Research in Science Education **33:** 143–162, 2003.

The Influence of CASE on Scientific Creativity

Chongde Lin[1], Weiping Hu[2], Philip Adey[3] and Jiliang Shen[1]
[1]*Beijing Normal University, China*
[2]*Shanxi Teachers University, China*
[3]*Kings College London, U.K.*

Abstract

This paper describes a study of the influence of the Cognitive Acceleration through Science Education (CASE) programme on the scientific creativity of secondary school students. 1087 pupils from six suburban mixed comprehensive schools in England took part in the investigation. Three of the schools had participated in the CASE programme and three had not. Samples of students in years 7–11 from each school were given the *Scientific Creativity Test for Secondary School Students*, an instrument designed to tap various aspects of scientific creativity. The results indicated that the CASE programme did promote the overall development of scientific creativity of secondary school students, although the effects on different aspects of scientific creativity varied. As expected from previous work on delayed effects of CASE on academic achievement, the results indicated that the effects on creativity were not necessarily immediate, but tended to be long-lasting. Possible interpretations of these results are discussed.

Cognitive Acceleration through Science Education (CASE) is an intervention programme designed to be used with students aged about 12–14 years old (in years 7 and 8 of secondary schools in England) with the intention of raising their general intellectual processing ability. It is based on Piagetian ideas of cognitive conflict and the schemata of formal operational thinking, and on Vygotskyan ideas of the social construction of understanding. Additionally, CASE places an emphasis on developing students' metacognitive reasoning, that is, their ability to reflect on their own problem-solving ability, successes, and difficulties encountered. CASE was developed during a project funded by the UK Economic and Social Research Council from 1984–1987. It is represented by a set of curriculum materials which describe 30 activities (Adey, Shayer, & Yates, 2001) designed to be taught at the rate of one every two weeks, instead of a regular science lesson, over two school years. In the UK these are the first two years of secondary school, years 7 and 8, when students are about 12 to 14 years of age. Associated with the materials, and thought to be an essential component of the programme (Adey & Shayer, 1994), is an extensive professional development course for teachers to introduce them to the materials and the novel pedagogy required. Approximately 10% of British secondary schools have participated in this programme and introduced the materials, and very many more have bought the materials and attempted to implement the programme with little or no help.

Studies of the long term effects of CASE (e.g., Adey & Shayer, 1994; Shayer, 1999) have shown that schools trained to use the materials produced significant gains in academic achievement, measured by externally set and marked national examinations ("Key Stage 3 National Curriculum Tests" and "General Certificate of Secondary Education") – not only in science, but also in mathematics and English. This long-term far transfer effect is the basis of the claim by the CASE authors that CASE impacts on general intellectual development, and not just on the specifics of scientific thinking.

Scientific Creativity

The concept of creativity has proven over the years to be an elusive one to define. As early as 1960, Rapucci (cited by Welsch, 1981) counted between 50 and 60 definitions in the literature on creativity. Twenty years later, an extensive review forced Welsch (1981) to conclude that the literature contains such a variance of definitional statements that the task of arriving at an integrated and agreed definition is virtually impossible. Analysis of these definitions suggest that creativity consists of at least four components: (1) the creative process, (2) the creative product, (3) the creative person, and (4) the creative situation (MacKinnon, 1970; Mooney, 1963). It is generally accepted that creativity is an important aspect of scientific ability. Problem solving, hypothesis generation, experimental design, and technical innovation all require a particular form of creativity peculiar to science. Alexander (1992) and Amabile (1987) have shown that all creativity has a domain specific component and so there is a need to distinguish scientific creativity from creativity in general.

The question of assessing scientific creativity has been considered in detail by Hu and Adey (2002), where a fuller account of the relevant literature can be found. Drawing on previous work on creativity in general (especially the Torrance Test of Creative Thinking – Torrance, 1990) and on domain-specific creativity in particular, they proposed a Scientific Creativity Structure Model. On the basis of this model they designed a paper and pencil test: *The Scientific Creativity Test for Secondary School Students*, designed for group administration to students aged from about 10 years. There are seven items in the test, each measuring one aspect of scientific creativity: Unusual Uses, Problem Finding, Product Improvement, Scientific Imagination, Problem Solving, Science Experiment, and Product Design. The test items are reproduced in the Appendix. The scoring rules (also given in the Appendix) give credit for fluency, flexibility, and for originality in each item. After Torrance, the test developers took the view that creativity is a composite of these factors, and it is unlikely to be meaningful to try to offer a profile of the separate elements of fluency, flexibility, and originality. By adding scores obtained for each factor, one is allowing for an individual to compensate, say, for lower fluency scores by increased originality scores. In the context of a paper and pencil test which must for practical reasons be given within a specified period this seems to be the fairest way of obtaining a general creativity score for each individual.

Hu and Adey (2002) reported that the Cronbach Alpha coefficient of internal consistency of this test based upon scores of 160 secondary school students in England is .893. The inter-scorer reliability varied from .793 to .913 with a median of .875. When factor analysis with principal components was run on the data from this test, only one main factor was obtained. This suggested that the test has good construct-related validity. The validity assessed by asking the opinions of expert science education researchers and science teachers is generally high. Draft items which generated doubt or disagreement from this group were discarded during development.

