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RESEARCH REPORT

Cognitive acceleration through science education II: its effects and scope

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Jones and Gott (1998) argued for 'the conceptual dismembering' of the CASE programme into a vehicle for the promotion of process skills – regarded as procedural content. This paper joins the debate by offering a different description of the CASE teaching art, and also extends the presentation of the evidence.

Introduction

Jones and Gott (1998) raise issues of the use of research and on professional teaching expertise which are timely and important. They examine in some detail whether and how the methods of the cognitive acceleration through science education (CASE) project contribute to our knowledge of the teaching art. But I have to disagree with their proposing, as a dichotomy, these conditions:

If the programme is to be judged *educationally* useful, two conditions apply:

- it works, which requires empirical evidence which is *educationally* as well as statistically significant; and
- the programme can be justified on philosophical grounds, which requires that its 'content' be described in appropriate detail and its inclusion in a curriculum defended by reasoned argument.

I agree with both their conditions and argue that they both need to be present. If it doesn't work, then consideration of its philosophy is effort wasted; but if it does work, then unless its philosophy can be adequately described, the development of new teaching skills could only with difficulty take place. 'I can't tell you: watch me and do likewise' was never a good model for professional development. Jones and Gott are completely free of this and I am delighted to find the opportunity to join in their argument and contribute to the discussion of what further research is called for.

The empirical evidence

First, it is necessary to amplify Jones and Gott's presentation of the empirical evidence. For the record the King's team themselves thought that the data reported in Adey and Shayer (1990) and Shayer and Adey (1992) – gathered in 1987 and 1988 respectively – indicated that further research was still needed.

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CASE III (1989/91) was an ESRC supported applied research project during which I worked closely with the teachers in three local schools with the aim of obtaining a better description of the CASE teaching art than was possible to publish in *Thinking Science* (Adey, Shayer and Yates 1989). It was only when the long-term GCSE results were obtained in 1990 (reported in Shayer and Adey 1993) that the King's team called a press conference, in the belief that they were now justified in going beyond the research phase. In Autumn 1991 they offered a two year Professional Development programme (PD) for schools prepared to use the CASE intervention with whole year groups, which has been repeated each year since. They also ran a PD programme for trainers, which included Marion Jones. I need first to report large-scale results from this cohort of schools: discussion of the professional development programme will be deferred until the philosophy is discussed.

Large-scale use of CASE in schools (1991–1994)

Pre-post-test results on Piagetian tests

In all schools Piagetian Reasoning Tasks (PRTs) (NFER 1979) were used early in Year 7 (1991) as a baseline and in summer in Year 8 (1993) to assess the effects, for each class, of using the CASE intervention. These were the same tests used in the CSMS survey of 14,000 pupils between the ages of 10 and 16 (Shayer *et al*. 1976, Shayer and Wylam 1978) – PRT II, volume and heaviness as pre-test and PRT III, pendulum as post-test. This sample contained 8 schools, 1452 pupils, 568 of which received the CASE approach in year 7/8 and 884 in years 8/9. The total number of school classes involved were 63. Here was the opportunity to test some of the suggestions originally put forward tentatively on, admittedly, small-scale reseach evidence in Shayer and Adey (1993).

Here I have to reply to one of the points made by Jones and Gott. *No* apology is needed for using Piagetian tests to assess the effect on children of an intervention which was partially inspired by Piagetian psychology. This was one essential step (but not the only one) in obtaining a value-added estimate of the CASE intervention. I do not agree that 'such tests are bound to show improvement for a class taught such ideas'. They can also (and do) show no improvement. It makes no sense to avoid using a measuring instrument because it is based on the same theory as an intervention. Such an instrument would be most scientists' first choice to see if their use of a theory has or has not been valid.

First, under conditions where the whole school science department was involved in the theory and practice of CASE – as distinguished from CASE II where each CASE teacher was on his/her own in the school – what effect on the magnitude of the changes would one find? Second, was there an age/gender interaction, as suggested in Shayer and Adey (1993)? Third, was there any evidence that the CASE intervention favours more able pupils? Last, was there any bimodality in the data?

Effects of CASE in large-scale use

In table 1 three aspects of the analysis are shown. First, since the aim of CASE was to increase the proportion of formal thinkers, those assessed at the early formal

Table 1. General effects of CASE inservice training on teachers within schools, as tested over two years with pre- and post-tests (Piagetian reasoning tasks) on their pupils.

School	Year	*% Early formal or above* *July 1993*	*(previous year)*	*($3A^+$)* *CSMS average*	*Effect-size (standard deviations)*	*Percentile points of school year mean on the CSMS survey* *1991*	*1993*	*Change (%le points)*
1	7/8	42.2	7.6	(17.9)	0.67σ	48%le	75%le	27
1	8/9	45.4	—	(21.9)	0.76σ	45%le	76%le	31
2	7/8	36.7	—	(17.9)	0.69σ	43%le	72%le	29
3	7/8	65	25	(17.9)	1.12σ	55%le	86%le	31
4	7/8	16	—	(17.9)	1.12σ	14%le	55%le	41
5	8/9	31	—	(21.9)	0.80σ	28%le	59%le	31
6	7/8	58	—	(17.9)	1.0σ	44%le	82%le	38
7 (all)	8/9	17	—	(21.9)	0.29σ	39%le	47%le	8
7 (4 classes)	8/9	22	—	(21.9)	0.75σ	20%le	53%le	33
8	8/9	50.3	10.0	(21.9)	1.260σ[1]	26%le	72%le	46

[1] Effect-size obtained by comparison with a previous Year 9 year group

level, or above, are compared with the national average as shown by the CSMS survey for the age of the pupils at post-test. In three cases data was also available from a previous year-group who had not received the CASE intervention. School 3 was one of the schools I worked with closely during CASE III. It can be seen that the proportion of those at 3A and above was more than doubled, compared with the previous year. Second, the effect-size of the intervention is shown. This is the mean gain of the year-group between pre- and post-test, compared with the gain predicted over the period of the intervention predicted from the CSMS survey, given the mean level on pre-test, expressed in standard deviation units $((M_e - M_c)/\sigma_c)$. These effect-sizes are all large, except for those in school 7 where, for various reasons, only four classes received effective CASE teaching. School 8 did not get a pre-test on entry in year 8, so here the year 9 data from the previous year group were used for making the comparisons. Lastly, the pre-test data for each school were converted to the norms of the CSMS survey, and compared with the CSMS norms at post-test. Mean gains of the order of 30 percentile points were found. These are substantially higher than the mean gains of 23 percentile points cited by Jones and Gott from the original CASE II research articles.

An age-gender interaction?

