Subject Knowledge for Science Teaching at Primary Level: A Comparison of Pre-service Teachers in England and Singapore *

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Abstract

There is a growing body of evidence that a sound scientific knowledge base is important for teachers of primary science. International studies can indicate features which are common around the world and those which may be distinctive because of differences in curricula, teachers' education or socio-cultural factors. This paper reports on a comparative study of aspects of the science knowledge of primary student teachers carried out in Singapore and England. Student teachers' subject understanding was tested for three areas of science. Their teaching ability was assessed in terms of ideas on lesson planning, responding to pupils' questions and the use of analogies to explain concepts. Similar levels of knowledge and ability were found in both groups. Although a science qualification helped with some test items, in general, in neither group was any clear connection found between science knowledge and the ability to teach that knowledge.

Introduction

The teaching of science at the primary level is of world-wide concern, particularly because it is seen as the foundation for a scientifically and technologically literate society as well as being necessary for national economic development. In England, the main aims of science education are seen as 'preparing students for life in a technological society and for employment' (Keys, 1991). The UK government's policy for science education with the advent of the National Curriculum in 1989 (Department of Education and Science [DES], 1989a) is that science should have a place in the curriculum of all students of compulsory school age whether or not they are likely to follow a career in science and technology. The importance of science is reflected in the subject being a core subject beginning at age five.

In Singapore, the 1990s have seen an emphasis on increased investment in high value-added technological operations. Yeoh (1991) points out that, seen in the context of the new technologies being developed, 'school science education is intended to offer individuals not only initial scientific knowledge but also the capacity for coping with the rapid changes in science and technology that affect their daily lives at home, in society and work'. Singapore has had a National Curriculum since 1980. The government's policy for science education is that science be a compulsory subject in

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the school curriculum from age eight to age fourteen. From then on, science is merely one of the optional subjects.

In both countries the importance of the processes of science at the primary level is acknowledged. At the same time a number of broad content areas which students should meet at the primary level is indicated. An examination of the science curriculum outlined in both countries reveals much similarity. Both provide for some study of living things and their interactions with the environment, materials and their characteristics and forces and their effects. Singapore includes some ideas on energy, although officially the topic 'energy' seems to have been deleted in the recently revised National Curriculum in England (Department for Education [DfE], 1995).

How should we prepare our student teachers to achieve these aims which both governments clearly desire? Shulman (1986) although arguing that mere content knowledge is as likely to be as useless pedagogically as content-free skill, stressed that as much attention needs to be paid to content as had previously been devoted to teaching processes. His message was very much the need for beginning teachers to learn not just 'how to teach', but rather 'how to teach electricity' - and his description of an outstanding teacher is not simply a 'teacher', but rather a 'history teacher' or a 'chemistry teacher'.

In 1990, Shulman addressed the Thirty-sixth World Assembly of the International Council in Education for Teaching held in Singapore. He spoke then of how a 'teacher should be someone who doesn't merely know one discipline; a teacher should know how to think about a discipline pedagogically'. He added that it was 'one thing to know the subject matter in a flexible and eclectic way; it is yet another thing to develop the capacity to transform and represent these understandings for teaching purposes'. He suggested that the 'pedagogical way of knowing requires that the teacher possess and continually develop a repertoire of representations - analogies, metaphors, examples, demonstrations, visualisations, stories - to build the necessary bridges between student knowledge and teacher knowledge'. Educationalists have, in general, supported Shulman's views and the research literature contains many examples of how various people have looked at some of the implications for pre-service education (McDiarmid, Ball and Anderson, 1989; Ferguson and Womack, 1993; Bennet and Carré, 1993).