Notwithstanding the single-factor solution and high internal consistency which suggests a common factor on which all seven items load, there is some residual variance which can be ascribed to particular features of each item. In the study reported here, we will be looking at both the whole test scores as a general measure of scientific creativity, and at scores on individual items testing specific aspects, or sub-factors, of this general creativity.

The Research Question

Until now no study has attempted to investigate the effect of CASE on scientific creativity. CASE claims (Adey & Shayer, 1994) that its methods and materials accelerate the development of cognitive processing ability, and this ability is characterised as quite general (Adey, 1997) across academic domains as providing the individual with increased facility in making connections between different bits of information. In information-processing terms this would be seen as either increasing working memory capacity and/or increasing the efficiency with which working memory is utilised. These are all aspects of intelligence. Although the notion of intelligence as a fixed property of an individual has properly fallen into disrepute, the idea of intelligence as a general ability to make connections remains useful. Sternberg (1985, p. 125) shows that intelligence is a covariant of creativity. This is hardly surprising, since a characteristic of creativity is the making of surprising or unusual connections. Genuine creativity means using existing knowledge and processing ability to create novel connections. Of course, covariance does not necessarily imply causation, and it may be that intelligence is a necessary, but insufficient, condition for creativity. Nevertheless, it seems to be a hypothesis worth pursuing that a programme which appears to increase intelligence may also increase creativity. CASE is set in a science context, so it seemed reasonable to seek evidence to support this hypothesis by looking specifically at scientific creativity.

One could hypothesise a number of possible mechanisms by which the CASE programme might effect scientific creativity: metacognition, bridging, and a safe atmosphere for intellectual experimentation. Metacognition is one of the five main ‘pillars’ of the CASE programme (Adey & Shayer, 1994, p. 67). In the simplest interpretation of the word, metacognition means thinking about one's own thinking, becoming conscious of ones' own reasoning. It is a feature of the development of higher order ability that seems to carry almost universal support from cognitive psychologists (Brown, 1987; Karmiloff-Smith, 1991; Perkins & Salomon, 1989). There is a general consensus that metacognition is linked to creativity. For example, Bruch (1988) has proposed the idea of 'metacreativity.' It is viewed as an approach to examining what to do and how to do it in creative processing, choosing and attending to a creative strategy and reviewing in one's mind and feelings what happens during the creative process. Although it differs from metacognition, they have similar characters. We can regard metacreativity as metacognition related to the creative process. Pesut (1990) presented a model that conceptualises creative thinking as a metacognitive process. Armbruster (1989) discussed the function of metacognition in the process of creation, and concluded that metacognition plays a very important role in creativity. Sternberg (1985) proposed a three-facet model of creativity: the intellectual facet of creativity, intellectual style, and personality. One aspect of the intellectual facet is a metacomponent, the higher-order executive processes used in planning, monitoring, and evaluating one's problem solving. Because CASE specifically promotes metacognition, this may well be an important route to the development of scientific creativity of students.

Another important feature of CASE is 'Bridging' (Adey & Shayer, 1994, p. 72). The term is taken from Feuerstein's Instrumental Enrichment, and describes a feature of every Instrumental Enrichment lesson. Sometimes in the initial discussion, always in the final part, students are encouraged first to summarise how the successful strategies they used help them solve the problems (metacognition), and secondly to use their imagination see how the same strategies might be used in other school learning contexts, or outside school. When bridging is designed for the generalisation of formal operational schemata from specific activities in science, the process increases the depth of insight the students have into science content. This may be achieved in two ways: (a) the development of new contexts specifically for the practice of a reasoning pattern first met in a special 'thinking' lesson, and (b) the recalling, while in a regular school lesson, of the applicability of a reasoning pattern previously developed. In this latter sense, bridging means seeking examples of its use in other lessons and in everyday life. It is notable that many highly creative individuals express their creativity by bringing the knowledge and procedures of one field into another, and this can properly be described as bridging. Miller (e.g., Miller, 1956) integrated linguistics with psychology, Simon (e.g., Newell & Simon, 1972) integrated computer science with psychology, and Piaget (e.g., Piaget, 1950) integrated aspects of philosophy and biology with psychology. The bridging in CASE is similar to Guilford's (1967) transfer recall and to Mednick's (1962) remote associations, which are regarded as a kind of creative process. So the bridging in CASE may be another mechanism for the acceleration of the development of scientific creativity.

Designing a facilitative environment is a key factor for the development of students' scientific creativity. Even creative personalities can be suppressed by a non-conducive environment. Garfield (1989) states: "... given the atmosphere of freedom and institutional support, there seems to be plenty of evidence that many suppressed personalities may thrive under the right conditions." Creativity flourishes best in a climate where students are allowed to work independently (Anderson, De Vito, Dyrli, Kellog, Kochendorfer, & Weigand, 1970), take responsibility for their own learning, and feel confident that they can take risks without fear of ridicule or censure. In CASE classes, teachers aim to create a free atmosphere in which students think independently and it seems reasonable to suppose that such an environment also contributes to the development of scientific creativity.