In figures 1 and 2 the evidence for age-gender interactions is tested. Are girls advantaged by an intervention starting at 11+ years of age? In figure 1 for three of the five schools the effect-size is substantially larger for girls than for boys in the same school with a year 7 start. The mean effect-size is 1.03σ for girls, compared with 0.77σ for boys. In figure 2 the mean effect-size is 0.87σ for girls and 0.93σ for boys. This does support the age-gender interaction suggested in Shayer and Adey

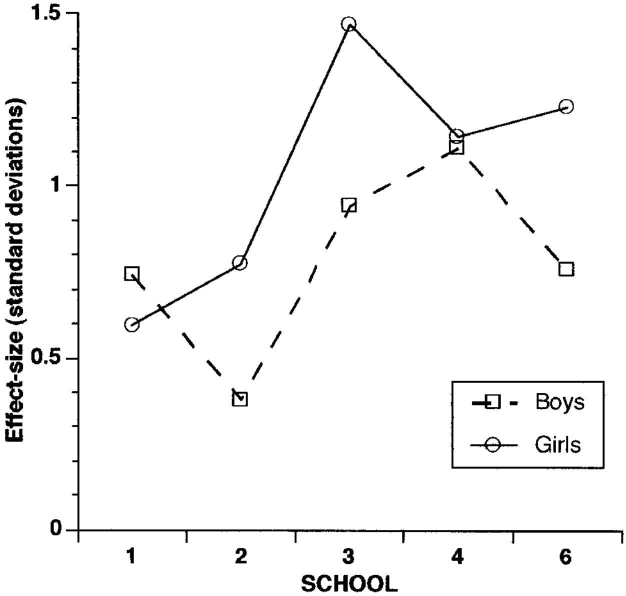

Figure 1. Boy/Girl comparisons for year 8 pupils starting CASE at 11+ in year 7.

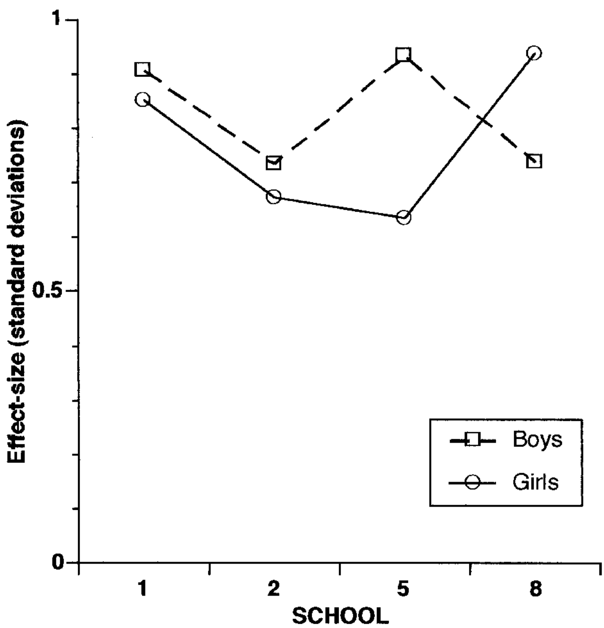

Figure 2. Boy/Girl comparisons for year 9 pupils starting CASE at 12+ in year 8.

(1993): girls do seem to be favoured by an earlier start. The question then arises, what implications does this have for policy? The mean for whole schools is 0.9σ whether the start be in year 7 or year 8. In school 8 for a year 8 start the interaction goes the other way, and in schools 1 and 4 for a year 7 start the trend is not in

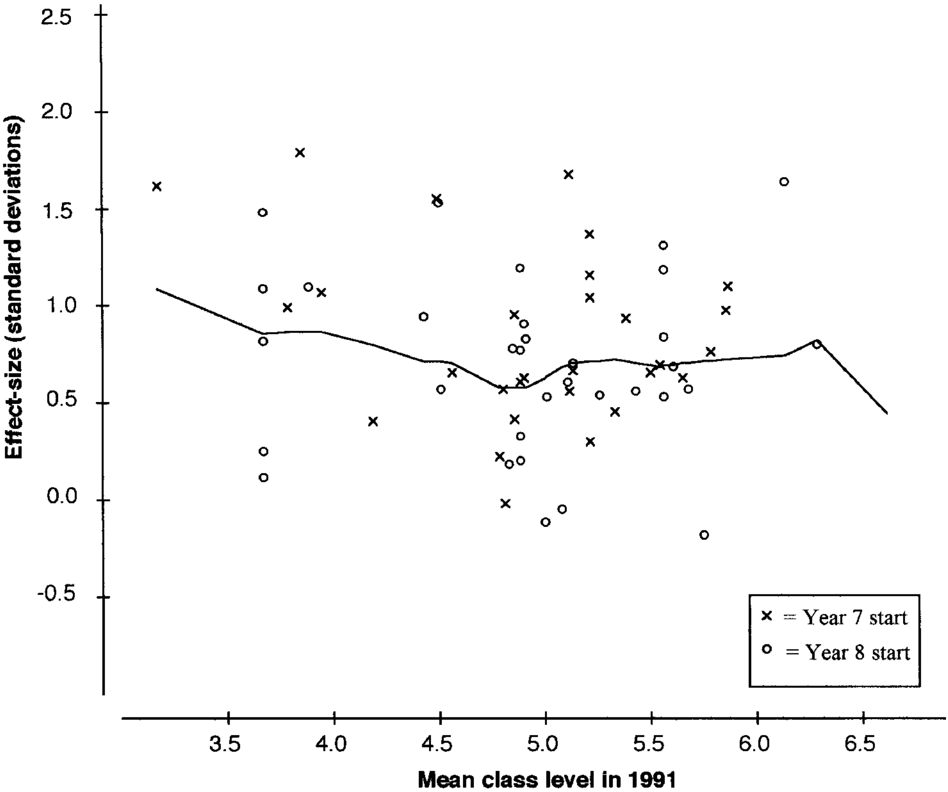

Figure 3. Comparison of class effect-sizes in relation to mean Piagetian level of class in 1991.

favour of girls: clearly issues to do with school ethos also come into play. Bearing in mind that a year 7 start gives pupils – if CASE really does affect their learning ability – an extra year in which to make a better use of their regular instruction in school before they take GCSE, the evidence seems to favour the earlier start, with possibly some of the use of the later *Thinking Science* lessons postponed until year 9. In school 1, where a direct comparison can be made, the teachers may have benefited from their experience of teaching the TS lessons to year 7 classes before the year 8 classes.

An interaction between use of CASE and pupil ability?

Does the CASE style favour more able pupils, as the teachers cited by Jones and Gott seemed to believe? I have to admit that between 1991 and 1993 when I was making many on-service training visits to schools and watched teachers struggling with less able classes, I did wonder whether this was the case, and so decided to test the hypothesis on these large-scale data.

