general cognition.

IN-SERVICE PROFESSIONAL DEVELOPMENT

If the conclusion to the last section is true, then the development in teachers of the pedagogical skills required to teach for cognitive acceleration will depend on continuing professional development through in-service courses for teachers. There may be formidable problems associated with motivating teachers to participate in such programmes, with funding them and with accrediting them, but in this monograph I will concentrate only on the underlying theory and the practice we have developed within the CASE project.

Research into effective in-service practices

Quite a lot of research has been undertaken into factors which impinge on the effectiveness of in-service courses in changing teachers' classroom practice. Joyce and Showers (1980, 1988) noted that an in-service programme designed to introduce a new method might include the following features:

- the provision of **information** and theory about the method;
- **demonstration** of the method by the trainers;
- an opportunity for participants to **practise** the new method during the workshop;
- provision of **feedback** to participants on their practice;
- **coaching** of participants in the method in their own school setting.

They noted further that the following outcomes were possible from an in-service programme:

- Teachers' **knowledge** about the method is increased.
- Their **skill** in using the method is increased. In other words, they are better able to use the methods.
- Their **classroom practice** is changed. This is distinguished from skill development in that not only can they do it, but also they do in fact do it as a matter of course in their teaching.

Joyce and Showers undertook a meta-analysis of nearly 200 studies of the effect of Staff Development. They state their conclusions strongly, summarized in Table 3.

TABLE 3. Mean effect sizes in standard deviation units of different Staff Development procedures on possible INSET outcomes

Outcome:		Development of teachers'	
Feature of course	knowledge	skill	practice
Give information	0.63	0.35	0.00
+ demonstrate	1.65	0.26	0.00
+ opportunity to practise		0.72	0.00
+ feedback	1.31	1.18	0.39
+ coaching in school	2.71	1.25	1.68

Source: after Joyce & Showers, 1988, p. 71.

Note that these are cumulative effects. We do not, for instance, have information on the relative effect of coaching in school that does not include a theory element in the training, and so we would be wise not to assume that 'practice is all'. In fact, experience suggests just the opposite: if teachers are not given a chance to understand why they are being asked to change their practice, they are far less likely to do so. Nevertheless, the message from Joyce and Showers' work is clear. The occasional day spent in a university or professional development centre will have no effect, however well structured and organized it may be. Work by the tutors in schools is essential. Such research evidence supports the experience of in-service providers who often hear teachers say 'Well, your ideas seem well and good in this nice university setting, but they wouldn't work in my school/with my students'. Many teachers, quite reasonably, need to be convinced that the theory can be put into practice in their own schools, and the only way to do this is to work with the teachers in their classes, supporting them there in the implementation of the teaching of thinking.

CASE professional development—learning from experience and research

The in-service professional development programme we devised to introduce CASE to schools takes Joyce and Showers' findings seriously, and includes elements of theory, practice and in-school coaching. It also includes elements concerned with the management of change in schools.

As described above, CASE methods are rooted in Piagetian ideas of cognitive conflict and equilibration, and in Vygotskyan ideas of social construction and metacognitive reflection on the development of one's own thinking. Thus the methods that teachers are to implement, although described in print, are rooted in theory which it is essential to understand for effective deployment of the necessary skills. No teachers' guide, however comprehensive, can ever convey the richness of a classroom practice that is required to raise permanently students' general levels of thinking. Some understanding of the learning process is essential for any successful teacher development, but it is especially important in interventionist teaching aimed at the development of thinking. This requires that teachers are able to 'read' an individual's response or the progress of a whole lesson in terms of the levels of understanding exhibited and the challenge provided. They must also be able to provide the right type and level of stimulus in the context of the lesson and of the cognitive objectives of the programme. No specific rules can be given for this process, and the teacher must rely on his or her growing understanding of the principles of intervention on top of their normal professional competencies.

The construction for oneself of intervention methods is related to the sense of ownership that teachers build in taking on the new methods. Until one has taken ownership of a method with one's own idiosyncratic interpretation and colouring by personality and the particular school environment, it will remain an 'add-on' skill which is easily lost when the external stimulus of the in-service programme is removed. The curriculum in the classroom is created and managed by the teacher. Ownership of a method for teaching thinking enables it to be built in naturally to this classroom curriculum.