On the basis of these hypotheses, the main research question was: do students who participate in the two year CASE programme demonstrate a higher level of scientific creativity than matched students who do not do CASE?

Subsidiary questions were:

- Are any effects of CASE general across all aspects of scientific creativity measured, or are they specific to certain aspects?
- At what time, with respect to the two year CASE programme and subsequent years, do any effects of CASE on creativity become apparent?

The first of these arises because it may be that the main claimed effect of CASE – to raise general intellectual processing ability – will affect some aspects of scientific creativity more than others. The second question is prompted by the evidence that CASE effects on cognitive development occur immediately at the end of the two year programme, but effects on academic achievement are delayed by at least one year after the end of the programme.

Method

Essentially the method consisted of identifying a set of schools which had introduced CASE into their year 7 at least five years before this study was conducted, so that even pupils in year 11 would have experienced CASE (when they were in years 7 and 8), and to compare the scientific creativity of these students with those from similar schools which do not use CASE.

Sample

It was decided to choose three schools to represent each condition – CASE and non-CASE. Clearly one school each would have been prone to special effects of a particular school. While a larger number of schools might have been desirable, three schools in each condition, selected to exclude any schools which were either unusually favoured or unusually disadvantaged (in terms of catchement area or resources), were considered adequate within the research resources available to explore any systematic differences between CASE and non-CASE students. The schools were all suburban mixed comprehensive schools with a broad ability range intake. The

CASE schools were all ones which had participated in the two year CASE Continuing Professional Development (CPD) programme in 1996–98, such that their original CASE pupils were now in year 11 (age 15+ years). The non-CASE schools were in fact schools which had signed up to participate in CASE CPD from July 2000. They were tested for scientific creativity before any effects of CASE could have occurred. This sampling counters a possible concern that the CASE schools might have been generally more enthusiastic and innovatory than the non-CASE schools.

From each school, we asked for two classes in each of years 7 to 11 (students typically aged 11+ to 15+), that is 10 classes per school. Where the school banded (setted, streamed) its students, we requested one more able and one less able group, but excluded extremes. Ability here is interpreted as ability in science, perceived by the school according to whatever criteria they chose – typically course marks and end-of-year test marks. We were not looking for interaction of any CASE effects on creativity with ability, and so wanted to randomise ability distribution as far as possible. In practice, since the schools were doing this testing as a favour, it was not always possible for them to test as many classes as we asked for, especially in the examination-oriented years 10 and 11. We have assumed that there is no systematic difference in the selection of classes for inclusion between the CASE and non-CASE samples.

The final sample from which we obtained completed creativity test papers was 1087 students. The detailed distribution of the sample is shown in Table 1. It can be seen that no one school in either condition contributes disproportionally to the sample except possibly that school CASE 2 provided no students in years 10 and 11, and non-CASE 2 none in year 11.

Procedure

Copies of the *Scientific Creativity Test for Secondary School Students* were sent to the selected schools with a covering letter explaining the purpose of the research (which was of some interest to all of the schools since they had all used CASE or were about to use CASE) and describing the sample to be tested. In some cases follow-up telephone calls were needed but eventually a good sample of completed papers were returned. They were marked and the item data entered into SPSS 10.0 for Windows together with information on treatment group, age group (year), and gender. The tests were administered between May and July, toward the end of the school year.

Analysis

We investigated the differences of scores between all CASE and all non-CASE students on each item and on the whole test, testing for statistical significance of differences with a t-test. We also conducted a similar analysis separately for each age group (school year).

Table 1
School, Year Group and Gender Distribution of Sample.

School and condition		Year				
		7	8	9	10	11
CASE 1	Male	29	25	20	21	18
	Female	21	27	20	18	15
CASE 2	Male	32	9	13		
	Female	24	10	15		
CASE 3	Male	29	26	26	24	27
	Female	26	13	25	21	20
Non-CASE 1	Male	16	26	23	15	10
	Female	8	27	21	20	17
Non-CASE 2	Male	27	26	23	28	
	Female	22	23	20	14	
Non-CASE 3	Male	21	37	42	33	24
	Female	0	10	0	0	0

Results

Differences Between CASE and Non-CASE Schools on the Whole Test and on Each Item

Means for the whole sample from each treatment group (CASE and non-CASE) on the whole test and on each item are shown in Table 2.

Overall, students in CASE schools score significantly higher statistically on the science creativity test than do non-CASE students with a large effect size but when we look at individual items the story becomes more complex. It appears that the major contribution to CASE students' superiority comes from the items testing Science Experiment and Product Design with very large effects, and Creative Imagination with a smaller, but still statistically significant, effect. On the other hand, non-CASE students score statistically significantly higher than CASE students – albeit with small effect sizes – on items assessing Unusual Uses and Problem Solving. There are no statistically significant differences of scores between CASE and non-CASE students on Problem Finding and Product Improvement.

Before discussing possible interpretations of these findings, we should look at the development of differences between CASE and non-CASE students with age. Here we will find that the situation is even more complex.

Table 2
Means, Standard Deviations, Differences, and Significances: Whole Test and Each Item.