In figure 3 the mean class level on PRT II, administered as a pre-test, is related to the mean effect-size for each of the 63 classes in the data-set. The mean class level is reported on an equal-interval scale in which 3 = early concrete; 4 = middle concrete; 5 = mature concrete and 6 = concrete generalization, in Piagetian terms. A smoothing function (Vellemann 1997, chapter 33) through the data-points shows no trend upwards as the mean pre-test level of the classes increase. It does not appear that in the first two years of its large-scale use, CASE favoured the more able classes and pupils.

But the problem does exist. The published materials (Adey *et al.* 1989) were originally generated with the pupils between the 30th and the 70th percentile specifically in mind, with the Piagetian levels of the activities designed for this ability range, i.e. assuming pupils were at least at or near the mature concrete level. The median CSMS survey level for year 7 entry is 5.39 on the scale in figure 3 and the 30th percentile is at 4.77, so it can be seen that there are quite a few classes lying below the original design. Teachers and schools who have persevered with this problem have found they need to simplify the language of the worksheets and also spend more time covering less of the agenda for each TS activity, so that all the pupils are stretched rather than discouraged.

Do pupils either show very large gains, or none?

No evidence of bimodality was found in these large-scale data – that is, it was not the case that a minority made gains of the order of two standard deviations, contrasted with others showing only ordinary statistical variation in their gains over a two-year period. So this aspect of Shayer and Adey (1993) has to be attributed to small-sample variation, or possibly to teacher-pupil interaction.

Effect of CASE on school achievement: key stage 3 test and GCSE results

In Britain there are national tests of achievement taken by all pupils at 14 years of age, at the end of their third year in secondary school (key stage 3 runs from 10 to 14 years of age) and each pupil is assessed on which level – between 3 and 8 – of the National Curriculum (NC) they appear to function at. These results are a convenient test of the longer-term of the effect of CASE on school achievement.

The Sunderland data

Marion Jones undertook the training of the teachers in five schools in the Sunderland LEA, who began with CASE in 1992. In the data-analysis of the Sunderland data in the Jones and Gott paper there was no adjustment made for the difference in initial ability-levels of the CASE and non-CASE groups featured in their tables 1 and 2. In the treatment of the same CASE data in comparison with a much larger sample of control schools, the way in which this adjustment can be made will be shown. Seventeen control schools' data were obtained from schools whose younger year-cohorts were receiving CASE, but where the year 9 who furnished the key stage 3 data were non-CASE. From year 7 pre-test data using PRT II, volume and heaviness (NFER 1979) the mean percentile level of the school intake was computed in relation to the norms of the CSMS survey. In figure 4 the percentage of pupils assessed at NC level 6 or above in key stage 3 science was plotted against the mean intake percentile of the school.

It can be seen that the KS3 data of all the Sunderland schools lie well above the variation of the control schools around the regression line and in table 2 the

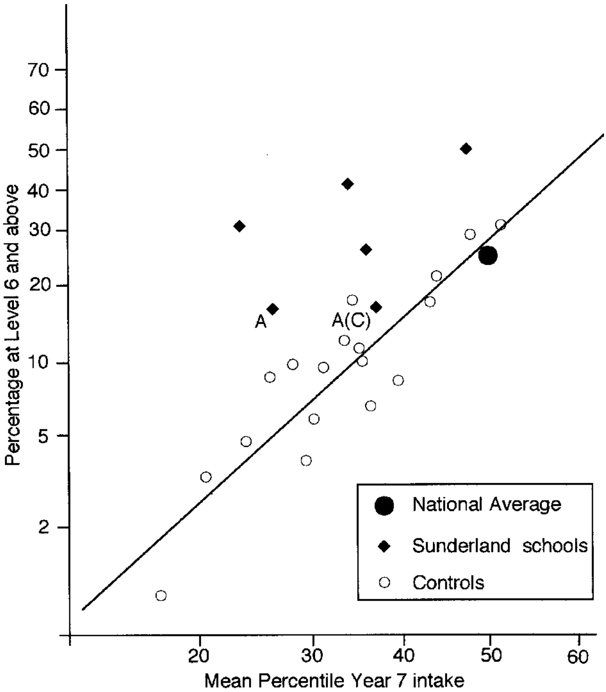

Figure 4. Key stage 3 science 1995 for Sunderland schools.

obtained level 6 and above results are compared with those predicted from the regression, given the pre-test level of the school's year 7 mean percentile on PRT II. The very high t-value for school E is due to the fact that as a scale percentages are not linear, so a 27.5% change starting from 3.6% is much larger than one, as for school B, where the 26.1% change starts at the 23.9th %le and ends at the 50th %le where the scale is nearly linear.

All the differences are statistically significant beyond the 0.01 level, with the exception of the non-CASE sample from school A. This value – A(C) – was inserted in figure 4 to show the importance of allowing for the initial levels of groups which are being compared. Whereas in Jones and Gott's table 2 both groups are shown as having almost identical performance, it can be seen that the

Table 2. Key stage 3 science test 1995 in Sunderland schools.

School	*Predicted % 6+*	*Obtained % 6+*	*t-value of residual*
A	4.9	16.2	3.2
B	23.9	50.0	2.8
C	11.0	26.3	2.6
D	9.4	40.9	4.6
E	3.6	31.1	6.0
A (non-CASE)	11.9	16.3	0.9

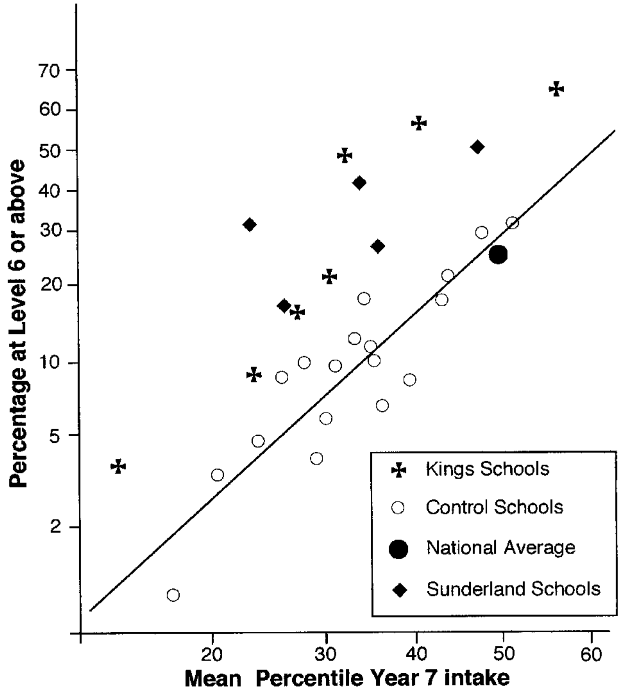

Figure 5. Key stage 3 science 1995.