The CASE professional development (PD) programme is a two-year course intended to run in parallel with a school's initial implementation of the two-year Thinking Science programme. Over the two years, there are about eight days when teachers attend our in-service centre and a further five or six half days when we work with the teachers in the school. A typical complete programme is summarized in Table 4. The amount of time devoted, in particular, to the coaching visits by expert CASE trainers makes these rather expensive programmes. Typical fees for the two-year programme are about US$6,000 per school. In-service education in the United Kingdom is now funded by monies which are devolved to individual schools, so that each school has its own in-service budget. Schools often see investment in the CASE in-service course as worth while in terms of the general professional development of teachers as well as enhancing student achievement.

Who attends these courses? A most important principle is that we will not work with individual teachers, but only with whole school science departments. We often need to explain to headteachers that if they wish their school to become involved, it is essential that all science teachers participate in the programme. Our and many others' experience of working with individual teachers is that however enthusiastic they may be, the difficulties of maintaining a distinctly different and novel teaching method in a school surrounded by others who continue with mainstream curriculum teaching are formidable. Plans by an individual teacher to pass on the message of the PD programme to others in the school are usually unrealistic since the individual, by definition, is only ever one step ahead of her colleagues. As with all teaching, a very secure grasp of the theory and practice is required before one can become a good teacher. Through insistence on working with a whole department, it becomes far more likely that the new teaching goals and methods will be made part of the culture of that department and that school. This ensures its deep rooting in the school, and also helps to carry along members of staff who initially may be sceptical or resistant to change.

TABLE 4. A typical two-year CASE-PD programme.

Year/month	In Centre	In school	Purpose/activities
1—June.	2 days		Introduction to underlying theory. Go through first six activities. The testing programme and administration of the pre-test. Development of individual school plans.
1—Sept.		1/2 day	Meet with Head. Meet with all science teachers, outline principles, timetable, and commitment required. Provide plenty of opportunity for questions and for all to raise concerns.
1—Sept.–Dec.		1/2 day	Coach and/or team-teach with teachers starting implementation in their own classes.
1—Jan.	2 days		Feedback from schools on progress so far. More depth on theory. Next few activities. Issues concerning the management of change in the schools.
1—Jan.–June		1/2 day	Coach and/or team-teach with teachers in their own classes. Possible sessions with whole department.
1—May	3 days		Residential conference: one day for INSET participants only, two days to include many others. Sharing experiences, working on bridging, writing own 'Thinking Science' type materials.
2—Oct.	1 day		Next activities. Updating school plans, further management issues.
2—Oct.–May		2 x 1/2 days	Coach and/or team-teach with teachers in their own classes. Possible sessions with whole department.
2—June	1 day		Post-testing, data collection. Forward plans and the network for continuing support.

Since it is not practical for a school to release all of its science teachers for the Centre-based days, which are held on normal school days, a school will usually send two teachers. One may be the 'CASE co-ordinator' in the school, and the other may rotate, with a different person coming on each occasion. This provides a balance between continuity and exposure of as many of the department as possible to the PD programme. In addition to our own inputs in the schools, CASE co-ordinators are encouraged to develop implementation plans that include in-school PD sessions that the co-ordinator runs. In an attempt to alleviate the difficulty mentioned above about being just one jump ahead, we (a) use part of our school visit time to support the co-ordinator in his/her PD sessions in the schools, and (b) provide every school with a comprehensive pack of PD materials (Adey, 1993).

The 'CASE INSET pack' was developed after our first cohort of schools and trainers (1991–93) had completed their course. It was based on the sessions we had developed over those two years, and owes much to the contributions of that cohort of trainers in particular. The pack includes:

- introductory material explaining how the pack can be used and a warning about what can, and what cannot, be reasonably expected from a package of print and AV material;
- a list of registered trainers from whom assistance can be sought;
- a video tape including an introduction to the project (useful for parents and school governors as well as for teachers) and a series of short extracts from exemplary Thinking Science lessons to illustrate features such as cognitive conflict, construction and bridging;
- a course of PD sessions, each of which addresses some theoretical point as well as covering a sub-set of the Thinking Science activities. Each has tutor's notes, masters for overhead projector transparencies, references to the video, and exercises for teachers. These are arranged as ten ninety-minute sessions, but suggestions are offered for ways in which they can be presented in other formats if half-day or whole-day slots become available;
- 'garnishes'. These are rather detailed notes providing background information on particular aspects of the underlying theoretical model, such as Piaget's stages of cognitive development, Vygotsky's Zone of Proximal Development, the five pillars of CASE wisdom, national norms of cognitive development and value-added measures.