The importance of subject-matter knowledge is reflected in teacher education courses in both England and Singapore. In England, the government showed its concern in this matter by bringing in the requirement that all primary B. Ed. student-teachers study at least one subject for half their course at a standard appropriate to higher education (DES,1989b). In Singapore the Diploma in Education programme, which is one route to becoming a primary teacher, aims at teachers not only having an understanding of the concepts of teaching but also a strong foundation in two academic subjects (Diploma in Education Handbook, National Institute of Education [NIE], 1995). The assumption appears to be that mastery of a subject and its application facilitate more effective teaching and learning. In addition, in both countries, curriculum science courses are offered. In England, the time that primary student teachers must spend on science studies directly related to the primary

curriculum has grown from 100 hours in 1989 to 150 hours in 1996 (DfE, 1993). While the curriculum science course is compulsory for all teacher trainees in England, it is optional in Singapore where those who do offer the unit spend in total 90 hours over a two year period. It is interesting to note that in Australia the Discipline Review of Teacher Education in Mathematics and Science recommended minimum requirements for science in pre-service courses (Department of Employment, Education and Training[DEET], 1985). In the USA, Project 2061 proposed in its recent Blueprint for Teacher Education that all prospective elementary school teachers should have an undergraduate major within the context of a broad liberal arts background that includes several science courses (Floden, Gallagher and Wong, 1995). It is in this area of science knowledge, pedagogical knowledge and pedagogical content knowledge for pre-service student teachers in England and Singapore that our research was undertaken. This last aspect, pedagogical content knowledge, is, as Shulman (1987) puts it, 'a special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding'..

Bennet and Carré (1993) looked at how a deep knowledge of science affected teaching practices as part of a larger investigation into the beliefs and knowledge of graduates on a one year teacher education course. The subject knowledge of students was assessed by tests based on questions previously used on national samples of pupils by the Assessment of Performance Unit (see Bennet and Carré, 1993; DES, 1989), then related to other features of their professional learning and their teaching in four lessons. They found that student teachers in general did not do as well as 'able' eleven year olds on items where comparisons were possible. Science and mathematics graduates performed better on tests of their science knowledge than those with arts degrees. However on some areas even they had similar misunderstandings to pupils. Science graduates' planning and classroom performance in science lessons was in some ways better than that of non-science graduates but they gained lower scores for their lesson evaluations and tended to teach in a more didactic style despite the course's emphasis on science as inquiry.

Gee *et al.* (1995) investigated whether students who selected science as their area of concentration for their undergraduate degrees in elementary education know the appropriate science content, possess appropriate pedagogical knowledge and exhibited pedagogical content knowledge before their student teaching experience. A comparison group of students with other areas of concentration also participated in the study. The researchers found that, although the science area of concentration students were somewhat able to function theoretically within the three types of knowledge, they were unable to apply that knowledge adequately or appropriately in real-life teaching situations.

A longitudinal study conducted at Redford University, Jackson State University, University of Charleston, Oregon State University and Singapore (Dickman *et al.*, 1994) looked at pre-service teachers' knowledge structure as they progressed through the various education programmes. Their studies indicated these pre-service teachers develop content and pedagogy knowledge structures and form bridges between the two, but pedagogical content knowledge may be an unrealistic challenge for pre-service teachers. Pedagogical content knowledge may be a salient point of

experienced teachers' knowledge structures but the teachers studied did not describe it as a separate knowledge structure.

Outline of the Study at Sheffield Hallam University (England) and the National Institute of Education (Singapore)

The questions we wished to consider were

- How well were our chosen areas of science understood by the students?
- How well did the students cope with the pedagogical content tasks set?
- Did a science background at either GCE O-level, A-level or university help with either the content knowledge or pedagogical content tasks?
- Were there any differences between an equivalent group taken from England and Singapore?
- How was the teaching of selected scientific concepts influenced by knowledge and understanding of these concepts?

The Sample and Methods

The student teachers in this study come from a teacher training institution in England (Sheffield Hallam University [SHU]) and another in Singapore (National Institute of Education, Nanyang Technological University [NIE]). Because of their locations in two different countries and training programmes there was an attempt to try and capture two cohorts which were approximately equivalent. The equivalences were

- Both cohorts were doing a unit in curriculum science preparing them for primary school teaching of children in the age range 8-11 (8-12 in Singapore)
- Although the Singapore cohort were in their second year of a two year programme, and the English cohort in the third year of a four year BEd programme, the latter had no science unit in their second year, and the researchers agreed that the two cohorts were equivalent in this respect.
- At the time of administration of the research instruments both groups had completed two rounds of teaching practice (eleven weeks by Singapore students and 10 weeks with the English students).
- Tutors of both groups had at some stage covered some of the ideas related to the three questions asked in the science knowledge section of the research instrument. However, this teaching would have been incidental and not geared to the exact scientific ideas covered in the instruments as the teaching had been carried out before this research was conceived.