CASE class's key stage results for school A are rather good. This is the same issue as the desirability of using value-added measures for comparing schools.

I would claim, in disagreeing with Jones and Gott, that the verdict on the question 'does it work?' is 'yes, and substantially', rather than 'not proven' as they answered. That is, even in terms of their own data. But there is more.

Further key stage 3 evidence

The Sunderland data just discussed is a sub-sample of a larger survey of key stage 3 and GCSE results, featuring about 4500 pupils. One research question addressed was, Did the CASE intervention have the effect, as originally intended, of raising the general thinking ability of the pupils, or did it merely teach science process skills? For this purpose data was collected for mathematics and English, as well as science. Figure 5 is a fuller version of figure 4, featuring as well the key stage 3 results of CASE schools who had received the King's PD programme and one other London school which had received PD from another trainer. Here, apart from testing the effect of CASE generally, the question was being asked, is the training transferable outside King's?

The mean of the residuals for the Sunderland schools is approximately the same as that of the schools given PD from King's. This is an important result, as it shows that the PD *was* transferable, with Marion Jones doing as well for her Sunderland schools as King's College with theirs. In figures 6 and 7 the other research question is tested. It could perhaps be argued that the enhanced results for mathematics might have been expected, as many of the *Thinking Science* lessons

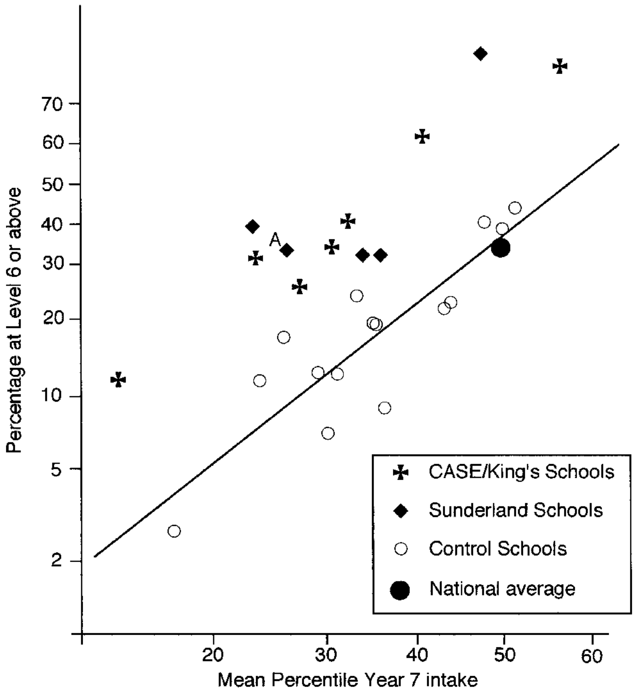

Figure 6. Key stage 3 mathematics 1995.

feature mathematical modelling. But that argument could not apply to the enhanced English results: it just isn't plausible to believe that science process skills could transfer to English. This is part of the evidence that use of CASE does have a general effect on the learning ability of pupils. In table 3 these results are summarized and it can be seen that the Piagetian post-test gains shown in table 1 do predict subsequent school achievement – not just in science (there is the same numbering of schools in tables 1 and 3). It can also be seen in figures 6 and 7 that the Sunderland schools' results were just as impressive in mathematics and English, so that evidence has to be interpreted as meaning that the use of CASE there did more than just teach science process skills.

Long-term effects on GCSE

In Britain the General Certificate of Secondary Education (GCSE) is taken by all pupils approximately at age 16, at the end of their fifth year in secondary school. It is therefore the best value-added test for the long-term effect of an intervention given in the first two years of secondary school. In figures 8, 9 and 10, the 1997 GCSE results for the schools beginning CASE in 1992 in year 7 are treated in relation to control schools in a similar way to the analysis for key stage 3 1995 (they are the same pupils). Here the percentage obtaining C-grade and above has been used as the statistic – in order to allow for different school's policies for entering pupils for GCSE, all statistics have been related to total year 11 rolls.

Table 4 shows the data on which figures 8, 9 and 10 are based. It can be seen that the long-term gains for the CASE schools – of the order of 30 percentile points

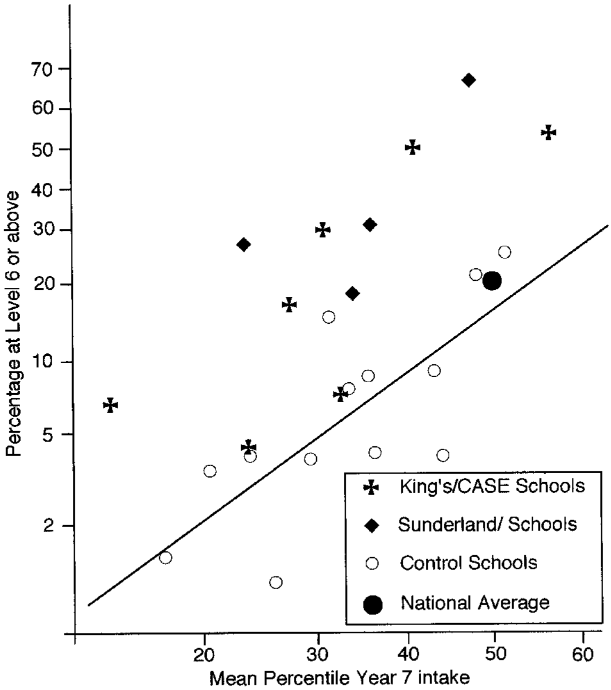

Figure 7. Key stage 3 English 1995.

– are of the same order as those shown in table 1 for the gains as tested in year 8 (or 9) by the use of Piagetian tests. This confirms that the Piagetian test results do predict a permanent gain in pupils' subsequent school achievement.

Discussion

In view of this evidence from the large-scale use of CASE the initial premise of Jones and Gott – that the efficacy of CASE is non-proven – has to be rejected and this alters the grounds on which discussion of the important issues they raise can take place.

The first thing to be said is, despite the valuable details given by Jones and Gott on problems of management of change in their schools A to E – detail which will be familiar to anyone who has been involved in delivering PD within schools – it is remarkable that despite the difficulties described, which are roughly correlated with the gains shown in tables 2 and 3, there were still substantial effects on pupils' achievement showing at key stage 3 and not only in science. This suggests to me that could the underlying professional skills be better made available to teachers so that they were adopted by all, much more striking changes in pupils' learning ability might occur than have been recorded so far. A glance at figure 3 shows that there were a sufficient number of classes showing effect-sizes of 1.5 to 2 standard deviations to make one wonder whether these estimate what the approach can do in the hands of those who adopt all the features of the art (perhaps Shayer and Adey's (1993) bimodal distribution was one of teachers, not pupils). This suggests careful thought about just what it was and is about the CASE art that

Table 3. Key stage 3 tests results 1995.

