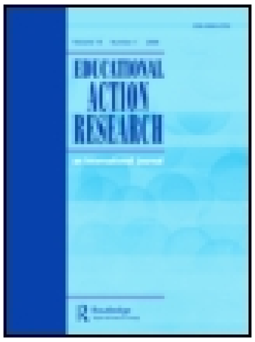

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Numeracy through Literacy

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Numeracy through Literacy

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ABSTRACT This article describes an investigation of how language is used in learning mathematics. An English teacher and a mathematics teacher videotaped a group of students working through a mathematics problem. The focus of the research was to consider students' use of language (in both oral and written forms) to express their mathematical understanding. The research highlighted the significant part language plays in learning.

This is a report on a small research project carried out jointly by a mathematics teacher and an English teacher. We began this research because we were both interested in the role of language in the learning process. We wanted to explore how students use language in order to think through concepts, express and communicate their learning. We wanted to consider their use of language in both oral and written form. The format of pupils working through a mathematical problem gave us a vehicle for this exploration.

The written form of communication has become especially important in mathematics in view of the recent introduction of the National Curriculum in England and Wales which affects General Certificate of Secondary Education (GCSE) assessment at post-16. The revised National Curriculum for Mathematics consists of four Attainment Targets; the one that is pertinent here is Attainment Target 1 – Using and Applying Mathematics. This contains phrases such as 'pupils discuss their mathematical work and are beginning to explain their thinking', at Level 3 and 'Pupils make general statements of their own, based on evidence they have produced, and given an explanation of their reasoning', at Level 5. Level 3 is the attainment expected by the average child at the end of the primary school and Level 5 would be the attainment of an average pupil at about 14 years, according to government guidance. The statements at higher levels (they extend to Level 9) include more about the explanation and justification of the different strategies used and generalisations discovered, always referring to substantial tasks and complex problems.

In order to assess this type of work, it is essential that the students produce a written account of their strategies, reasoning the discoveries. The written account may not be the only way teachers can know about their students' capabilities but it is the only practical, explicit way in which they can prove that they know, for the purposes of external assessment. The written record resulting from students' exploration of a mathematical problem must therefore display each student's abilities and thought processes as completely as possible. Unfortunately, the mathematics teacher could point to incidents from his or her own classroom experience where the written script did not show all of the strategies that had been considered by the students, or the reasoning that had gone on. This intuitive feeling, that students were not making a complete record of their mathematical reasoning, was strengthened by an article by McNamara & Roper (1992) which showed students to be reluctant to record alternative strategies or the reasoning behind their results. From the first years at secondary school and in many primary schools, these students had been asked to write about the mathematics problems in which they were engaged but it appears that the students were still unable to express their mathematical thinking in written form. They did not appear able to write clear explanations of their inner thinking processes.

It seemed important, therefore, to try to identify some of the stumbling blocks that inhibited the students from producing a full written account of the mathematics they had been using. The decision to focus on the role that language in all its forms, spoken, written and symbolic, plays in learning mathematics seemed inevitable in view of the written account being the expected culmination of a problem-solving process. Linguistic skills are demanded more and more in the mathematics classroom to fulfil the National Curriculum requirements and it would seem that, if students were helped to use language more effectively, they would be able to construct and explain mathematical ideas more successfully. Greater competency in language use may help them develop their mathematical skills and become confident in their use. This in turn could help them to be more confident in recording all their thought processes and discoveries in writing. These beliefs are based on work from several sources providing insight into the potential link between mathematics and purposeful use of language.

The transition from the spoken to written word is problematic. Pimm (1987) explains that there may be tentative thoughts which are hard to pin down in written symbolic form. The work of the National Writing Project pointed out conflicts in using written language caused by the artificial constraints imposed by teachers' expectations of accuracy and correctness.

> *The trouble with most school writing is that it is not genuine communication. When adults write they are usually trying to tell someone something he doesn't know; when children write in school they are usually writing for someone who, they are well aware, knows better than they do what they are trying to say and who is*

concerned to evaluate their attempt to say it. (Martin et al, 1976, p. 29)

The language the students are required to use could be beyond their linguistic and cultural experience. Mathematics expects accuracy and specific expressions which are not generally featured in ordinary conversational spoken language. Laborde (1990) asserted that lack of language competency could be a barrier to mathematical understanding. It inhibits students exploring their own hypotheses. The popular feeling of mathematics being hard to understand may be due to an inability to comprehend metaphorical use of language rather than mathematical concepts.