- The cohort size in the English sample was 41, of whom there were 33 female students and 8 males. The Singapore sample size was 43, of whom there were 38 females and 5 males.

Some differences about the cohorts were:

- The curriculum science unit undertaken was compulsory for the English sample but an elective for the Singapore students.

- For the Singapore sample a pass in GCE O-level science was a pre-requisite for the unit. Because of the compulsory nature of the unit for the English sample, there was no pre-requisite. Changes in policy will make a C grade or better GCSE pass in science a compulsory requirement for the 1998 intake.

- Sixteen students in the Singapore sample were concurrently taking a science academic unit as an elective (biology, physics or chemistry), while in the English sample the only students classed as studying a science were those specialising in Environmental Science. Students studying a mainstream science (i.e. biology, physics, chemistry) were not included in the English sample as they did not follow a similar curriculum science unit.

The research instrument used in this study comprised written tests developed by the authors at Sheffield Hallam University. The test was organised into two parts. Part one comprised three items designed to elicit specific science content knowledge. The specific areas had been selected to reflect the ideas in the science knowledge based attainment target of the National Curriculum. The first item (1a) asked questions about seed germination, the second item (1b) asked about photosynthesis in the context of trees and the atmosphere; items (1a) and (1b) each had an initial stem question and further extension questions. The third question (1c) was about the forces acting on a ball as it was rising and falling.

In part two there were three items exploring students' ability to apply science knowledge to teaching tasks. The first of these (2a) asked students to outline a plan for extending pupils' understanding of the process of germination, highlighting an activity suitable for ten year old pupils, teaching points and assessment suggestions. Item (2b) asked how they might use models or analogies to help ten year old pupils understand photosynthesis. Item (2c) asked how they would respond to a pupil's question about how there could be any force without movement. Students' answers to this second set gave evidence of their use of more general pedagogic knowledge as well as specific pedagogical content knowledge.

These tests had been piloted and used in a separate study by the Sheffield Hallam authors (Smith and Lloyd, 1995). For the purpose of this study, the test items were validated by the Singapore authors and any amendments made to suit the local cohort were discussed with and agreed to by the Sheffield Hallam authors.

In both countries the tests were administered in such a way as to encourage responses and to minimise the perception that this was an examination. Both groups were not

given any prior notice of the nature of the questions and hence no specific preparation was requested of them. Students were encouraged to include notes at the end of each item explaining their ideas, expressing any uncertainties and views about the task. This produced some insights into their awareness of their own needs and strategies for enhancing their science knowledge.

Responses to each question were graded from 0 to 5. If a student gave no answer this was graded 0, and a substantially incorrect answer was graded 1, a 2 indicated some incorrect statements while grades from 3 to 5 represented increasingly strong answers. Marking was done in accordance with criteria which had been developed by the Sheffield Hallam authors and agreed to by the Singapore authors. To ensure inter-rater reliability, the Sheffield Hallam scripts were marked independently by the Sheffield Hallam authors using the agreed criteria and a final grade agreed through negotiation. The experience of the Sheffield Hallam authors was that the difference of grades awarded were few and small in size and agreement on the final grade was not difficult. To ensure consistency of marking with the Singapore scripts, samples of graded scripts from both countries were exchanged. At a meeting held in Singapore between JKL and the Singapore team further clarification was discussed and approaches to grading confirmed.

To these test results we added background information on each student. This consisted of the academic subject studied by the student at the college (for Singapore where two subjects were studied we considered science over-rode mathematics which over-rode any other subject), whether the student had a GCE in at least one science (all the Singapore sample did, for the UK sample we took grades A-C in GCSE as equivalent to a GCE), if the student had A-level in at least one science subject and if the student was reading any science as part of their training course.