Item		CASE ($N = 554$)	Non-CASE ($N = 533$)	Mean difference	Effect size	t	p
Whole test	M	49.94	41.94	8.00	0.50	7.11	< .001
	SD	20.95	15.93				
Sub tests							
1 Unusual uses	M	8.14	9.05	−0.91	−0.20	−3.27	< .001
	SD	4.69	4.49				
2 Problem finding	M	8.37	8.29	0.08	0.02	0.32	n.s.
	SD	4.34	4.13				
3 Product improvement	M	8.06	7.44	0.62	0.10	1.85	n.s.
	SD	4.78	6.19				
4 Creative imagination	M	6.32	5.53	0.79	0.26	4.02	< .001
	SD	3.49	3.00				
5 Problem solving	M	3.74	4.56	−0.82	−0.21	−4.24	< .001
	SD	2.38	3.85				
6 Science experiment	M	8.04	4.11	3.93	0.93	11.46	< .001
	SD	6.73	4.25				
7 Product design	M	7.21	3.27	3.94	1.09	14.82	< .001
	SD	5.04	3.62				

Comparisons of Scientific Creativity Between Each Age/Year Group

To explore the differences between CASE and non-CASE schools, we compared the mean scores and standard deviations of each year group of students on each item. For items 2 and 3, not only were there no statistically significant differences between CASE and non-CASE students when taking the whole year 7 to 11 sample, there were no statistically significant differences between the CASE and non-CASE students within any one of the five year groups (even taking $p < .05$ as statistically significant for the smaller numbers involved). We will therefore not present more detailed results for these two items. Results for the remaining items are presented in Tables 3–8 and Figures 1–6. The figures show the differences between the mean score of CASE schools and of non-CASE schools for the whole test (Figure 1, Table 3)

Table 3
Whole Test.

Year	Treatment	*N*	M	SD	Mean difference	*t*	*p*
7	CASE	161	38.37	18.44	3.89	1.83	n.s.
	Non-CASE	94	34.48	12.01			
8	CASE	110	49.66	20.48	10.54	4.55	< .001
	Non-CASE	149	39.13	15.19			
9	CASE	119	56.80	18.24	9.04	4.31	< .001
	Non-CASE	129	47.76	14.36			
10	CASE	84	50.74	18.60	7.87	3.06	< .01
	Non-CASE	110	42.86	17.14			
11	CASE	80	62.56	20.95	15.39	4.30	< .001
	Non-CASE	51	47.18	18.34			

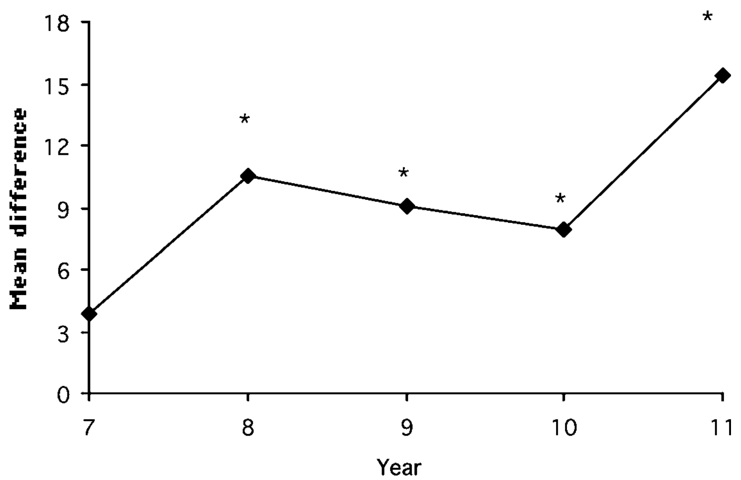

Figure 1: Whole test. (In this and following figures, * indicates statistically significant difference at $p < .01$.)

and for each item (Tables 4–8 and Figures 2–6). Differences which reach statistical significance at a probability level of less than .01 are marked on the figures with an asterisk (*). Brief comments are added to each, but a fuller discussion will follow presentation of all data.

This seems to indicate that near the end of two years of CASE, pupils in CASE schools are scoring significantly higher statistically on scientific creativity than those

Table 4
Unusual Uses.

Year	Treatment	*N*	M	SD	Mean difference	*t*	*p*
7	CASE	161	4.99	3.88	−2.74	−5.44	< .001
	Non-CASE	94	7.72	3.87			
8	CASE	110	9.36	4.97	1.53	2.57	< .05
	Non-CASE	149	7.83	4.56			
9	CASE	119	9.87	4.67	0.00	−0.01	n.s.
	Non-CASE	129	9.87	3.98			
10	CASE	84	8.69	3.56	−1.49	−2.46	< .05
	Non-CASE	110	10.18	4.88			
11	CASE	80	9.69	3.71	−0.90	−1.28	n.s.
	Non-CASE	51	10.59	4.24			

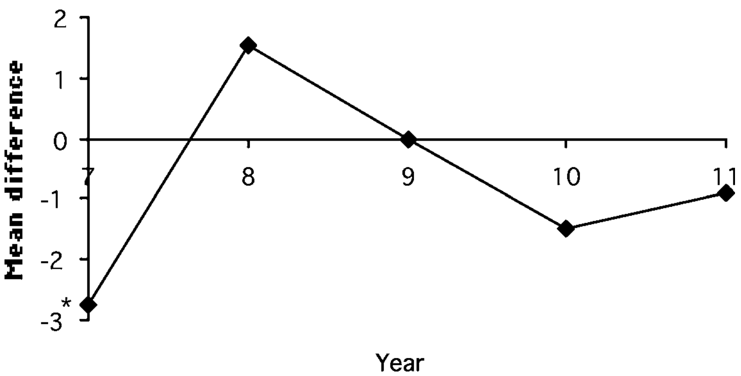

Figure 2: Unusual uses.

in non-CASE schools. The apparent increase in mean difference in year 11, however, is not easy to explain.