School	*Mean %le 1992 intake*	*% 6+ predicted*	*% 6+ obtained*	*t-value of residual*	*p*
Science					
1	33	8.4	47.9	5.9	<0.001
2	31	7.3	20.7	3.1	<0.005
3	41	15.5	56.3	5	<0.001
4	14	1.1	3.6	3.2	<0.005
9	28	5.5	15.4	2.9	<0.005
10	24	3.7	8.7	2.3	<0.025
11	57	39.6	64.3	2.6	<0.01
National average			25		
Mathematics					
1	33	13	39.7	3.2	<0.005
2	31	11.5	33.1	2.9	<0.01
3	41	22.2	63	3.9	<0.005
4	14	2	10.2	3.8	<0.005
9	28	8.7	24	2.6	<0.025
10	24	6.3	30.4	4.1	<0.001
11	57	48.4	78.6	3	<0.005
A	27	8	32.4	3.7	<0.005
B	48	32	80.9	4.8	<0.001
C	36	16.4	31.2	1.8	<0.05
D	34	14.3	31.2	2.2	<0.025
E	24	6.1	38.5	4.9	<0.001
National average			33		
English					
1	33	7.2	7.3	0.41	n.s.
2	31	6.4	30.1	3.1	<0.005
3	41	11.9	50	3.4	<0.005
4	14	1.4	6.6	2.8	<0.01
9	28	5.1	16.5	2.3	<0.025
10	24	3.4	4.3	0.6	n.s.
11	57	27.2	53.6	2.1	<0.05
A	27	(information not available when data was gathered)			
B	48	17.1	66.6	3.8	<0.005
C	36	8.9	31.2	2.7	<0.025
D	34	7.9	18.2	1.8	<0.05
E	24	3.6	27	3.8	<0.005
National average			20		

is worth propagating, and what might be the best methods of propagating it. Is it just science process skills, as Jones and Gott argue?

The aims of CASE

In a brief survey of research on the effects of different kinds of thinking skill interventions Shayer (1993) distinguished between *context-independent* programmes such as Feuersteins IE or DeBono's CoRT materials which were deliv-

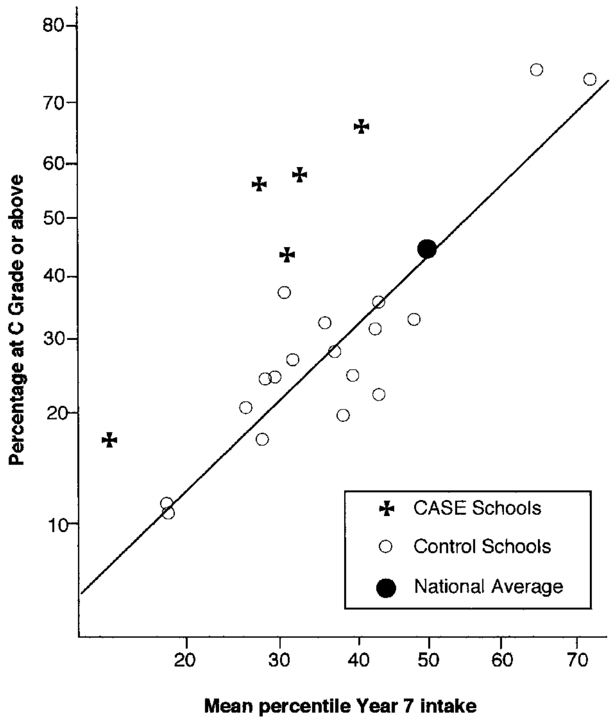

Figure 8. GCSE science 1997.

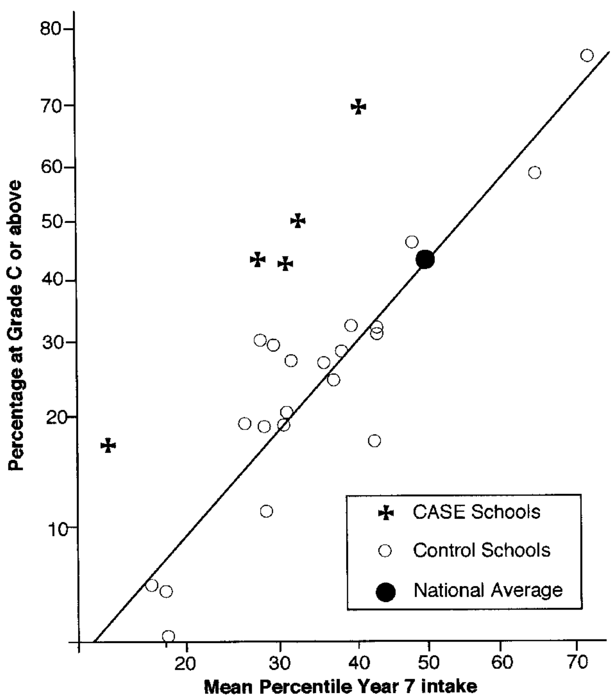

Figure 9. GCSE mathematics 1997.

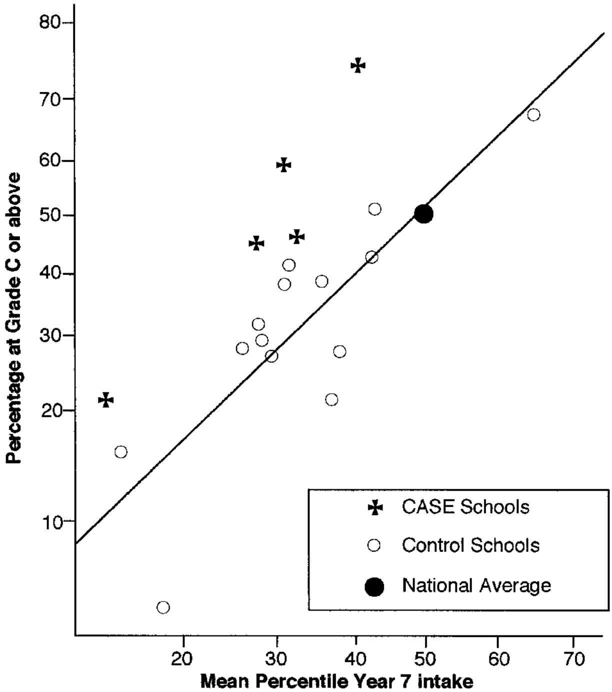

Figure 10. GCSE English 1997.

ered in separate lessons as far removed from ordinary school activity as possible and programmes with the same aim of enhancing pupils' thinking ability in general which were *context-delivered* – that is, placed within the context of a major school subject. He showed that, although research on both kinds showed gains on psychological tests, only the context-delivered programmes were accompanied by permanent effects on school achievement (see also Adey and Shayer 1994, chapters 3 to 5). CASE has the long-term aim of promoting the development of formal operational thinking in those 70% of the population which the CSMS survey showed were lacking in this ability even by the age of 16. The success of CASE in promoting this aim does improve dramatically pupils' ability to process science learning, but it is a conceptual error to wish to consider it under the heading of procedural knowledge, as Jones and Gott argue.