Results

Tests of science knowledge

Table 1 shows the percentage of each sample scoring 0, 1 etc. in the tests of science knowledge. For each question q1a1 to q1b3 a score of 1 or 2 indicates that their response includes actual incorrect statements, although there may be some correct information. For question q1c a score of 1, 2 or 3 indicates some incorrect response within the answer. Table 2 shows the percentages for the two samples of those giving responses containing incorrect information for any part of q1a, q1b and q1c.

	NIE % 0	SHU % 0	NIE % 1	SHU % 1	NIE % 2	SHU % 2	NIE % 3	SHU % 3	NIE % 4	SHU % 4	NIE % 5	SHU % 5
q1a1	4.7	2.4	20.9	9.8	58.1	29.3	4.7	53.7	9.3	4.9	2.3	0.0
q1a2	2.3	0.0	0.0	0.0	41.9	87.8	39.5	12.2	14.0	0.0	2.3	0.0
q1a3	4.7	4.9	39.5	61.0	25.6	12.2	23.3	14.6	7.0	7.3	0.0	0.0
q1a4	7.0	7.3	39.5	43.9	7.0	24.4	30.2	12.2	14.0	12.2	2.3	0.0
q1b1	0.0	0.0	4.7	9.8	14.0	26.8	25.6	39.0	53.5	19.5	2.3	4.9
q1b2	2.3	7.3	16.3	24.4	62.8	63.4	18.6	4.9	0.0	0.0	0.0	0.0
q1b3	55.8	24.4	4.7	48.8	9.3	12.2	18.6	9.8	7.0	4.9	4.7	0.0
q1c	2.3	0.0	48.8	2.4	37.2	56.1	9.3	22.0	0.0	19.5	2.3	0.0

Table 1 : percentage who scored 0,1 etc. for the knowledge questions; NIE denotes the Singapore sample, SHU the Sheffield Hallam sample.

	q1a	**q1b**	**q1c**
Singapore NIE	95.3	83.7	97.7
Sheffield Hallam	95.1	92.7	80.5

Table 2 : percentage with incorrect aspects (see text) on any part of q1a, q1b and q1c

Both Tables 1 and 2 show that very few responses demonstrated the depth of knowledge necessary to be graded 4 or 5, indicating a correct answer with different levels of detail in their explanation. If we take a total score of 12 (averaging 3 or above for each part) for the sum of the parts of q1a, 9 for q1b and 4 for q1c (since 3 was still an incorrect answer here) as being acceptable then the percentages of students with acceptable scores were 10.7%, 20.2% and 10.7% respectively for the combined sample. We then examined the effect of various factors on these proportions using Fisher's exact test for two by two tables.

Possession of a GCE O-level or equivalent in science was weakly linked ($p=0.09$) with success at q1a but not at all with q1b and q1c. Students with an A-level in science did significantly better at q1a ($p=0.008$), q1b ($p=0.002$) but not at q1c. It is likely that few of the students possessed an A-level in physics and so this result is perhaps not as surprising as it seems at first. Studying a science at university level significantly helped with the questions q1a ($p=0.01$) and q1b ($p=0.004$) but not q1c.

Table 3 shows the proportions giving acceptable answers in each group with the scores for the combined sample for comparison.

	N	**q1a**	**q1b**	**q1c**
Combined sample	84	10.7	20.2	10.7
Singapore NIE	43	9.3	30.2	2.3
Sheffield Hallam	41	12.2	9.7	19.5

Table 3 : percentage giving acceptable answers (see text)

We can see proportion doing well was similar for both groups on q1a while significant differences were found on the other two topics (p=0.02 for q1b and p=0.01 for q1c).

Tests of Pedagogic Content Knowledge

Table 4 shows the percentage of each sample scoring 0, 1 etc. in the tests of pedagogic content knowledge. For each question q2a to q2c a score of 1 or 2 indicates that their response includes actual incorrect statements, although there may be some correct information. Table 5 shows the percentages for the two samples of those giving responses containing incorrect information for any part of q2a, q2b and q2c.

