

## Issues Raised by Testing Trainee Primary Teachers' Mathematical Knowledge

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For the past four years, pre-service teachers on a postgraduate primary teacher preparation course have been able to enhance their knowledge and skills of the mathematics they will be teaching by opting for additional classes. At the beginning of the course, the pre-service teachers had not really engaged with the content knowledge they required in order to teach pupils up to 11 years of age. In many cases they initially assumed that they had the required knowledge but experienced difficulties during practical placement when it was too late to access additional classes. Therefore, it was decided to audit the pre-service teachers' mathematical knowledge at the beginning of their 38 week course. This paper highlights the issues raised with regard to pre-service teacher confidence, attitude and course provision by the decision to expose them to deficits in their knowledge. This is of current importance in Wales and England as recent Government regulations require all pre-service teachers to demonstrate levels of competency in mathematics.

If teaching involves helping others to learn, then understanding the subject content to be taught is a fundamental requirement of teaching (Aubrey, 1997a, p. 3).

During the last twenty years, the subject knowledge of primary school teachers and pre-service teachers has attracted much attention from both government and educational researchers. Much of the academic interest stemmed from Shulman's Presidential Address to the 1985 meeting of the American Educational Research Association, and his subsequent papers. Shulman (1986, p. 9) suggested three categories of content knowledge: (a) subject matter content knowledge that "refers to the amount and organisation of knowledge per se in the mind of the teacher", (b) pedagogical content knowledge that "goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching", and (c) curriculum knowledge which is represented by "the full range of programs (and materials) designed for the teaching of particular subjects and topics at a given level".

Other researchers, including Grossman (1989), Peterson, Fennema, Carpenter, and Loeff (1989), McDiarmid, Ball, and Anderson (1989), and more recently Turner-Bisset (1999), have modified and developed a more comprehensive list of Shulman's categories. Grossman, Wilson and Shulman (1989 p. 32) recognised that "both teachers and teacher educators may have been unaware of the powerful influence knowledge, or lack of knowledge, of a subject exerts on teaching". Fennema and Franke (1992, p. 147) stated "no one questions the idea that what a teacher knows is one of the most important influences on what is done in classrooms and ultimately on what students learn". Aubrey (1997b) also considered it to be one of the most important influences on classroom practice.

Whilst not denigrating the importance of knowledge range in teaching, the emphasis for this project was on subject content knowledge.

### Recent Government Initiatives

The importance of subject knowledge has also been expressed by Government. In the White Paper, *Teaching Quality*, Her Majesty's Inspectors report "that in nearly a quarter of the primary school lessons seen, teachers showed signs of insecurity in the subject being taught" (Department of Education of Science [DES], 1983, p. 8). Subsequently, there was a move towards greater emphasis being placed on the acquisition of subject knowledge (DES, 1989). This was accentuated by the introduction of the National Curriculum.

In 1992 the Department of Education and Science (DES) commissioned a discussion paper by Alexander, Rose and Woodhead, which stated that

good subject teaching depends on the teachers' knowledge, skills and understanding in the subject concerned . . . subject knowledge is a critical factor at every point in the teaching process . . . Problems . . . may stem from weaknesses in teachers' subject knowledge and understanding (p. 24).

Following a report by the Office for Standards in Education (1993) and the National Curriculum Council (1993) a set of competences was issued focusing on "subject knowledge and teaching skills new teachers require to be effective in the classroom" (Department of Education and Science, 1993, p. 3).

Following a consultative process with Higher Education establishments, a set of standardised criteria, which included content knowledge, was issued to regulate teacher training (Department for Education and Employment [DfEE], 1997). This culminated in 'Requirements for Courses of Initial Teacher Training' which commented that "the mathematics qualifications held by trainees may not be sufficient to ensure they feel confident about, and are competent in, the mathematics they have studied and are required to teach" (DfEE, 1998, p. 69). It "sets out the prior knowledge and understanding of mathematics which trainees need in order to underpin effective teaching of mathematics at primary level" (Welsh Office, 1998, p. 54) and that this knowledge must be audited. The Government did not clarify the term 'audit', and in an endeavor to achieve a common definition, all Teacher Training Institutions in Wales agreed to conduct a standardised test. The appropriateness of the content of these requirements is not the focus for this paper.

A national numeracy test was also introduced in England in 2000 (computerised from 2001). Again, the pre-service teachers are required to pass this to become a qualified teacher. This numeracy test is not the stimulus for this project.