The Vygotskian and Piagetian aspects of CASE

Jones and Gott mention only the Piagetian theory-base of CASE in their presentation. But of equal importance is the Vygotskian aspect, with an emphasis on social construction of reasoning through metacognitive reflection and a carefully managed use of the language of thinking.

Piaget's was indeed the only theory-base mentioned explicitly in *Thinking Science*. Yet in the often hectic days of CASE II (1984–87), where the three workers were faced often with the demand to generate and test in schools and write up a new TS activity every fortnight, much of the team communication both with each other and with the nine teachers who were teaching CASE for the first time was

Table 4. GCSE results 1997.

School	*%C+ predicted*	*%C+ obtained*	*t-value of residual*†
Science			
1	23	57.3	4.0
2	21.4	43.2	2.7
3	31.1	65.5	3.8
4	7.6	16.8	2.4
9	18.5	55.5	4.5
National average		44*	
Mathematics			
1	20.7	50	3.7
2	19.1	42.3	3.1
3	29.6	69.2	4.6
4	5.7	16.7	3.3
9	16.1	43	3.7
National average		43*	
English			
1	29.6	45.8	1.5 (n.s.)
2	27.7	58.6	2.8
3	38.9	74.2	3.3
4	10.5	20.9	1.8
9	24.2	44.8	2.0
National average		50*	

† t for $p < 0.05$: 1.8; for $p < 0.01$: 2.7
* For each subject the average of these gains is equivalent to increasing the National average from the present value to 74%

tacit rather than explicit. At a frontier of knowledge one 'drives by the seat of ones pants' and it is only later, maybe much later, that one finds out all one needs to know of how one did it. The Vygotskian aspect was certainly there in the first sample of eight TS lessons generated during CASE I (1980–83) and it was taken from the practice of Feuerstein's *Instrumental Enrichment* (Feuerstein *et al.* 1980, Shayer and Beasley 1987). But it was there implicitly as a class-management strategy and it was only during CASE III (1989–91), and then in the writing of *Really Raising Standards* (Adey and Shayer 1994) – *RRS* – between late 1991 and 1993 that the source was acknowledged explicitly and later added to the King's PD practice. In *RRS* (chapter 6) it was suggested that the Vygotskian aspect was maybe the engine of CASE practice and the Piagetian the gearing, to do with getting just the right match between the cognitive demand of the lesson and the cognitive level of the learners so that they were driven on without being discouraged by concepts that they were way too hard. In combination these theory bases provide the 'five pillars of CASE': *concrete preparation, cognitive conflict, construction, metacognition*, and *bridging* as shown in figure 11.

Figure 11 shows an almost equal debt to Vygotsky and Piaget. From Piaget was drawn the selection of different science contexts in which at least eight of his original formal operational reasoning patterns (schemata) occur. From the failure

	Piaget	Vygotsky/ Feuerstein
Schemata of Formal Operations	√	
Concrete Preparation	√	√
Cognitive Conflict	√	
Metacognition		√
Bridging		√
Construction	√	√

Figure 11. Theory-base of CASE project.

to generalize of earlier attempts to train just on one reasoning pattern, it was assumed there should be some synergistic effect if the intervention features many of them. From the Feuersteinian research it appeared that unless an intervention covered two whole years or more of a student's life it was unlikely to have a permanent effect on their development (Shayer and Beasley 1987). From Piaget also the idea of provoking and then assisting in the resolution of cognitive conflict was taken as likely to assist students' own construction of more powerful strategies. But from Vygotsky comes the insight that only a small proportion of a child's cognitive development is self-constructed. By far the larger proportion is done by internalizing a successful performance seen in another person in their social environment and/or by working collaboratively with their peers in the construction of more powerful strategies. Although with infants much of this may be by various forms of 'scaffolding' offered by parents and siblings, by the time of adolescence the 'other' is going to be someone 'just-like-them', but who has gone just beyond where the adolescent presently is – that is, one of their peers who has completed the creation of a strategy the other is already perhaps three-quarters of the way towards (the idea of a zone of proximal development, ZPD). From this comes the 3/4 act model of a CASE lesson shown in figure 12.

Students need to be introduced to the activity (concrete preparation) in such a way that they collaborate in small groups of two to four or more to construct enough of solutions to the task in hand in a given time so that, when the word is given they have something worth presenting to the rest of the class. Orchestrating or chairing his whole-class discussion so that six or seven working groups listen (and cross-question) each other – while the teachers try to 'get out of the way' themselves – is the principal class-management skill the teachers have to develop. In twenty minutes' collaboration so many interesting things are dealt with by different students in different groups – but for each student to have a chance to benefit they need to witness the 'successful performance' of that one person who is just beyond them. If that person was in another group, then 'bad luck' – unless the key episodes of each group are made available to the whole class. Metacognition occurs when students are asked to reflect collaboratively on what the class has achieved and are encouraged to find 'good names' for the ideas or strategies developed, to aid subsequent retrieval from long-term memory.

Finally, from Feuerstein (1980) is drawn the idea of 'bridging' – taking a strategy or a technical term or concept from the context where it is learnt and