Table 4, Figure 2 shows a situation where the non-CASE students have scored significantly higher statistically than the CASE students before the CASE intervention, and we could interpret this as showing that the intervention had the effect of raising CASE students' creativity in this area to that of the non-CASE students', although non-CASE student scores in years 10 and 11 remain higher than CASE students, the difference does not reach statistical significance. (Strictly, the probability of the differences in year 8 (in favour of CASE) and year 10 (against CASE) being 'real' are

Table 5
Scientific Imagination.

Year	Treatment	N	M	SD	Mean difference	t	p
7	CASE	161	4.94	3.07	0.51	1.36	n.s.
	Non-CASE	94	4.43	2.57			
8	CASE	110	5.92	3.59	0.65	1.58	n.s.
	Non-CASE	149	5.27	2.81			
9	CASE	119	6.77	2.84	0.11	0.32	n.s.
	Non-CASE	129	6.65	2.75			
10	CASE	84	6.81	3.79	1.48	2.88	$< .01$
	Non-CASE	110	5.33	3.37			
11	CASE	80	8.50	3.43	2.58	4.32	$< .001$
	Non-CASE	51	5.92	3.18			

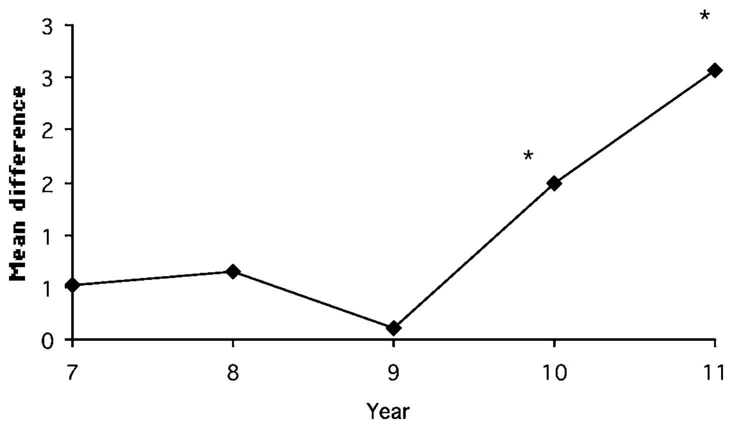

Figure 3: Scientific imagination.

1 in 20, but with so many results reported it is inevitable that one in 20 comparisons will reach this level of significance.)

In Table 5, Figure 3 there appears to be a delayed effect of CASE, with statistically significant differences appearing only two years after the intervention programme.

In Table 6, Figure 4 the non-CASE students score generally higher than the CASE students and the difference actually increases statistically significantly 2 years after the intervention and then disappears in year 11.

Table 6
Problem Solving.

Year	Treatment	*N*	M	SD	Mean difference	*t*	*p*
7	CASE	161	3.35	1.66	−0.83	−2.81	< .01
	Non-CASE	94	4.18	2.56			
8	CASE	110	3.11	2.04	−0.79	−2.42	< .05
	Non-CASE	149	3.90	3.20			
9	CASE	119	4.03	2.00	−0.71	−2.27	< .05
	Non-CASE	129	4.74	2.88			
10	CASE	84	3.94	2.38	−1.66	−2.79	< .01
	Non-CASE	110	5.60	5.61			
11	CASE	80	4.76	3.80	0.25	0.34	n.s.
	Non-CASE	51	4.51	4.57			

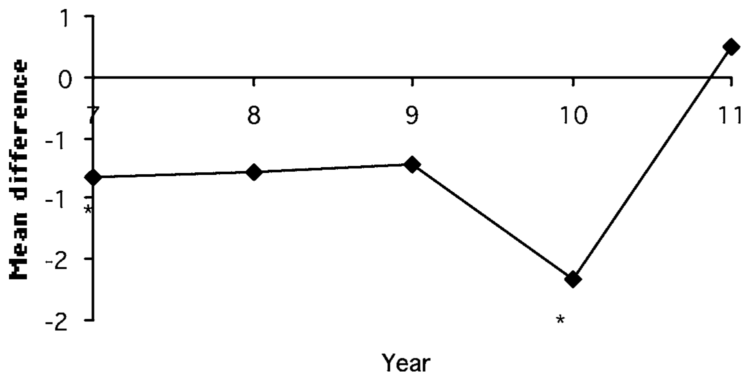

Figure 4: Problem solving.