We also run a parallel programme for the training of CASE trainers. Trainers may be drawn from university departments of education, from local government advisory services, from freelance consultants or from schools themselves. Some headteachers see an advantage in having their school become a training centre for CASE. Trainers attend many of the same sessions as the teachers from schools, but they also have sessions of their own devoted to management of change in schools, to research data on effective professional development, and to the writing of action plans for the training programmes they propose to run. Our 'visits' to trainers are to observe and support them in their work with teachers. Successful graduates from the trainers' programme are certificated to run their own CASE training courses. We do not encourage trainers to train other trainers, since we believe that this would be a 'cascade too far'.

EVALUATING PROFESSIONAL DEVELOPMENT

There is a general way in which the effectiveness of the professional development programme is evaluated by the academic gains made by students in schools which participate in the programme, described above in the section entitled 'Trials and evaluation'. But making a more specific link between the professional development course, the development of teachers' practice and cognitive gains made by students is a more difficult form of evaluation to establish. We have made a start on such evaluation, postulating a number of factors such as senior management support, teachers' sense of ownership, their understanding of the theory, and levels of communication within a school as variables mediating between the input of the professional development course and the outcomes in terms of teacher and student change. Data are collected by interview, questionnaires and observation, and preliminary results suggest important correlations: (a) between the extent to which teachers actually use CASE methods and the effects on their children; (b) between the amount of relevant discussion within the school about the methods and the general school effect; and (c) between senior management's motivation for taking on CASE and the long-term effect. The continued evaluation of the professional development programme remains an ongoing area for research.

Policy and publicity issues

WITHIN THE UK

There is no doubt that CASE has been a remarkable academic success in terms of its proven effect on student academic achievement. In a political context in which 'raising educational standards' has a high priority, it might be thought that an innovation such as CASE would receive substantial public and financial support from government. In the United Kingdom, this would be to misunderstand the relationship of guidance and policy established by the Ministry of Education on the one hand to curriculum implementation at local government and school level on the other. Since the early 1990s, a large proportion of the funding available for staff development, the purchase of textbooks and other materials, and even the employment of teachers, has been devolved to the school level. Headteachers, overseen by a school's Board of Governors (who are voluntary appointments), have responsibility for the school's budget and so control over decisions concerning the introduction of curriculum and staff training innovations.

A school's funding depends on the number of pupils it attracts, and parents have considerable freedom of choice about which school they send their children to. The choice will be influenced by location, a school's reputation (an elusive factor, established largely by local word of mouth), the child's friendships and, very importantly, the school's demonstrable academic standards. Achievement in public examinations of all schools is published annually as 'league tables' showing the relative success of schools in achieving high percentages of high grades, and ensuring that all students achieve to the best of their ability. More recently, some effort has been made to make allowances for the different socio-economic areas in which schools are located in assessing the 'value-added' effect of a school on its students' academic achievement. With or without allowance for intake, it will be seen that academic achievement reflected in examination grade success is an important factor in parents' choice, and thus with regard to the number of pupils wishing to enter a school, and also therefore with regard to the school's funding.

The operation of this market economy in education, introduced by a Conservative Government and supported by the current Labour Government, has a profound influence on the mechanism by which innovations may be introduced into schools. Whereas in a centralized system either the national Ministry of Education or local government education authorities may decide to implement an innovation and then provide the necessary funding for it, in a market economy such decisions are made at school level.

The relevance of this to the implementation of CASE in schools in the United Kingdom is obvious. It becomes a school-level decision whether or not to buy into the programme. Headteachers and heads of science departments need to be convinced that the investment of time and money in the programme will be worth while. The current fee for the professional development programme is about US$6,000 per school, to which must be added the cost of employing substitute teachers while staff attend the Centre-based PD days. The time commitment can be seen as a greater problem, since the CASE programme requires one sixty- or seventy-minute lesson every two weeks which has to be taken from the regular science curriculum.

This does not mean that the local education authorities and the national Department for Education and Employment have shown no interest at all in the potential of CASE. Many local authorities, including the large City of Birmingham authority, have launched authority-wide programmes to encourage their schools to participate in CASE training. By providing information, some extra funding and negotiating special programmes of training in local professional development centres, they have been able to make CASE available to many schools which might otherwise have found it too expensive. At the national level, the Government has made it clear that CASE contributes to its policy imperative of raising educational standards. In a recent White Paper (Department for Education and Employment, 1997) the contribution of cognitive acceleration to the academic achievement of students is specifically acknowledged.