Borasi & Siegel (1994) assert that students should be enquirers and makers, not receivers of knowledge. To them, genuine learning requires genuine communication, entailing the use of language in an interactive way: "rather than simply telling the student what to do and how to do it, inquiry teachers demonstrate such processes as formulating questions and extending them so that they are substantial and require students to make new connections".

Pimm's (1987) research on the use of metaphor in mathematics is relevant. He claims that students often seem unable to interpret metaphors, which causes problems, as much in mathematics is expressed in metaphor using a prescribed vocabulary. As will be shown later, the students in the research struggled to find the language to describe a relationship in clear, unambiguous language to the English teacher. It may be that this had to do with the unperceived need to use metaphor. The word 'face' to describe part of a cube is a direct form of metaphor. To quote Pimm (1987), because of this common use of metaphor, students do not recognise this non-literal use of language: "there is nothing to indicate they are grappling with something new".

One of us, a teacher of English, was involved in a larger project investigating the specific language skills being used in all parts of the school curriculum and this project would give her an opportunity to observe at first hand the difficulties involved in language use in mathematics (Lawson, 1994).

We decided to study a group of four Year 10 students working collaboratively on a mathematical problem typical of a GCSE assessment assignment. The research looked at a situation where the need for clarity and accuracy in language use were important. The GCSE assessment criteria require students to investigate a mathematical problem by hypothesising and making deductions and to produce a written record of the strategies and thought processes involved. Evidence is also required of systematic working, predicting results and checking their veracity. The students should make generalisations from the particular problem they are engaged in and provide explanations and justifications for them. By studying students involved in investigating mathematics, we would be able to consider potential benefits or impediments to learning caused by language. Did language help them construct their learning or obstruct their understanding? Were they able to use language to express what they knew and what they discovered or learned?

We planned to observe the students tackling the mathematical problem to provide our data in various ways. The most important of these was the video recording of the proceedings which would provide the basis for future analysis. The English teacher, as part of the student group, could provide direct insights and observations of the process of students investigating the mathematical problem. The mathematics teacher became an observer after initially explaining the problem to the group. The English teacher took on various roles within the group: of observer, audience, non-expert. The intention was to challenge the students by reversing their normal working pattern by placing a teacher in the role of non-expert. It was clearly explained to the students that the English teacher was unused to this investigative method of working in mathematics. In this situation, she could ask for explanations of their understanding, providing the need for clear and effective language.

By becoming part of the group the English teacher could intervene in the group's learning in order to gain a unique picture of how language was used in mathematics by each student. The mathematics teacher could observe what happened to their mathematics when the students' language competencies were challenged by someone used to dealing with language as a discipline. The use of clear, precise language was important if the English teacher was to follow the workings of the group. It was apparent to all members of the group that she did not share the knowledge of this type of working that the students had built up in mathematics lessons. It was expected that they would be prepared to include the English teacher in their ideas. We also expected that paying particular attention to the language they used to express their ideas orally would help them record that language in written form.

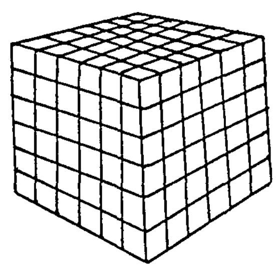
From our reading and other research, we had identified common principles, underlying students' use of language needs in English and mathematics. We considered that students' learning is improved by giving them greater control and ownership of the learning process. Students need to use their own vocabulary in formal language culture to think through their ideas, to formulate and articulate learning in spoken and written forms. They also require a sense of audience, to whom they can present their findings, discuss their ideas and gain a response. Talking and writing in the learning process enables students to reflect upon and analyse their learning. An important factor was the need to establish a learning context based on interactive communication; on the need to write for an audience who would respond by listening, reading, questioning, challenging, encouraging. It is at this direct point of communication that the most effective teacher intervention in learning can take place.