In Table 7, Figure 5 the CASE students start off scoring statistically significantly higher than the non-CASE students, but there is also a general increase of the difference over the five years, so that the difference at the end of year 11 is over twice as great as it was at years 7 or 8.

Also with the last item, Table 8, Figure 6 CASE students score statistically significantly higher than non-CASE students in every year, including year 7 when less than half of the CASE intervention will have been taught. There is a small rise in the difference from year 9 on, but it would be difficult to argue from this evidence alone that CASE is responsible for the difference on creative product design scores.

Table 7
Science Experiment.

Year	Treatment	*N*	M	SD	Mean difference	*t*	*p*
7	CASE	161	5.87	5.17	2.84	5.29	< .001
	Non-CASE	94	3.03	3.39			
8	CASE	110	6.60	5.30	2.47	4.28	< .001
	Non-CASE	149	4.13	4.00			
9	CASE	119	10.23	6.91	4.96	6.72	< .001
	Non-CASE	129	5.26	4.18			
10	CASE	84	7.04	6.72	3.93	4.85	< .001
	Non-CASE	110	3.11	3.82			
11	CASE	80	12.15	8.25	6.86	5.11	< .001
	Non-CASE	51	5.29	6.11			

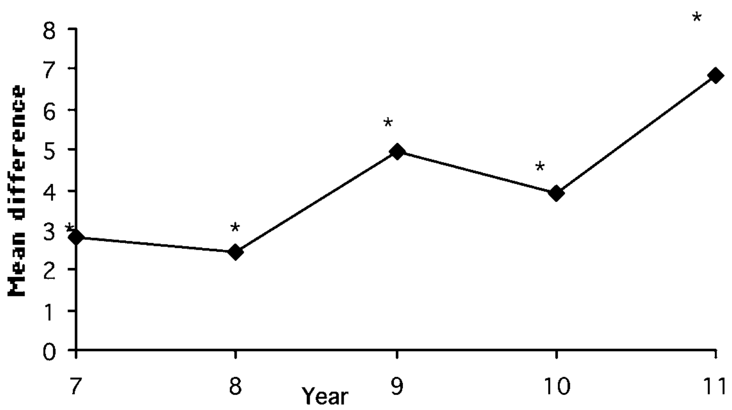

Figure 5: Science experiment.

Discussion

Data for the test overall presented in Table 3 and Figure 1 suggest that the CASE programme is associated with the development of overall scientific creativity of secondary school students. Although there is no statistically significant difference of scientific creativity between CASE and non-CASE students in year 7 when students have completed less than half of the programme, the scientific creativity of CASE students becomes increasingly superior to that of non-CASE students in all subsequent years. Since CASE is the only systematic difference between the two types of

Table 8
Product Design.

Year	Treatment	*N*	M	SD	Mean difference	*t*	*p*
7	CASE	161	6.80	4.42	3.61	7.39	< .001
	Non-CASE	94	3.19	3.32			
8	CASE	110	6.57	5.68	2.82	4.61	< .001
	Non-CASE	149	3.75	3.52			
9	CASE	119	8.61	5.37	4.52	7.64	< .001
	Non-CASE	129	4.09	3.73			
10	CASE	84	6.39	4.97	4.51	7.26	< .001
	Non-CASE	110	1.88	3.14			
11	CASE	80	7.65	4.45	4.71	5.98	< .001
	Non-CASE	51	2.94	4.31			

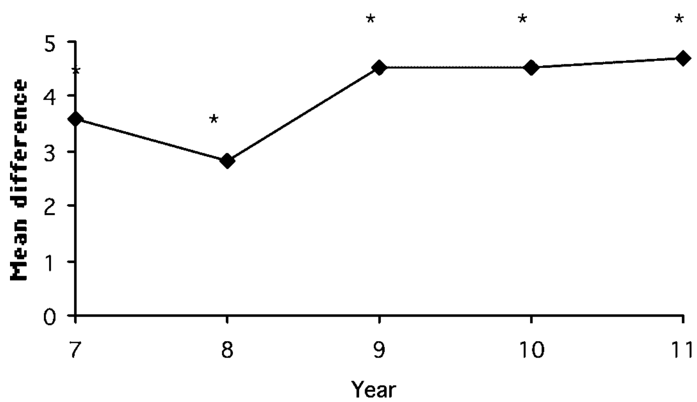

Figure 6: Product design.

school, it is reasonable to ascribe these differences to CASE, while bearing in mind the caveat that with only three schools in each condition, there is some possibility that the differences had other casues.

When we look at the separate components of scientific creativity, the story is not so clear. We can say that in 28 measures (7 items $\times$ 4 years post-CASE), the CASE groups score significantly higher statistically ($p < .01$) than the non-CASE groups in 10 measures, non-CASE students score significantly higher statistically in 1 measure, and there are no statistically significant differences in the remaining 17 measures. One might want to add 3 to the CASE score in this tally from item 1 on unusual uses where CASE has apparently countered an initially significantly better non-CASE group, but one must also question 4 of the scores from item 7 (Figure 6) where there is little improvement in the CASE group from an initially advantageous position.