	NIE % 0	SHU % 0	NIE % 1	SHU % 1	NIE % 2	SHU % 2	NIE % 3	SHU % 3	NIE % 4	SHU % 4	NIE % 5	SHU % 5
q2a	0.0	0.0	9.3	2.4	65.1	56.1	23.3	29.3	2.3	12.2	0.0	0.0
q2b	11.6	17.1	14.0	12.2	53.5	53.7	18.6	12.2	2.3	4.9	0.0	0.0
q2c	9.3	31.7	7.0	26.8	20.9	29.3	32.6	9.8	23.3	2.4	7.0	0.0

Table 4 : percentage who scored 0,1 etc. for the pedagogic content knowledge questions; NIE denotes the Singapore sample, SHU the Sheffield Hallam sample.

	q2a	**q2b**	**q2c**
Singapore NIE	74.4	67.5	27.9
Sheffield Hallam	58.5	65.0	56.1

Table 5 : percentage with inadequate or incorrect aspects on q2a, q2b and q2c

On lesson planning and responding to a pupil's misconception the scores were higher than for the corresponding content tasks although the use of analogy was answered poorly. The proportion obtaining acceptable scores (3 to 5) were 33.3%, 19.0%, and 38.1%.

Examination was made of the effect of different factors, again using Fisher's exact test..

Possession of a GCE O-level equivalent was not significantly associated with success in the first two questions but was with q2c (p=0.0004). Having an A-level did not significantly affect the result and neither did studying science at university level.

Table 5 shows the proportions giving acceptable responses (a mark of 3 or greater) for the two groups.

	N	**q2a**	**q2b**	**q2c**
Combined sample	84	33.3	19.0	38.1
Singapore NIE	43	25.6	20.9	62.8
Sheffield Hallam	41	41.5	17.1	12.2

Table 6 : percentage giving acceptable answers (see text)

For q2a the difference between Singapore and Sheffield Hallam was almost significant (p=0.1) but no significant difference was found for q2b while the Singapore group scored significantly better on q2c (p=0.006).

Relationship between content knowledge and pedagogical content knowledge tests

To examine how success on the science content knowledge part related to the pedagogical content knowledge we calculated Kendal's tau-b rank correlation between the scores for each question. To avoid problems with using partial non-response for this analysis only we used the following procedure. Where a student failed to answer any part of a question we excluded their replies from the calculation for that question. For germination we had 75 students with p=0.26, for photosynthesis we had 43 students and p=0.27 and for forces we had 67 students with p=0.003 although it was an inverse relationship. When we repeated the analysis leaving in students who had any zero scores the probabilities became 0.47, 0.02 and 0.001, the last being again an inverse relationship. The significant relationship for photosynthesis when zeroes were included may reflect the large number of incomplete answers for this topic in both parts (42.8% on science content and 14.3% on pedagogic part).

Discussion

Specific Research Questions

How well were our chosen areas of science understood by the students?

The results for the knowledge tests show a worrying lack of understanding of the concepts examined in both the Singapore and Sheffield Hallam samples separately and taken together. For all the questions over 80% of the students made at least one incorrect statement despite the fact that over three quarters of the sample possessed the equivalent of GCE O-level in at least one science subject, over 17% had an A-level in a science subject and over one quarter were continuing to study science as an elective academic subject. Amongst those studying science at tertiary level we found biology students scoring poorly on q1a, environmental science students giving incorrect statements on q1b and physics students who showed a poor understanding of forces in q1c. It sometimes seems that some trainees (and possibly even some policy makers) hold the opinion that teachers of the primary age group need to know only 'a bit more' than the pupils are required to have. Even if this was true, our data shows that we are not necessarily at the stage of having trainee teachers with that level of understanding, a conclusion also reached by Bennet and Carré (1993) working with PGCE students. Our subject questions covered only three small areas but each could reasonably be described as important to biology, chemistry and physics respectively. A wider-ranging test instrument would be more likely to reveal further misconceptions rather than to reassure us as to the students' level of scientific understanding. If a large proportion of pre-service teachers leave university with their misconceptions intact then they may, over their years in service, pass on these ideas to hundreds of pupils, some of whom will no doubt choose to become teachers. The

cycle of poor understanding needs to be broken at some point if the teaching of science is to improve substantially.

How well did the students cope with the pedagogical content tasks set?