The purpose of our research was to consider these ideas in relation to the way in which the students worked through a mathematics problem. We considered particularly the way in which students used language to think through their mathematical understanding and their ability to express their understanding in spoken and written forms.

The Task

The group used in this research were Year 10 students, taught by both teachers. They were confident that they knew what was required of them in a mathematics investigation and were competent users of spoken and written language. The mathematics teacher presented the task and explained the requirements of the task. Much emphasis was placed on clearness of expression and working as a group. They were asked to be sure that everyone in the group, including the English teacher, understood their ideas and ways of working.

THE PAINTED CUBE



Imagine that the six outside surfaces of a large cube are painted blue.
The large cube is then cut into 6 x 6 x 6 = 216 small cubes
How many of the small cubes have: 0 blue faces?
1 blue face?
2 blue faces?
3 blue faces?
4 blue faces?
5 blue faces?
6 blue faces?

Now suppose that you cut the cube into n^3 small cubes ...

Figure 1. The painted cube.

The task set was an investigation well known to mathematics teachers called 'The Painted Cube' (Figure 1). In this investigation, the students are presented with a cube that has had all its sides painted blue. They are asked to imagine the large cube sliced into smaller cubes, initially 216 smaller cubes, by cutting each side evenly into six. They are then required to investigate the numbers of these smaller cubes that have none of their faces painted, one of their sides painted, two of their sides painted and so on. They are asked to generalise their findings for other numbers of smaller cubes and provide reasons why these generalisations are true.

The Students' Activity

The students begin tentatively, working with their own ideas. They speak in short phrases, mainly just numbers. One of the group says: "Shall we just work out each of them?" By the general murmurings, it appears that the others in the group, except the English teacher, know what she means and agree to do that. Several times, the English teacher asks for an explanation of what they are doing but although they are polite, none of the group are willing to spend time explaining to her what appears to be common knowledge among the others. Twice, the student attempting an explanation for the English teacher is interrupted by another student and returns to a conversation with the others. The conversation is made up of half finished sentences, often containing mathematical operations but never related specifically to the problem. For example:

L: Times by six because there are six faces.

G: No, that's not going to work.

L: Oh yes, we're doubling up on those again.

The part where an observer finds out what L is suggesting, 'you times by six', is not missed out; it is not there. However G seems to be aware of what was being suggested. They reach a consensus about many things by using this implicit type of conversation. They seem not to need to use specific nouns to communicate ideas between one another. The verbalisations are transient, sometimes seeming to change to a different idea as the speaker is talking. From the way the conversation goes, the members of the group generally appear to keep up with one another's ideas without the references being any clearer to the 'outsider' who does not share their understanding. They seem to share a knowledge of what the others are thinking about. The English teacher is very left out at this point, as the conversation is impossible to follow without 'insider' knowledge. When asked for clarification the students were unable to provide it.

They reach a consensus about methods but make no attempt to use a vocabulary which would enable them to refer specifically to the parts of the cube they are dealing with. This does not seem to disadvantage them in the discussions which go on, but does hamper them later when attempting to write down their ideas. They do develop a system to answer one part of the problem, which, because of the way they have looked at it, is hard to justify. No one in the group seeks to find an alternative way of solving the problem but a lot of informal discussion goes into justifying the system they have developed.

The next step they are required to take is to write down both the generalisations they have developed and an explanation of those generalisations related to the cube. This proves to be a difficult task. They try to make excuses for not writing a full explanation but the continue to rack their brains to translate their inner thoughts and workings into words.

> *T: Did that work then? What was it? What did you do?*
>
> *G: Well I took two from that. [points]*
>
> *T: Why?*
>
> *G: Because um ... that's the length here [points] 'cus there's six there six there and um ... is it ... yea here which adds up to 216 so um ... I just used four here so this like cube here has only one painted face on so times that by six, that should say six so if you used a different cube like this cube you always lose two of what you started with 'cus like if there's five times five, that and that ... they take away two from five which leaves three.*
>
> *L: That's three times three then you times it by six.*
>
> *F: Why do you times it by six?*
>
> *G: 'cus that times that gives you the area.*

They seem unable to use specific terminology to express their mathematical conclusions. Is it that they have never picked up the proper use of 'faces', 'edges' and 'corners' in relation to a cube, or are they unwilling in this group situation to use words which others are not using?