Overall, we believe that the evidence provided here lends support to the contention that CASE does increase student's scientific creativity, but we need to consider two aspects in a little more detail: the apparent delayed nature of the effect and the differential effect across different items.

Delayed Effect

In fact it is not surprising that the effect of CASE on creativity is often delayed until one or more years after the end of the intervention programme, and that the effect appears to last at least three years after the end of the intervention. It has been argued (Adey & Shayer, 1994, pp. 90–91) that a cognitive intervention programme necessarily works slowly and that its effects on students' cognitive processing are unlikely to become apparent in less than two years. Further, it is only after this enhanced processing ability has been achieved, that the higher level processing can start to be brought to bear on new learning. A similar argument applied to the development of scientific creativity would say: the CASE programme improves students' cognitive processing, and only when this has been achieved can it be applied to problems requiring creative thinking.

The continuing growth in differential scientific creativity in subsequent years is probably a 'success breeds success' effect. Better processing leads to more imaginative answers, and more imaginative answers both provide more satisfaction to task-oriented students and win higher reinforcement for ego-oriented students, and so the process becomes self-promoting. A similar effect was observed with measures of academic achievement of CASE versus non-CASE students for three years after the intervention programme (Shayer, 1999).

Differential Effects across Items

We are, frankly, at a loss to explain adequately the observation that CASE students demonstrated improved scientific creativity compared with non-CASE groups only in certain aspects of scientific creativity. We have looked at the items in an attempt to estimate whether some make more demands on prior knowledge than others (for example, thinking of scientific uses for a piece of glass may be supposed to draw more on experience in laboratories than does making a bicycle more interesting or more beautiful); whether some make more obvious cognitive demands than others (for example, the science experiment question requires an understanding of control of variables in a multi-variable situation), or whether some items make heavier demands on free-flying imagination than others (for example, absence of gravity and apple picking machines, compared with dividing a square into four equal sections). Whilst one can identify some such distinctions, there appears to be no relationship between any of them and the pattern of items that CASE students do relatively well at, whether immediately after the CASE intervention (such as Unusual Uses) or some years later (scientific imagination, science experiment). We also looked at the original $2 \times 3 \times 4$ structural model of scientific creativity on which the test of scientific creativity was based (Hu & Adey, 2002), but again could see no relationship between the cells of the model tapped by each item and the relative success of CASE students on that item. Finally (at the suggestion of a reviewer of an earlier version of this paper, for which we are grateful), we looked to see whether the differential effects might be explained by different weightings given to fluency, flexibility, and originality in the scoring of the items. Again, no pattern emerged.

We are left with the somewhat lame (and oft-written) conclusion that 'more research is needed' to elucidate possible causes of the item differences. Such research might involve interviewing students while they attempt the item to try to uncover more of the nature of the thinking they employ in answering the question. It would also be useful to attempt to replicate the work reported here, perhaps with a larger and more diverse sample of schools and with a longitudinal rather than cross-sectional design.

Conclusion

In setting up the research questions that this study attempted to address, we discussed the relationship of intelligence to creativity and argued that if CASE did indeed raise students' general ability to process information, then it might also be expected to impact on creativity, since intelligence and creativity are associated. Although in overall terms we did find that CASE students made greater gains in scientific creativity test scores than non-CASE students, the design and data do not allow us to specify in detail the mechanism by which this happens. Indeed, in real CASE classrooms it would be practically impossible to tease apart the different aspects of CASE which we supposed might influence creativity (metacognition, bridging, and the secure environment) since they are part and parcel of the same complex intervention known as CASE.

Consideration of the relationship between creativity and intelligence during the past half century has occupied the attention of psychologists with varied perspectives (Haensly & Reynolds, 1989). There are several prevalent viewpoints: first, creativity is not independent of the general factor of intelligence; second, intelligence appears to be a necessary but not sufficient condition for creativity; third, intelligent thinking must also include some degree of creative thinking; fourth, creativity is a distinct category of mental functioning that has limited overlap with intelligence, both in the processes used and characteristics of individuals who exhibit them. We believe that the results reported here weaken the last of these hypotheses both because of the association of cognitive acceleration with growth in scientific creativity, and from our analysis of the characteristics of CASE lessons related to common understandings of scientific creativity.

Our results do lend weight to those, such as Sternberg (1985), Amabile (1987), and Pesut (1990) who argue that creativity can be influenced by the environment. Even if we cannot pinpoint the specific factor within CASE that influences scientific creativity, we do have evidence that as a package it can influence broad measures of scientific creativity. We remain uncertain, however, about why the effect seems to be more prominent in some aspects of scientific creativity than in others.

Note

1. This paper reports the research results of the Chinese National Education Ministry key project "The development and promotion of intelligence and ability of primary and middle school students." It is also supported by funding from the Shanxi Scholarship Council.

Correspondence: Professor Philip Adey, Centre for the Advancement of Thinking, King's College London, Stamford Street, London SE1 9NN, England
E-mail: philip.adey@kcl.ac.uk

References

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

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

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

Alexander, P. A. (1992). Domain knowledge: Evolving themes and emerging concerns. *Educational Psychology, 27*, 33-51.