The students seemed to cope a little better with the pedagogic content knowledge tasks. These tasks gave greater freedom to the students to draw on their strengths (e.g. they could choose any aspect of germination for their lesson plan for q2a) than did the content knowledge questions. They may have been drawing on recollections of activities carried out during their own school days, on lessons given by mentor teachers or taught during their time in school, lessons given by their tutors or on idea seen in books rather than their own creative skills and so their success may depend more on memory than on understanding. However the standard was still disappointing and many misconceptions would have been transmitted to pupils had these responses been turned into real activities carried out in a school setting. In our sample we found occasions when answers were weakened by over-simplification. This was probably caused by a pedagogically commendable desire to simplify the concepts in an attempt to explain the ideas to children in a way that they could grasp.

Did a science background at either GCE O-level, A-level or university help with either the content knowledge or pedagogical content tasks?

Looking at the content knowledge questions it appears that an O-level equivalent is insufficient to make any significant difference to success. Having passed an A-level course or continued study of science during their course helped with some questions but not all. We were pleased to see that some students with little science background produced good answers in both the content knowledge and pedagogic content knowledge sections. This might suggest that science qualifications are neither necessary nor sufficient. However it is more likely that it warns us against assuming that a science qualification guarantees a good understanding of specific science concepts.

Harlen, Holroyd and Byrne (1995) interviewed fifty-five practising teachers as part of a research project on teacher confidence and understanding in teaching science and technology in Scotland. They concluded that the 'proportion of primary teachers who do not themselves understand the concepts they have to teach must be seen as a problem'. The inspectorate in England have recently stated that 'steps need to be taken to enhance the science subject knowledge of teachers, especially those teaching the older Key Stage 2 classes' (Office for Standards in Education [OFSTED], 1995, p.5). The UK government's DfE circular 14/93 "The Initial Training of Primary School teachers: New Criteria for Courses" announced that from 1998 a GCSE grade C or above in a science subject or in combined science will be a requirement to enter primary teacher training in England for those born after September 1979. Huggins (1994) rightly states that 'improving entry qualifications whilst welcome can only be described as marginal help in improving the quality of science teachers in the medium term'. The other issue, also addressed by Huggins, is that a qualification in one science is insufficient to guarantee understanding of other sciences and we must bear

in mind that primary science contains idea drawn from biology, physics and chemistry, although in differing proportions.

Were there any differences between an equivalent group taken from England and Singapore?

One interest in carrying out the research in different countries was to see if we could ascertain a detectable difference that might point us towards a practice in one country that the other country could learn from.

On the content knowledge questions we found no significant difference on germination, that Singapore was significantly better on photosynthesis, while Sheffield Hallam was significantly better on forces. The Singapore group had covered germination and photosynthesis in year one of their course but had studied forces only briefly in year two. At Sheffield Hallam more time had been spent on forces in year one while germination and photosynthesis were only briefly touched on during the course. Given the limited amount of time in a training course some topics will inevitably be covered more intensively than others.

The large difference found on q2c is somewhat puzzling. The National Curriculum for England contains more material on forces, including balanced forces, than the corresponding Singapore syllabus, although the materials developed by the Curriculum Development Institute Singapore (CDIS), which are widely used in Singapore schools, do describe activities with balanced forces. One way in which the English and Singapore groups differ is that the Singapore group would all have been in a system with a formal science content during their time in primary education while this may not be so for the English group since a national curriculum for science was introduced only after they would have left primary education. Similarly there is no obvious reason for Sheffield Hallam's better showing on q2a. Examination of the responses showed that the Singapore group frequently failed to mention warmth as a condition for germination while few of the UK group made this mistake. This differènce is perhaps unsurprising if one is aware that the minimum temperature in Singapore never falls below 20°C and warmth is a condition for germination which is always satisfied while the coming of spring is obvious to all in the UK. It is salutary to be reminded that not all science questions are independent of culture (or climate).

How was the teaching of selected scientific concepts influenced by knowledge and understanding of these concepts?