We have had discussions with the Director of the Qualifications and Curriculum Authority about the possible inclusion of aspects of cognitive acceleration in the National Curriculum. My own view is that the process of intervention for the development of higher-order thinking would not necessarily be well served by being specified as a learning objective within the written National Curriculum. The danger is that it may be reduced to a formula and that the National Curriculum is not the place where radical shifts in pedagogy can be adequately characterized. Rather, we have proposed that in any future revision of the National Curriculum, some statement should be included in a preamble to the effect that the content specified within the National Curriculum should not be viewed as exclusive of other material, but that time has been allowed for materials and teaching beyond that specified in the National Curriculum, so as to allow schools to develop or adopt their own individual innovations. Trying to specify cognitive acceleration in the curriculum could stultify it, whereas allowing space without specifying cognitive acceleration gives freedom to schools to adopt it when they are ready for it and when they have made their own positive choice to adopt it.

We have taken a low-key approach to publicity for CASE. Results are reported regularly at conferences for academics and for teachers, and we maintain a steady programme of submitting papers and chapters to academic journals, books and monographs such as this one. On two occasions when we have had particularly striking results to report, we have issued press releases and have received a gratifying amount of publicity in the national press and broadcast media. But such publicity is short-lived, and often attracts inquiries from people who think that there may be a quick solution to the problem of raising levels of thinking and of academic standards. We need to explain that cognitive acceleration is a subtle process that requires considerable investment of time and effort by teachers and by students over at least two years.

In spite of the time, cost and hard work involved, the demand from schools for CASE training has been increasing steadily since our first course in 1991, and we now estimate that at least 10% of secondary schools in the United Kingdom have engaged in systematic training to introduce CASE. A much higher proportion have purchased the materials and will be using the activities more or less as intended, with little or no professional development support.

CASE OUTSIDE THE UNITED KINGDOM

It has been difficult to track the use of CASE outside the United Kingdom, and I can only quote here a few examples that have been brought to my attention. In most instances, CASE has been introduced as an experiment on a trial basis, and it is too early to be able to report any results.

In the United States, one school district in Arizona adopted CASE as the freshman-year science course for its nine high schools. Since one hour per week was available for the course, they wrote many more lessons in the style of Thinking Science to make a complete curriculum.

In Malawi, CASE has been introduced in a few secondary schools on an experimental basis. Adaptations have been necessary to make the activities suitable for classes of 50 or 60 students and then to adjust to the relative difficulty of obtaining laboratory equipment. Two academics from the Curriculum Centre of the Ministry of Education in Malaysia have spent a month with us at King’s College learning about CASE and the professional development programme with a view to testing it in Malaysia.

In Europe, one group of schools around Utrecht is implementing CASE with the assistance of one trainer from the United Kingdom and one from the British school in Brussels. A Dutch version of the materials is being prepared. A small group of schools in Bremen have just started to use the German version of Thinking Science, with assistance from the University of Bremen. A doctoral student from the University of Potsdam has compared CASE and non-CASE schools in London with schools in Potsdam (Burrmann & Adey, forthcoming).

There may be much wider use of CASE outside the United Kingdom than these few examples indicate.

Conclusion

Cognitive Acceleration through Science Education is a long-term approach to increasing general intellectual capability in the population of young adolescents. It is long-term in its implementation since it requires two years of curriculum intervention, and it is even longer-term in its evaluation, since the effects are tracked up to three years after the end of the intervention. It is therefore inevitable that the adoption of CASE in the pedagogy of schools is a slow process. Nevertheless, there is already a significant take-up, and indications that its use will continue to grow for many years to come. We may attribute the success of CASE to two general features: the interplay of theory and practice in its design and implementation, and the view of 'curriculum' as encompassing both printed material and teacher professional development. I will say a little more about each of these features.

THEORY AND PRACTICE

In section 2 of this monograph, 'The underlying psychology', I described the theoretical basis of CASE, rooted in Piagetian notions of cognitive development arising from equilibration in the face of conflict, and in Vygotskyan ideas of language as mediating learning, and of the role of social construction in the development of knowledge and intelligence. This is the science *of* thinking. The theoretical model we developed acted as a touchstone through the phase of material development, and as a reference for the design of activities. It continues to play a central role in the process of professional development as teachers are being introduced to the theory as an explanation for the type of pedagogy they are being encouraged to adopt. We do not ask teachers to do something on simple empirical grounds, 'because it works', but because that is what theory predicts will work, and because with a better understanding of why they are doing it, teachers are able to make the pedagogy their own and adapt it to their own teaching style.