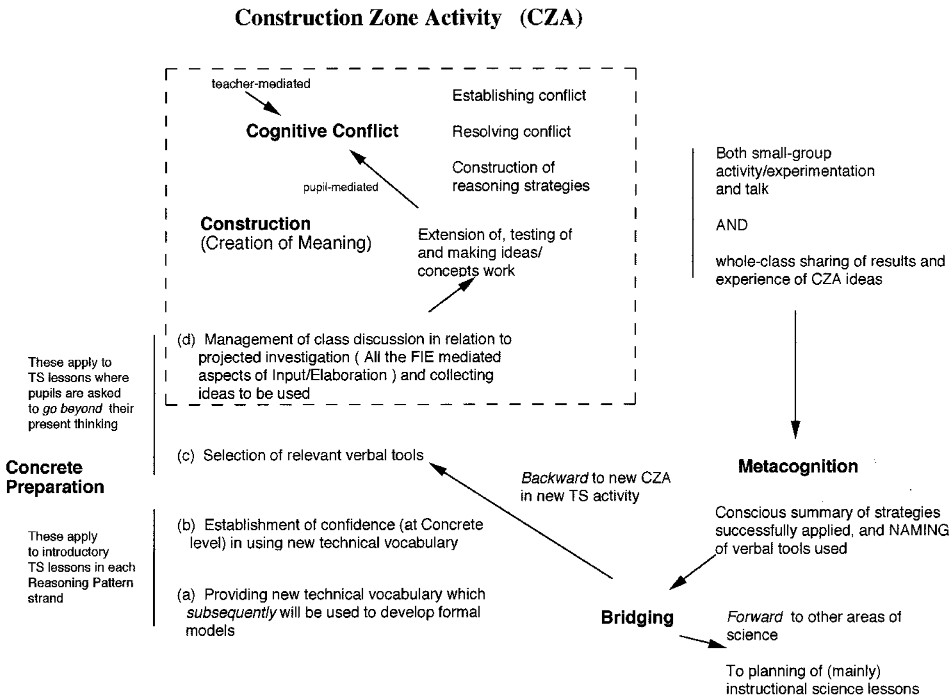

Figure 12. Technical terms used to describe phases of CASE lessons.

applying it to a different but relevant one. As teachers learn to see the cognitive content of their normal science lessons in Piagetian terms they transfer the class-management skills specific to *Thinking Science* lessons to the rest of their science teaching. In British practice, it can be argued that the gradual development by teachers of bridging from TS lessons to the rest of the science curriculum is possibly responsible for more of the long-term and large effects of the CASE intervention than the TS lessons themselves.

Subsequent experience of the *Cognitive Acceleration in Mathematics* projects (CAME 1993–97) has reinforced the relative importance of the Vygotskian aspect.

The CASE intervention art and process skills

From this brief description of the teaching art of CASE, it can be seen that, certainly it should have an indirect effect of enhancing context-specific process skills in science – since reasoning patterns of control of variables, exclusion of variables, ratio and proportion etc. feature in those skills – and the point made in Jones and Gott's table 3 and figures 1 and 2 that there are parallels between Gott's investigative work in science, and *Thinking Science* is well taken. But there is a difference also between the implied treatments compared in their figures 1 and 2. In their figure 1 the process skills to do with relationships between variables are treated as procedural knowledge and pupils' ability to marry cause-and-effect with information given. But in their figure 2 the *Thinking Science* agenda is at a further level of abstraction. Some of the examples given are trivial scientifically, but the use of the vocabulary of variables, values and relationships is the name of the game being played here and pupils readily join in this game, detaching it from the somewhat joky contexts (metacognition) so that later they can readily bridge the use of the vocabulary to serious scientific contexts where its use is relevant and powerful.

Both Jones and Gott and ourselves connected with CASE are concerned with the development of professional skills of science teachers, so the argument is more to do with strategy and tactics. Looking at the process skills of science, as incompletely described in National Curriculum Sc1, is one level of abstraction deeper than just teaching scientific knowledge and is certainly desirable, as Jones and Gott argue. This is not disputed. But CASE suggests teachers go one level of abstraction deeper than this, at least for part of their contact time with pupils, and this is so that pupils can gradually learn to construct their own learning, with a consequent effect on their school achievement. Again, this is partially with the intention of creating a long-term gain in pupils' belief in their own ability to control their own learning, with a consequent effect on their motivation and a decrease in learned helplessness. The substantial effect shown by the pupils in school A (figures 4 and 6) who received CASE teaching (Jones and Gott p. 763) can be seen as evidence for this.

The Piaget/Vygotskian style of teaching has already successfully been re-contextualized within mathematics in the CAME projects and only the ever-increasing difficulty of obtaining research funding (Adey 1993, 1994) has stood in the way of attempts to use it within history. In the preceding description of CASE methodology the word 'science' could be substituted by 'mathematics' all through with no loss in meaning.

Do science teachers not have enough to think about, without being asked to handle their science lessons at two levels of abstraction deeper than those to which they are used? Not with their very bright pupils in mind, admittedly. But for the majority, the problem of the match between the cognitive demands of the subject and the different abilities of pupils to process them is not trivial (Shayer and Adey 1981). Our subsequent experience of CAME with maths teachers has more quickly brought this issue to the fore than in the earlier science context. Many welcome the opportunity this methodology gives to focus on the learning difficulties of their students and to class-management strategies which enable maths teachers to share in their students' growth of the ability to construct their own knowledge within this specialized knowledge context. It quickly deepens their own appreciation of the hidden depths and implications of their own subject, and many science teachers – and those working with them on their own PD programmes – have found the same within the context of science teaching.

Strategy and tactics

To my understanding it is stretching the meaning of the words 'content' and 'knowledge' too far (Jones and Gott p. 767) to apply them to essential features of CASE such as cognitive conflict, metacognition and bridging. This would be to imply that the teacher has clearly in mind the 'procedural knowledge' content of each CASE lesson, with the intention of 'teaching' it in that very lesson. This is a misconception of the CASE method. We hope the contexts of each CASE lesson have been well chosen to be favourable to cognitive challenge and sufficiently varied as to reasoning patterns. But there is no way in which the teacher can be consciously aware of and plan for the needs of all the pupils in a typical mixed-ability or banded class. Her art is to set running a process by which a context of a multi-level problem generates for each group of pupils the cognitive challenges they need, and then to manage both the small-group work on task and the subsequent whole-class communication so that each pupil gets their chance to jump a little beyond their present level of understanding – to complete their ZPD in some important strategy or conceptual understanding. Here the teacher's art is the ability to respond creatively to the dialogue her pupils generate, to help the process on. Although this is bound to affect their pupils' learning in science, the teacher's attention is at the deeper level of abstraction from the science content that is related to pupils' cognitive development. The thinking-skill intervention is context-delivered, but is aimed deeper than science process-skills.

It is certainly desirable to teach science process-skills, but for this you need a different professional teaching art – related to CASE, but clearly differentiated from it. One approach to this is shown admirably in a recent issue of *School Science Review* (Raw 1998). Andy Raw shows how the deficient learning strategies of sixth form pupils for physics can first be elicited and described by skilful individual interview and then consciously addressed in context by suitable algorithms, with a large effect on the pupils' present learning. These are strategic algorithms, not mindless formulae for getting right answers, so they operate at the process-skill level of abstraction in the pupils' minds. These skills have also been described in relation to the chemistry learning of average and below-average year 9 pupils (Strang and Shayer 1993). Thus if the promotion of process-skills is the aim, then the recommended kind of tactics are these, not those of CASE. Why then, from a strategic view, are we insisting that CASE is not this?