Recent developments in educational policy continue to be influenced by the need to efficiently utilise available resources and offer greater accountability (Turner-Bisset, 1999). These, together with the push for higher standards in education (Aubrey, 1997a), are seen as factors contributing to this interest in the subject knowledge of teachers. This appears to be the case in both America and Britain (McNamara, 1991).

## Background to the Course

The Post-Graduate Certificate in Education (PGCE) at the University of Wales, Swansea, is a one-year teacher-training course. Pre-service teachers spend 20 weeks out of 38 in university; the rest is spent on school placement. They are required to study the eleven National Curriculum subjects, which are taught in primary schools. Mathematics is allocated 55 hours, with an additional 1-2 hours per week for supplementary subject knowledge tuition. The content of these additional classes initially covered the mathematics taught in primary schools (before school placement occurred) and subsequently any extra mathematics needed to meet the Government requirements. It is these classes which are discussed in more detail.

All students on the PGCE course are required to have a General Certificate of Secondary Education (GCSE - age 16 national qualification), grade C or above, in mathematics, as an entrance qualification. One would have expected this to give Primary PGCE pre-service teachers sufficient subject content knowledge to teach mathematics to the end of Primary School.

By the mid-nineties, it became apparent to the Department that some pre-service teachers' subject knowledge in mathematics was deficient. There were two identifiable deficiencies: inadequate subject knowledge and serious fundamental misconceptions. These findings concurred with those found by Bennet and Carré (1993). Consequently, we implemented course content changes five years ago, which were specifically designed to address these concerns.

Initially, attempts were made to increase the amount of content knowledge taught within the course, but these were met with resentment by a significant number of the pre-service teachers, as they "already had a GCSE" and "didn't need to learn any more mathematics". Following a discussion with Dr. Beverly Moriarty of the University of Central Queensland, permission was given to use a modified version of an instrument she had developed to examine pre-service teachers' knowledge of factual information and central concepts in mathematics (Sanders & Morris, 2000). The pre-service teachers were given this audit as a form of self-assessment, and marked their own tests. They were given guidance and encouragement to improve areas of the curriculum where their knowledge was not satisfactory. Due to the pressures from an intensive PGCE course, it was found that this "extra mathematics" was not a high priority for the pre-service teachers, consequently their lack of knowledge was not being rectified. A more direct approach was needed.

The next cohort of pre-service teachers was subject to the same audit. However, in this instance the tests were marked and analysed by an independent tutor. These results were then used to develop optional mathematics classes in topics where knowledge was lacking. Later during that year, a retest was arranged for those students who received an unsatisfactory result in their initial audit.

Generally, the pre-service teachers showed an improvement in their subject knowledge by the end of the academic year. However, some students had chosen not to attend these optional classes and this appeared to hinder their progress. For

this reason the Department decided to make these additional mathematics sessions mandatory.

Prior to course commencement, a detailed syllabus together with information on the audit was sent to the prospective pre-service teachers. It was hoped that this would allow them to improve their content knowledge before the start of the course. This did not result in an improvement as 45% continued to fail the audit. In order to focus their revision, the Department decided to provide a specimen paper for the following academic year. There was a subsequent decrease in the failure rate, which stood at 30%.

## Research Project

There were two fundamental aims underpinning the research project: to examine the impact of subject knowledge audits on students' confidence, and to inform future curriculum planning and development for the course in light of the research.

In keeping with previous studies (e.g., Bandura, 1997; Moriarty, 1995), it was decided to use simple six point Likert scale items to indicate levels of confidence. During their first few days on the course, the pre-service teachers were asked to fill in two simple questionnaires, the first asking for details of qualifications in mathematics, years since study of mathematics, confidence about their own mathematical ability, and confidence in teaching mathematics. The second was a copy of the Likert scales to be used in the audit, where pre-service teachers were asked to indicate their confidence in dealing with a particular topic in mathematics. An identical set of confidence scales were used during the audit, and again after the pre-service teacher had received their results. This allowed for direct comparison between their self-confidence scores. Information was also collected through informal interviews.

The Moriarty Test used by the Department had been trialed previously (Moriarty, 1995) but needed minor changes before use, and the audit has recently been restructured to reflect the sections in the UK National Curriculum – Number and Algebra; Shape, Space and Measures; and Data Handling.