The ideas discussed earlier from Laborde and Pimm seem to be demonstrated here, as the words needed here are metaphorical in origin and not part of their ordinary conversational spoken language. They produce a first draft of a written report after about an hour of discussion. The first draft is submitted to the English teacher, who reads it through and asks for clarification of some of the wording. The algebra contained in this first draft is well formulated. It is the explanation of their algebraic generalisations which is ambiguous. The clarification given to the English teacher by the students involved a lot of pointing at diagrams on the papers they are working on. They accepted the need to produce a better draft. The second written draft proves to be a lot more difficult to write than they envisage and despite a lot of discussion, they never pin down exactly what they want to say. In the words of one student, "I know what we're doing, I know why we're doing it but I don't know how to explain it".

Analysis

What does all this tell us? It seemed that the students were able to go from their tentative and tenuous statements to symbols fairly easily. Having established some figures they wrote down an expression in symbols. They related the symbols to the numbers they had tabulated rather than to the physical attributes of the cube. This process seemed to be almost mechanical, not related to the specific requirements of this problem. Having obtained a set of figures they set about finding some algebraic symbols to represent the figures. However, the figures became divorced from the reality they were meant to represent. The students encountered problems when they were asked to explain to someone with no insider knowledge what they had done and why they had done it: "We times it by two 'cus we do 'cus it works. We can't times it by six 'cus we've used some cubes twice".

> *F: We don't do it for any reason, we do it because it works.*
>
> *M: Voice of reason!*
>
> *G: It works but we're not sure why.*
>
> *F: We are.*
>
> *G: I know what we're doing, I know why we're doing it but I don't know how to explain it.*

We asked ourselves whether this was because they were used to mathematics being divorced from real situations. It may be they are used to mathematical problems starting with physical situations which give rise to a set of numbers which then can be dealt with as abstract entities in themselves. Whatever the reason, the students found it hard to find the language to make their meaning explicit. The search for an explanation based on the physical attributes of a problem seemed alien to them. It seemed to be writing down explanations, going from a concept in their heads to a permanent record, that presented problems.

Their natural way of discussing their work is in short, unfinished phrases. They point at drawings or use their hands, but rarely use a noun to reference what they are talking about. Mathematical explanations, in contrast, have a prominent use of nouns and adjectives. The 'good' mathematical explanation dispenses with person and time. A sentence from one of the group studied, "You take away the outside and then you're left with them in the middle", is not found in mathematics textbooks or in a teacher's writing. There seemed to be a conflict evident between the informal spoken explanations they gave using their own language and the students' own expectations of the more formal written explication required by the teacher, which needed to be structured and accurate.

We considered several possibilities which may explain the students' inability to express their mathematical deductions with the competence and confidence which reflects the ability evident when tackling the numerical and algebraic aspects of the problem. The difficulties involved seemed to be in the use of specific subject terminology and the difficulties inherent in the structuring and development of expressing concepts in writing.

Subject Terminology

The research indicated a reluctance on the part of students to use subject specialist terminology. They seemed afraid to use non-familiar terms, especially in front of a teacher. In fact, they avoided using even the simplest mathematical vocabulary, preferring to refer to 'things' and 'it', rather than specific terms. The vocabulary they did use had been introduced in Years 7 and 8, seeming to indicate a lack of progression and development of use of subject terminology, or demonstrating the length of time it took to become comfortable with these terms.

The mathematics teacher had encouraged the students in their lessons to experiment with using language to express mathematical ideas in order to develop their confidence and expertise. However, broader research undertaken by the English teacher, in language and learning across the curriculum, indicated that their use of terminology may be inhibited by other teachers' expectations. Teachers across the curriculum varied in their expectations of students' writing. Students were faced with different expectations from subject teachers. The form the writing had to take, for example, in writing an essay varied from subject to subject, as did the emphasis on different aspects of writing. The emphasis could be on neatness of handwriting or accuracy of spelling, punctuation and grammar.