The fact that on the pedagogical content knowledge test our students showed no significant positive relationship with their scores for the content knowledge questions is both interesting and disturbing - indicating the pedagogic content tests are poor discriminators of understanding of the related science concept. This lack of connection is disturbing because it suggests that we may observe our students conducting a class and leave, believing that they have mastered the underlying scientific concepts when a simple question from a pupil may cause them to reveal how tenuous their understanding is. Of interest here are the four students doing physics at a tertiary level in our sample who did well, scoring 3 and above in the pedagogic

content test (one of them scored a perfect 5) but all of whom scored 2 or below in the related content knowledge test, which would mean they held ideas on forces which were actually wrong. It seems that exposure to a subject at a higher level does not necessarily improve the understanding of basic concepts.

There is also then the communication of subject matter knowledge by these student teachers to their pupils. Geddis (1993) puts it as 'for novice teachers in particular, it is important to realise that there is a critical knowledge about content that needs to be understood in order to transform that subject matter content for students'. As an example we quote the responses of one student for the content knowledge and pedagogical content knowledge on forces. She gained a good score in question 1c for correctly identifying the force in the multiple choice part of the question on the ball travelling up in the air and coming down and providing the following explanation:

> As the ball is travelling gravity is constantly forcing it down. The point at which the ball begins to fall down is a point at which the ball runs out of the energy that forced it up in the first place. As the ball falls it proves that gravity is always there forcing the ball down.

However in the second question (q2c) requiring her to respond to a child's question asking how there can be any force if it is not moving she wrote:

> I don't know enough or feel confident enough to explain this.

More General Issues

It appears that even after extensive formal teaching many basic scientific concepts can fail to take root in people's minds. Roberts and Sutton (1984) have remarked that the recollections of school chemistry by a small group of well-educated adults are "relatively isolated" and do not amount to a "connected structure of chemical thought". In an investigation of the understanding of selected biological topics among a representative sample of 1033 adults, Lucas (1987) came to the conclusion that for most of the questions answered "an education in science improves the knowledge of the adult population, although the effect was not much more than an effect of general educational level". Why is this so?

A student in the Singapore cohort wrote, "I cannot remember what I had learned during my secondary school science lessons", while another commented. "... I usually use rote learning ...", a comment that probably describes many a student's feeling as described in the following:

> I was hopeless at physics. I burned my physics jotter at the end of the second year, because we hated it. I'm hopeless, I don't understand it, it's like I've got a real mental block. I can learn it, I even got good marks at college, but it was only pure memory, never understanding.

(Harlen, Holroyd and Byrne, 1995)

A great deal of what we take in as scientific knowledge comes from authority, not understanding. We often find that much of this authority comes from school. It so often comes about because children carry out activities without knowing exactly what they do. Often when one does not understand the scientific knowledge taught to us, we allow common sense to take over and there is a big difference between scientific thinking and common sense. But don't these students have assessment records indicating examination success? Solomon (1994) pointed out in a television documentary that "Nobody can say of assessment that it has got to be rigorous because it won't be - but unfortunately it gives the impression in the public arena that it is." According to a report of Kings College, London referred to later in this programme, 'the apparently acceptable level of examination performances hides disturbingly widespread areas of gross and damaging confusion'.

In his speech at the opening of the Creative Arts Programme Seminar in May 1996 (as reported in the Straits Times Weekly Edition of 1st June 1996) Lee Hsien Loong, the Deputy Prime Minister of Singapore, said, "Singapore needs to look at how its students are being assessed academically ... while acknowledging the good results as reflecting the hard work put in by the teachers and pupils". He added, "But it also had something to do with students becoming 'exam smart', or better prepared for examinations".

Teacher training institutes rightly spend time providing students with knowledge of pedagogy. General pedagogic knowledge and skills are likely to be the dominant concerns of student teachers who may underestimate the level of understanding of the subject knowledge required to teach primary level pupils. These ought to be powerful influences on a student teachers' grasp of how specific subject matter can be taught, especially if suitable practical teaching experiences are provided and evaluated.