The pre-service teachers were notified three months before the start of the course that they would be expected to take a mathematics audit during their induction week. They were sent a detailed syllabus (taken from the National Curriculum for primary schools), and a specimen paper, along with recommended revision texts. Calculators could not be used for the audit, but there was no time constraint. The papers were marked and analysed by a member of staff. All pre-service teachers were given details of topics in which they had not achieved a satisfactory standard. Anyone who did not obtain 66% of the total marks available in any one section was required to re-sit that section. Extra classes were arranged, the topics of which depended on pre-service teachers' errors and misconceptions. They were then notified which classes they were required to attend. The re-sit was taken eight weeks into the term. These classes covered the content knowledge they would be required to teach. The rest of the academic year was devoted to developing the extra knowledge to meet the new Government requirements,

approximately equivalent to GCSE standard (Senior school level), and the corresponding audits.

## Results and Discussion

### *Initial Discussion and Findings*

The qualification range in mathematics of pre-service teachers was similar to that of the past: 9% had studied mathematics (usually statistics) as part of their degree, 10% had A level (advanced level - national qualification, normally required for degree entry), and a further 7% had A (the highest grade GCSE), all had at least a pass at GCSE. In previous years, approximately 50% had failed to pass the audit at their first attempt. It was hoped that this year with the introduction of a specimen paper that the majority of pre-service teacher would pass. Out of 116 trainee teachers, 35 (30%) received an unsatisfactory score, and these came from across the qualification range, including two who had studied mathematics as part of their degree. Although the failure rate was lower than previous years, there was still a large number of pre-service teachers who did not appear to be preparing adequately for the audit. Previous qualifications gave no indication of test performance, neither did pre-test confidence scores. When asked to give a confidence score relating to their own ability in mathematics, the pre-service teachers who failed did not merely come from the lowest confidence group, although only 3% came from the top two groups. Many of the pre-service teachers were over confident in their mathematical ability, rating their confidence as high when unknowingly giving an incorrect answer. This is a common bias, especially in those who lack knowledge in a particular area (Lichtenstein & Fischhoff, 1977). Some of this overconfidence could be attributed to misconceptions. Many of these misconceptions and errors did not only come from topics that pre-service teachers may not have studied before such as statistics, but also from basic arithmetic. Several believed they had answered questions correctly, even when faced with their incorrect scripts, and argued that the marker had the wrong answer! One person was adamant that 204 remainder 6 in a division question was the same as 204.6. Following discussion of the correct solution, the pre-service teacher claimed "never to have done it like that before!"

### *Examples of Incorrect Answers:*

- Division was a common problem with 31% of the total pre-service teachers failing to obtain the correct answer. The most common error, occurring in over one third of answers, was missing out the zero in the result.
- The highest percentage of errors (43%) occurred in writing large numbers as words, with over one third of these spelling forty as "fourty".

- Metric conversion of kilograms to grams also produced a high percentage of incorrect answers; 41% failed to convert 23 kg to grams. 90% of these gave the answer 2300g.
- Multiplying 7 minutes 25 seconds by 8 also caused problems; 39% were unable to give the correct answer. There were no identifiable common errors, but answers ranged from 593m 33s to 35m 40s
- £6.06  $\div$  0.5 also caused problems with 35% failing to achieve the right answer. Again there was a range of answers, but the most frequent were: £30.30 occurred in 40% of answers, £303.00 in 14%, and £3.08 in 11% of incorrect answers.

Post, Harel, Behr, and Lesh (1991) reported that teachers have the same naïve conceptualisations and misunderstandings of mathematical knowledge as pupils. It appears that the same can be said for pre-service teachers. Worrying results, because unless rectified, they will take their misconceptions into their teaching.

### *Effect on Confidence*

The data were analysed to look for trends in pre-service teachers' confidence. In previous years it was found that poor performance affected confidence. In the simpler topics like addition, subtraction and money, there was a noticeable drop in confidence for the majority of pre-service teachers after failure. Conversely, there was an increase in confidence in the majority of topics, that were perceived as more difficult - volume, factors and subtraction using decomposition. Table 1 presents the changes in confidence on topics in number.