Writing was used most often in copying from the board or a textbook. There was little evidence of its use as part of a formulating process, or for articulating ideas. If redrafting took place the emphasis would be on tidying up the handwriting, spelling, etc. and not on developing and extending ideas. The idea of using writing as a medium to formulate hypotheses, develop and extend a line of argument was very rarely found. Teachers in some subjects required a high degree of spoken and written accuracy in the use of subject-specific terminology, without developing feelings of ownership or confidence in its use. The lack of emphasis on students' own use of language may be a possible explanation for students' inability to use the language of the subject to make sense of their understanding.

It seemed important to us that classroom practice should create specific teaching contexts, which provide purposeful reasons for students to use subject-specific terms as a familiar part of their learning. Confident use of specific language terms should be developed through strategies such as collaborative learning, talking, deliberately aimed at sorting out ideas and concepts. This is not an easy task. The research we looked at earlier and other research completed by both teachers (Lawson, 1994; Lee, 1994) indicates that the process of becoming familiar enough with subject terminology to be comfortable with its use is a lengthy one. However, being constantly aware of these difficulties has changed classroom practice for the mathematics teacher. Mathematics lessons often start as vocabulary lessons as students are invited to say new words out loud, then in context and be aware they are "grappling with something new" (Pimm, 1987). Every opportunity is taken to familiarise the students with the words they need to know to gain an understanding of the subject, examination credit and confidence in expressing their knowledge for successful achievement.

Structure and Development of Writing

The written outcomes of the investigation were not well structured; there was no cogent argument or explication. The students wrote in note form, related to the diagram and text model in the textbooks they were familiar with. The writing at this stage did not convey a coherent or sequential explanation of the mathematical problem and their conclusions.

Students seemed surprised and not able to understand why the English teacher could not follow the logic of their written explanation. She had watched and in some occasions joined in the development of their thinking about the problem but the students appeared to be unaware how little literal sense their words made out of context, and as an English teacher that is what she was looking for. They did not seem to be considering the wording of their explanation. They were primarily concerned with completing the task, rather than clarifying and developing their ideas. Transferring their ideas from spoken to written form presented problems. They found it difficult to find words which would express their shared visual and spoken understanding. The students claimed that they knew what they wanted to say but could not put it into words. The mathematics teacher was frustrated by their inability to use subject terminology and the English teacher was frustrated by their inability to communicate meaning.

The students were specifically asked to redraft their explanations after discussions with the English teacher had identified ambiguities and lack of clarity. The redrafting, however, showed very few changes in terms of reshaping, clarifying and refining thought. One student dictated and the other copied down, with no questioning or challenging of the reasoning behind the writing. The second draft was neater and some vague terms had been replaced by specific nouns. 'It' was replaced by cubes and 'things' by columns.

The purpose of redrafting is a complex issue. From the English teacher's wider investigations it seems that teachers and students in some subjects understand redrafting to imply simply copying up a rough draft neatly, having corrected spelling and punctuation mistakes. There is little awareness of the wider implications of redrafting, i.e. requiring students to consider and reflect on the meaning and coherence of their written work. In mathematics, writing should be perceived as an integral part of the curriculum, used as a means of formulating and recording full explanations of each skill and concept as they are encountered. This is now standard practice in the mathematics teacher's classroom. Here, every piece of writing is also a scrutinised writing, with neighbours being the initial and most common audience, but also wider contexts used to encourage clarity in expression. This is following the standard experience in the English classroom in an attempt to provide a common demand on children's writing to be clear and understandable in a range of contexts.

However, students often perceive writing as a tedious, laborious task and are not always willing to spend time on effective redrafting. They tend to be too easily content and the teacher already knows what they want to say. It is written neatly. What more could the teacher want? Whilst acknowledging the pressures of curriculum constraints, it seems important for teachers to recognise that sufficient time is required for students to rehearse their knowledge and practise the communication of ideas in both spoken and written forms. This will enable them to extend and reshape their understanding, thereby gaining familiarity with the subject and confidence to express their ideas competently.

The role of teacher as reader/audience of the writing may inhibit students from writing what they really mean, as they perceive the subject teacher to be the expert, who already knows and there is therefore no need to make their own meaning explicit: "We don't need to say it because the teacher already knows" is how one girl puts it in the research.