I recognize that our theory base is not, and possibly never can be, considered as 'proven'. For example, Leo and Galloway (1995) have suggested that the effects on academic achievement shown by CASE may be due as much to motivational factors as to the cognitive processes encompassed in our theory base. The point is that the theoretical foundation is testable, and is open to modification in the light of new experience and new results. The practice of CASE teachers and the theory underlying this practice are inextricably interwoven, and between them have the potential to continue to develop the practice and to continue to inform the theory.

THE 'CURRICULUM'

Nearly twenty-five years ago Lawrence Stenhouse (1975) raised our understanding of the notion of 'curriculum' from a set of printed guides for teachers and students to all of the transactions which take place in the classroom. From this perspective one cannot describe a curriculum simply in terms of texts and objectives, as it encompasses also the process of teaching and the methods employed by the teacher. Curriculum developers may have a picture of what they want to happen in the classroom, but this can never be translated simply into written materials which might then be reliably 'unpacked' by teachers in many different situations.

In CASE we do not suppose that many teachers can simply read the published materials and make the radical shift in their pedagogy that is required. For this reason we consider that effective implementation of CASE requires a programme of professional development of teachers as well as the adoption of the particular activities described in Thinking Science.

Certainly some teachers will be able to make real progress towards CASE-type teaching without a professional development programme, and we recognize the difficulty and expense involved for schools outside Northern Europe to gain access to CASE professional development. For this reason we would never tie the sale of Thinking Science to a requirement to engage in professional development. The integration of professional development and curriculum materials remains, however, an ideal and one of the reasons for the success of CASE where it has been properly implemented.

FUTURE DIRECTIONS FOR COGNITIVE ACCELERATION

The immediate future for CASE appears to be one of expansion, with more trainers and more schools in the United Kingdom, and more innovative methods of making it available to a wider world. But there are more general ways in which CASE principles might be applied. CASE is an innovation targeted at 11–14-year-olds and is set in a science context. We have used science *for* thinking. But the underlying theory is not limited to science, and not limited to adolescents. Thus two areas for wider expansion are other subject areas and other age groups.

Other contexts

Piaget and Inhelder described one particular set of schemas underlying formal operational thinking, but the general features of formal operations—the ability to think with abstractions, and multi-variable thinking—can find expression in different types of schema. This is a job for subject specialists very familiar with the nature of knowledge making in their subject. It has already been done for mathematics and there is a CAME project parallel to, but much younger than, CASE (Adhami, Johnson & Shayer, 1998). Beyond that, a small group of English and history teachers have started to explore what would count as formal operations in their subjects. Schemas are likely to include appreciation of multiple points of view, being able simultaneously to feel with a character in literature or history and also to see how an author or circumstances shape that character. There is a great deal of analytical and testing work to be done in this field before it could form the basis of a cognitive acceleration programme, but the signposts are in place.

It might be asked whether any subject matter is necessary. Can we not address high-level thinking skills directly, context-free? I think the answer is no, because we have to think about something, we need matter to think about. For young people in particular, the principles of thinking need plenty of concrete referents, a context in real life to which the principles can be applied. We have shown in CASE that by entering the realm of high-level thinking through a science 'gateway' general thinking is improved, and this shows up as enhanced performance in mathematics and in English. What is yet to be shown is whether entering through an alternative gateway—through CAME, or a yet-to-be-developed Cognitive Acceleration in English for instance—would have the same effect in reverse, enhancing performance in science.

Other ages

All of our work in CASE has been addressed to the promotion of formal operational thinking. But the principles of cognitive conflict, construction of schemas, and possibly metacognition have equal applicability to the development of concrete operations. While 11–14 years is the entry age for formal operations, the entry age for mature concrete operations is 5 and 6 years. We have just started a new project, well funded by one of the London boroughs, which will work with teachers and children in the first two years of schooling in the United Kingdom, when the children are 5 to 7 years old. The schemas we will be addressing are those of concrete operations, seriation, cross-classification, combination of two variables and conservation of displaced volume. Naturally, the context of a Year 1 classroom and of the background of the teachers will require an approach very different from that employed in CASE, but potentially the rewards of starting the cognitive acceleration process in the first years of schooling for all of the children's subsequent schooling are enormous. This is the most exciting immediate prospect for cognitive acceleration.

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