Amabile, T. M. (1987). The motivation to be creative. In S. G. Isaken (Ed.), *Frontiers of creativity research: Beyond the basics* (pp. 223–254). Buffalo, NY: Bearly.

Anderson, R. E., De Vito, A., Dyrli, O. E., Kellog, M., Kochendorfer, L., & Weigand, J. (1970). *Developing children's thinking through science.* Englewood Cliffs, NJ: Prentice-Hall.

Armbruster, B. B. (1989). Metacognition in creativity. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of creativity* (pp. 177–182). New York: Plenum Press.

Brown, A. L. (1987). Metacognition, executive control, self-regulation and other more mysterious mechanisms. In F. Weinert & R. Kluwe (Eds.), *Metacognition, motivation and understanding* (pp. 65–116). London: Lawrence Erlbaum.

Bruch, C. B. (1988). Metacreativity: Awareness of thoughts and feelings during creative experiences. *The Journal of Creative Behavior, 14*(2), 112–122.

Garfield, E. (1989). Creativity and science, Part 2. The process of scientific discovery. *Current Comments, 45*, 3–9.

Guilford, J. P. (1967). *The nature of human intelligence*. New York: McGraw-Hill.

Haensly, P. A., & Reynolds, C. R. (1989). Creativity and intelligence. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of creativity* (pp. 111–132). New York: Plenum Press.

Hu, W., & Adey, P. (2002). A scientific creativity test for secondary school students. *International Journal of Science Education, 24*(4), 389–404.

Karmiloff-Smith, A. (1991). Beyond modularity: Innate constraints and developmental change. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind* (pp. 179–198). Hillsdale, NJ: Lawrence Erlbaum Associates.

MacKinnon, D. (1970). Creativity: A multi-faceted phenomenon. In J. D. Roslansky (Ed.), *Creativity: A discussion at the Nobel conference* (pp. 17–32). Amsterdam: North-Holland.

Mednick, S. A. (1962). The associative basis of the creative process. *Psychological Review, 69*, 220–232.

Miller, G. A. (1956). The magic number seven plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81–97.

Mooney, R. L. (1963). A conceptual model for integrating four approaches to the identification of creative talent. In C. W. Taylor & F. Barron (Eds.), *Scientific creativity: Its recognition and development* (pp. 331–340). New York: Wiley.

Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice Hall.

Perkins, D. N., & Salomon, G. (1989). Are cognitive skills context-bound? *Educational Researcher, 18*(1), 16–25.

Pesut, D. J. (1990). Creative thinking as a self-regulatory metacognitive process – a model for education, training and further research. *The Journal of Creative Behavior, 24*(2), 105–110.

Piaget, J. (1950). *The psychology of intelligence*. London: Routledge & Kegan Paul.

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

Sternberg, R. J. (1985). *Beyond IQ: A triarchic theory of intelligence.* Cambridge, UK: Cambridge University Press.

Torrance, E. P. (1990). *Torrance tests of creative thinking.* Beaconville, IL: Scholastic Testing Services.

Welsch, P. K. (1981). The nurturance of creative behavior in educational environments: A comprehensive curriculum approach. *Dissertation Abstracts International, 41*(09), 3870A (University Microfilms No. 81-06456).

Appendix: The Scientific Creativity Test Items and Scoring Rules

Item 1: Unusual uses

Please write down as many as possible scientific uses as you can for a piece of glass.

For example, make a test tube.

Scoring: 1 mark for each use (fluency) + 1 mark for each different approach (flexibility) + 2 marks for each use which is given by less than 5% of all respondents (or 1 mark between 5% and 10%) (originality).

Item 2: Problem finding

If you can take a spaceship to travel in the outer space and go to a planet, what scientific questions do you want to research? Please list as many as you can.

For example, are there any living things on the planet?

Scoring: as for item 1.

Item 3: Product improvement

Please think up as many possible improvements as you can to a regular bicycle, making it more interesting, more useful and more beautiful.

For example, make the tyres reflective, so they can be seen in the dark.

Scoring: as for item 1.

Item 4: Scientific imagination

Suppose there was no gravity, describe what the world would be like?

For example, human beings would be floating.

Scoring: as for item 1.

Item 5: Problem solving

Please use as many possible methods as you can to divide a square into four equal pieces (same shape). Draw it on the answer sheet.

Scoring: 3 marks for each solution found by less than 5% of all respodents; 2 marks for those between 5% and 10%, and 1 mark for any found by >10% of respondents. (combination of fluency and originality).

Item 6: Science experiment

There are two kinds of napkins. How can you test which is better? Please write down as many possible methods as you can and the instruments, principles and simple procedure.

Scoring: For each method given, there is a maximum of 9 marks – 3 for instruments, 3 for principle, and 3 for procedure. So a respondent offering two excellent methods would get 18 marks initially. Additionally, 4 marks for each method proposed by less that 5% of all respondents and 2 marks for those between 5% and 10%. More marks are given for originality here because it was found that students found it difficult to think of more than 1 or 2 methods.

Item 7: Product design

Please design an apple picking machine. Draw a picture, point out the name and function of each part.

3 marks are given for each distinct funnction of the machine, plus an originality score of from 1 to 5 based on an overall impression.