Table 1  
*Change of Confidence (%) from Pre- to Post-test in Number (n = 35)*

| Topic            | Drop in confidence | No change | Increase in confidence |
|------------------|--------------------|-----------|------------------------|
| Addition         | 10                 | 59        | 31                     |
| Multiplication   | 14                 | 48        | 38                     |
| Subtraction      | 6                  | 52        | 42                     |
| Division         | 10                 | 40        | 50                     |
| Factors          | 11                 | 33        | 56                     |
| Decomposition    | 14                 | 48        | 38                     |
| Powers/indices   | 14                 | 54        | 32                     |
| Estimation       | 19                 | 41        | 40                     |
| Negative numbers | 14                 | 20        | 66                     |

The results did not follow the pattern expected from previous years. Although there was a drop in confidence for some pre-service teachers, they were in the minority. Confidence appeared to be unaffected, or increased for most of them. This result is consistent for those pre-service teachers who passed, and for other sections of the audit. The only apparent change for this year's pre-service teachers

was the provision of a specimen paper. How had increasing their prior knowledge of the test caused the confidence levels of the pre-service teachers to be less affected by failure, unlike previous years? It is possible that the specimen paper had acted as a focus for revision - they knew the structure of the questions, the degree of difficulty, and were able to practice audit type questions. Perhaps this had given some pre-service teachers greater confidence in their ability, and failure was attributed more to lapse in memory rather than lack of ability: "My metric conversions are not always 'instantly there'". Therefore failure was not seen as a problem, or a threat to perceived ability.

Many of the pre-service teachers, whose confidence remained unchanged, had given themselves the lowest confidence score possible - no confidence to work with a particular topic. This accounted for 26% of all pre-service teachers. Every one of these, appeared to have a negative attitude towards mathematics. At the beginning of the year, when asked if they liked mathematics, each had given an emphatic 'No'. The detrimental effect that this negative attitude can have on performance has been known for many years (Aiken & Dreger, 1961). Again these pre-service teachers came from across the qualification range, and 46% had actually passed the audit.

### *Self-efficacy and Reaction to Failure*

Bandura (1994) defines self-efficacy as "people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives . . . . Self-efficacy beliefs determine how people feel, think, motivate themselves and behave" (p. 71). He categorised people by their level of self-efficacy - either high or low, and it appeared our pre-service teachers could be categorised in a similar way - those with high self-efficacy we called *Nettle-graspers*, and those with low self-efficacy, *Ostriches* and *Mañanas*.

#### *The nettle-graspers are*

People with high assurance in their capabilities [who] approach difficult tasks as challenges to be mastered rather than as threats to be avoided . . . . They heighten and sustain their efforts in the face of failure. They quickly recover their sense of efficacy after failure or setbacks. They attribute failure to insufficient effort or deficient knowledge and skills which are acquirable (Bandura, 1994, p. 71).

This group of pre-service teachers saw failure as a challenge to be met, it was not a problem for them. They recognised the need for improvement and were determined to do so. Extra lessons were always attended - even when they were not required to be there (just in case they missed something they were unsure of), extra examples were completed, and they were even prepared to stay late (sometimes after 17:00) if there was a particular problem they could not understand. They were willing to put in the time and effort to succeed. The percentage of pre-service teachers in this category was lower than previous years: 30% of those who failed, compared to 40% the previous year. It is possible that good use of the specimen paper as a focus for revision accounted for this rise in pass rate.

The remaining people according to Bandura (1994) are

people who doubt their capabilities, shy away from difficult tasks which they view as personal threats. They have low aspirations and weak commitment to the goals they choose to pursue. When faced with difficult tasks, they dwell on their personal deficiencies, on the obstacles they will encounter, and all kinds of adverse outcomes rather than concentrate on how to perform successfully . . . . They are slow to recover their sense of efficacy following setback or failure (p. 71).

This group, following observation, were divided into two categories, the *Ostriches* and the *Mañanas*. The *Ostriches* refused to believe they had a problem. These were pre-service teachers who, in the previous year, chose not to attend any extra classes. Their lack of knowledge was attributed to other factors: "I did it a different way in my school"; "I never did statistics". They could not see the significance of their lack of knowledge, and believed it would all be fine when they got to school – after all they have a GCSE in mathematics! They stuck their head in the sand and waited for the end of the course.

The *Mañanas* knew they had a problem but never quite managed to do anything about it. On an intensive PGCE course there is always an excuse to avoid extra work, if you need one: "I can't come to extra mathematics today, my assignment is due tomorrow and I haven't done it yet"; "I won't come to the extra Shape lessons, I'm doing fractions next teaching practice. I'm going to concentrate on that instead".

Avoidance of tasks which are viewed as personal threats, or activities and situations that are believed to be beyond ones' coping abilities is a sign of low self-efficacy (Bandura, 1994, p. 75). It was surprising how many weddings, doctors' appointments and job interviews happened to be on the same day as our audits! This was a delaying tactic - they of course, had to take the audit at a later date.