If we are to consider the issue of how to help improve primary science teaching 'it will not be simply concerned with increasing teachers' subject knowledge but with providing help with subject related pedagogy' (Harlen *et al.*, 1995). What form should this help take? Harlen *et al.* report that in their interviews there were requests by teachers for detailed accounts of what to teach and for explanations of content which can be considered as being related to the needs for better personal understanding of the concepts of science. They state that a 'teacher lacking understanding of the ideas may either request help to improve his or her understanding or may ask for such detailed guidance to follow that there is little dependence on teacher thinking'. They deprecate such a procedure and say, 'the latter approach cannot cater for pupils' individual paths of intellectual development nor foster creativity and genuine problem-solving skills, for which unexpected situations have to be encouraged and tried. However this does not mean that some examples of activities, described in detail, are not valuable.'

There is a Curriculum Development Institute in Singapore [CDIS] that produces the kind of materials the Scottish teachers seem to have requested. Although the use of these materials is not compulsory, there is probably one hundred percent uptake of the material, comprising pupil textbooks and workbooks and teacher guides. Although CDIS is distinct from the group within the Ministry of Education [MOE] that set the

national curriculum they work closely together to ensure that these materials correctly interpret the national curriculum for science. The materials are written with the acknowledgement that for teachers who are not confident about teaching science, help with content knowledge and pedagogical content knowledge is invaluable. This has proven to be very popular with such teachers. For teachers with greater experience the use of other published material and less dependence on CDIS material is encouraged. There have been moves in this direction in England where the National Curriculum Council, and recently the Teacher Training Agency, have commissioned materials for use in schools.

The concern that Harlen *et al.* (1995) raised with regard to creativity is undoubtedly important. Over-reliance on guide books without teacher thinking certainly stifles the atmosphere of exploration and questioning by pupils - the hallmark of a good science lesson. In recent months in Singapore there have been calls by the politicians and agreement shown by academics that there is a need for creativity in the Singapore educational system which have been reported in the Straits Times. There is all the more need for teachers to have a level of understanding in science that allows for divergent thinking and does not assume that there is only one correct answer. As Harlen says elsewhere (Harlen, 1996),

> At the same time it must be borne in mind that the reason why understanding is needed is not so that teachers can convey factual information didactically to pupils but so that they can ask questions that lead children to reveal and reflect on their ideas, so that they can avoid 'blind alleys', ...

It is evident that teacher training institutions need to support the development of student teachers and practising teachers of science. The question is how to do this more successfully than at present within the current restraints of time and resources. The work of Dickman *et al.* (1994) expressed concern that pedagogic content knowledge may be an 'unrealistic challenge for pre-service teachers ... ' but 'a salient point of experienced teachers'. This appears unduly pessimistic but it cannot be denied that the task of training a successful teacher has become more, not less, difficult. A modern primary school teacher is no longer required to simply deliver information to receptive minds sat quietly in rows. Today a teacher of science has to be a facilitator organising many simultaneous acts of investigation and discovery, providing physical resources and information, leading young minds gently towards the ideas the curriculum prescribes without dampening the enthusiasm of pupils. This requires a deeper understanding of scientific concepts and a flexibility borne of confidence in one's own understanding. It must also be remembered that science is only one of the subjects taught by most teachers working in the primary sector.

It is important, if the aims of the science education policy in England and Singapore are to be achieved, that all in the enterprise realise that, to have a society that is at ease with science, needs well trained teachers to make it effective. Huggins (1994) suggests that teacher trainees may need an appropriate kind of differentiated professional preparation acknowledging the differing strengths of members of the student intake. Undoubtedly this will require time and a climate of appropriate

staffing and resources to pursue this route. Another factor that will need to be considered is that in an era where knowledge is increasing exponentially a question of the currency of teachers' knowledge emerges. The use of electronically retrievable information and the increasing use of information technology in schools points the way towards a judicious selection of content knowledge and the appropriate pedagogical content knowledge work that needs to be covered in initial teacher training programmes. The need for a well-structured approach to in-service training so that our teachers are kept well informed throughout their career is paramount. It may also mean that we carefully address the question, in the light of the science understanding held and required of primary school teachers, of whether the teacher is to be a specialist or a generalist. An initial training course cannot hope to cover everything a teacher will need to know over a career of forty years. More and more, schools will have to give young people the skills and habit of independent life-long learning. Teacher training institutions will have to start this process with their students. To quote T. S. Eliot (1940),

> We must be still and still moving
> Into another intensity
> For a further union, a deeper communion

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