Philip Adey has also addressed this issue (Adey 1997) in a lengthy discussion of the question of context-specificity versus general functions of the mind. He rejects the claim that science now – as classical education was once recommended for – is the vehicle for the development of general thinking ability. The CASE research had certainly established that science has been the first learning context through which general cognitive development has been affected, but there is no reason for believing that any major school subject would fail to provide a context by which the general and educable (Adey's terms) functions of the mind can be promoted. So how can we defend the addition of the CASE art to the battery of teaching skills which science teachers should have?

It is simply that for any teacher who is more than a technician the old cliché is true: it is people we are teaching, in addition to subjects. Our experience of CASE PD is that over a two to three-year period teachers learn a great deal about the learning difficulties of their pupils, and they do it through the context-specificity of the *Thinking Science* activities. Our PD approaches the teachers as we expect them to approach their pupils: we take seriously the meta-analysis of Joyce and Showers (1988) which shows the essential role of in-class support for teachers as they develop their art, to complement PD sessions at the College: the induction process is a slow and gradual one. During this period teachers learn far more consciously the existence of hierarchies of difficulty among the concepts in the science(s) they teach, so that their planning of lesson sequences is better matched to the learning abilities of their pupils (Shayer and Adey 1981). At the most concrete level of abstraction are the concepts and the experimental specificities of scientific activity. Hitherto these have been the main focus of attention of the teaching art. At the next level of abstraction are the process skills relevant to science, through which understanding becomes procedural as well as declarative or semantic. But if we are interested in the motivation of the pupil, and also her ability to process learning at these two previous levels of abstraction, we need also to use class-management skills which foster the construction of knowledge by pupils themselves, which is one further level of abstraction still. It is this level which is addressed through the CASE art. The argument is that the compleat teacher (in any school subject) is the one whose professional expertise encompasses all of these levels. It is on these grounds that the retention of the CASE art can be defended, over and above the fact that it does promote cognitive development and academic achievement.

Thus (Jones and Gott p. 768), 'the conceptual dismembering of the CASE programme' is a contradiction in terms: it is really a case of either you do it or you don't. Picking out a few apparently juicy plums relating to control of variables, or whatever, is certainly possible, and practised by some at the process level. But such a tactic is just to short-circuit the practice. At the strategic level: yes, it could be quite desirable to 'lift' the method from its embodiment in the *Thinking Science*, or now the *Thinking Maths* materials. But 'the method' isn't process skills! Getting 'the method' into *Thinking Science* took three people three years' hard work plus the work of many more teachers, and likewise with *Thinking Maths*. For those interested, the steps needed for the abstraction of the art described in some detail in Adey and Shayer (1994 pp. 134–146): these were written before work on the CAME project began.

Strange as it may seem ten more years down the road, those in the original CASE team, those who have joined subsequently as trainers and teachers with several years' practice behind them are all aware that – despite the fact that our programmes of PD are successful – we still have much to learn and indeed that the art itself is still evolving in the practice of teachers. The applied research that I envisage would yield far richer and varied descriptions than we presently have of the professional teaching skills required (but see *RRS*, chapter 4) first, for the better integration of process skills with conceptual understanding; and second, the class management skills required for the ultimate aim of all students reaching the developmental potential they were born with, during their period in high school. In many ways these aims and those of Jones and Gott, under *The Way Forward*, p. 767 are closely related, but I believe neither of them will be done well unless the essential difference between the two levels of abstraction of process skills versus cognitive development is kept in mind.

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References

Adey, P. (1993) *History education and the promotion of intellectual development*. Research proposal unsupported by the Economic and Social Research Council.

Adey, P. (1994) *General reasoning and domain specific reasoning in history and science*. Research proposal unsupported by the Economic and Social Research Council.

Adey, P. (1997) It all depends on the context, doesn't it? Searching for general, educable dragons. *Students in Science Education*, 29, 45–92.

Adey, P. S., Shayer, M. and Yates, C. (1989) *Thinking Science: Student and Teachers' materials for the CASE intervention* (London: Nelson (1st Edition)).

Adey, P. S. and Shayer, M. (1990) Accelerating the development of formal thinking in middle and high school pupils. *Journal of Research in Science Teaching*, 27(3), 267–285.

Adey, P. S. and Shayer, M. (1994) *Really Raising Standards* (London: Routledge).

Feuerstein, R., Rand, Y., Hoffman, M. and Miller, M (1980) *Instrumental Enrichment: an intervention programme for cognitive modifiability* (Baltimore: University Park Press).

Jones, M. and Gott, R. (1998) Cognitive acceleration through science education: alternative perspectives. *International Journal of Science Education*, 20(7), 755–768.

Joyce, B. and Showers, B. (1988) *Student Achievement through Staff Development* (New York: Longman).

NFER (1979) *Science Reasoning Tasks* (Windsor: National Foundation for Educational Research, now available as Piagetian Reasoning Tasks from Science Reasoning, 16 Fen End, OVER, Cambridge CB4 5NE).

Raw, A. (1998) A thinking skills approach to A-level physics questions. *School Science Review*, 20(290), 99–104.

Shayer, M. (1993) *Everything you always Wanted to Know about Acceleration/Intervention, but were too Afraid to Ask*. Paper delivered at the Annual Conference of the National Association for Research in Science Education, April: Atlanta.

Shayer, M. and Adey, P. S. (1993) Accelerating the development of formal thinking in middle and high school students IV: three years on after a two-year intervention. *Journal of Research in Science Teaching*, 30(4), 351–366.

Shayer, M. and Adey, P. S. (1981) *Towards a Science of Science Teaching* (London: Heinemenn Educational Books) (now available from the authors).

Shayer, M. and Adey, P. S. (1992) Accelerating the development of formal thinking in middle and high school students II: post-project effects on science achievement. *Journal of Research in Science Teaching*, 29(1), 81–92.

Shayer, M. and Beasley, F. (1987) Does Instrumental Enrichment work? *British Educational Research Journal*, 13(2), 101–119.

Shayer, M. and Wylam, H. (1978) The distribution of Piagetian stages of thinking in British middle and secondary school children II: 14–16 year-olds and sex differentials. *British Journal of Educational Psychology*, 48, 62–70.

Shayer, M., Küchemann, D. E. and Wylam, H. (1976) The distribution of Piagetian stages of thinking in British middle and secondary school children. *British Journal of Educational Psychology*, 46, 164–173.

Strang, J. and Shayer, M. (1993) Enhancing High school students' achievement in chemistry through a Thinking Skills approach. *International Journal of Science Education*, 15(3), 319–337.

Vellemann, P. F. (1997) *DataDesk, version 6.0. Statistics Guide* (Ithaca, NY: DataDescription inc).