## Conclusions and Issues Raised

A number of conclusions and issues were raised as a result of the continuing project. The introduction of a specimen paper increased the pass rate in the initial audit, and partially alleviated the subsequent drop in confidence experienced by pre-service teachers in previous years. Although misconceptions and errors were still prevalent, they were addressed within the extra mathematics classes.

The initial audit will continue to be used to examine pre-service teachers' mathematical knowledge to the end of Key Stage 2 (the end of primary school) as it appears to be an effective way of ensuring the knowledge necessary to embark on practical placement. At present the Government requirements expect pre-service teachers to demonstrate knowledge of *all* parts of the curriculum. In previous years a mark of more than 66% has been required to pass the audits. This implies there are areas of the curriculum in which some pre-service teachers would not be competent, as they may have a third of the audit incorrect. This does not appear to meet the requirements of *all* as specified by the Government. Can we impose a 100% pass mark? A higher pass mark will be used in future, which will only allow a few errors. Pre-service teachers will be notified of this through pre-course



information, as many will be familiar with a pass mark of nearer 50% in their academic studies.

The higher level of mathematics required by the government must also be audited, but does this mean formal testing? The testing process can be traumatic for some pre-service teachers, who have low confidence or negative experience of mathematics tests in school. Therefore the direction for future years will initially be to trial a portfolio approach, where pre-service teachers will be expected to complete a portfolio of work – answering questions designed to meet the requirements. Support will be given through formal classes, peer-led sessions (which have received favourable reviews in previous years), and self-study through a variety of resources. Previous qualifications gave no indication of test performance, nor of confidence in mathematical ability.

It seems that failure gave some pre-service teachers the impetus needed to improve their mathematical knowledge. Unfortunately, these were in the minority. For the majority of pre-service teachers who failed, it appears that avoidance or disbelief were the common traits. These traits cannot be ignored. Pre-service teachers need to be made aware that they do lack mathematical content knowledge and of the need to attend to this lack of knowledge. They were unaware of the implications this lack of knowledge could have on their, and their pupils' futures.

We, as teacher educators, need to address the lack of subject content knowledge, and attend to the low self-efficacy of many of our trainee teachers. Addressing the lack of subject knowledge has previously been carried out in a supportive environment, but we need to continue to do this in a way that causes pre-service teachers to confront their deficits while improving their self-efficacy.

Informal responses from the pre-service teachers indicate a variety of factors that can be seen as contributing to their low self-efficacy. Many of the students' causal attributions for failure are usually attributed to external factors and can therefore be remedied. Consider the following statement by way of example, "I've never seen that method before"; pre-service teachers can be shown that a variety of methods are acceptable and often necessary, and that the new methods or topics can be mastered. This needs to be achieved in small steps where they are involved in the goal setting (Bandura, 1997). The pre-service teachers need to be made aware that effort and ability are not the same and that with effort they can achieve their goals – they may not be the 'best mathematician' in the class, and it may take more effort, but they can succeed at mathematics and improve their self efficacy.

The intention is to continue to monitor the effect of course changes on pre-service teachers' knowledge and confidence, and how they can best be supported in their various needs. It is proposed to include more detailed formal interviews and observation of the mathematics classes they teach, and feedback from pre-service teachers who have since entered the profession and can evaluate the course and knowledge gained in the light of their teaching experience.

It seems clear that there is a lack of subject knowledge in mathematics amongst many pre-service teachers and that this must be remedied, but several key issues have been raised:-

Is the entry requirement of a GCSE a valid indicator of mathematical knowledge?

Is the ability to evaluate higher-order mathematics problems a valid indicator of a pre-service teacher's ability to master what is to be delivered at primary school, especially when the two are sometimes unrelated?

The content of the course cannot be changed (it is a statutory requirement) but the psychological underpinnings can be. The mathematics is presented in a positive and supportive environment, but can more be done to improve the confidence and self efficacy of the pre-service teachers?

The Government's recent *Requirements for Courses in Initial Teacher Training* (DfEE, 1998) expressed concern regarding the confidence and competence in mathematics of trainee primary teachers. They have detailed the way in which pre-service teachers' lack of competence must be addressed, but confidence cannot be neglected.

People need a strong sense of efficacy before they will try to apply what they have learnt and before they will try to learn new things... Refer to it as 'self-confidence' if you want to, but the fact remains: Skills unaccompanied by positive self-efficacy will lead to deficient or absent performance. (Mager, 1992, p. 36)

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