This has implications, in terms of providing a variety of 'audiences' to whom students can present their investigations in less threatening circumstances. An audience provides a reason for students to be clear and specific in their explanations. Students working in groups can provide the sense of wider audience to test their theories against and verbalise their inner thoughts. There are, however, problems inherent in working collaboratively. They may develop shared understandings which, although expressed in disjointed language, are understood within the confines of the group. This may be beneficial as a first step towards a coherent written record but the group can easily give weight to an erroneous idea. Indeed, someone who has difficulty keeping up with the group may feel confident in the information they have picked up from the group which may be incomplete and inaccurate. Problems in understanding and communication may easily arise as a result of differing paces of language use and assimilation of concepts. Even so, collaborative situations sensitively used, can help the students formulate their understandings and increase their confidence in expressing ideas, which should help them when transferring their spoken understanding to the written form.

Other audiences could be considered to enhance the student's need to speak and write clearly and fully. Perhaps a group of 11 year-olds could be helped to understand the skills involved in investigating mathematics by a group of 15 year-olds, by the older students taking the younger through a problem. Insights could be gained on all sides.

Conclusions

Our research has revealed the complexity and huge range of issues relating to the process of language and learning in both subject disciplines. There do appear to be principles underlying the teaching of mathematics, through the use of language. Students' understanding of mathematical concepts may be acquired through the common use of language skills such as: spoken discussion; written explication; questioning; formulating hypotheses;

understanding terminology; imagining and symbolic interpretation; and listening. All these are part of the English curriculum, and indeed form part of all subject disciplines, since using language is fundamental to effective learning. It would seem that students' competence and confidence in studying mathematics could be enhanced by greater proficiency in language skills. However, there may be insufficient awareness of the importance of the role of language in the construction of understanding in mathematics. The National Curriculum must bring greater interest in this issue as teachers of mathematics at all levels attempt to implement the demands of Attainment Target 1. How requiring younger children to discuss mathematical ideas will affect older students' competence in producing written records of their discoveries remains to be seen. There are reasons to hope.

Evidence is available to suggest that teachers may be restricting students' learning by their more formalised expectations of language use. Using language as a means of reasoning and justification must be developed progressively throughout a student's time at school. It must not be assumed that they will discover how to do this by themselves. Language use is not just a problem in mathematics; it is a whole school issue. Increased awareness and understanding of language and its significant role in learning should result in more effective teaching and learning across the curriculum.

As a mathematics teacher this investigation has brought home many messages relevant to my practice. It was an unusual position to be in, observing the students trying to use language to include someone who did not share the understandings that I shared with them. There were ideas that I understood perfectly but the English teacher's lack of understanding showed up the deficiencies in their arguments or descriptions. I had met these deficiencies before in their writings and it became clearer to me that language use in my classroom needed to be improved in clarity if the students' writing was to improve. Their inability, or was it unwillingness, to use specialist terminology came as a surprise. Do I usually supply the 'correct' term myself in conversations with the students? As has been mentioned already, I have taken steps to make sure the students are more aware of these specialist terms and I hope they will become more confident with their use. I gained insight into the difficulties presented by subject specialist terminology, particularly the metaphorical use of language in mathematics. I am more aware of the need to stress that redrafting means rethinking and use methods common with the English department to achieve this. A greater awareness of the problems presented to the students by being required to express their mathematical ideas in language has led to an ongoing emphasis in my classroom on developing the required skills.

As an English teacher, I found the opportunity to participate in a mathematics 'lesson' to be most illuminating. As a student myself, I had struggled with the student and had developed an antipathy to numbers, or anything vaguely 'mathematical'. Sitting in on the group of students working through a mathematical problem was a revelation to me. I had been taught mathematics very directly through the passive, transmissive teacher talk and chalk process. My most vivid mathematical experience was of being called out by the mathematics teacher to work through a quadratic equation on the board; this was his method of helping me to understand the process. I still remember the sense of stigma, the failure and embarrassment of working out this equation directed by the teacher in front of the whole class and my subsequent lack of confidence in mathematics. I still did not understand how to solve quadratic equations although I had gone through the mechanical process.

I was therefore totally unfamiliar with the concept of mathematical investigations and did not realise how much writing this approach required. I was struck by the similarities underlying the two subject disciplines. The idea that mathematics students would be grappling with metaphorical concepts and symbolic images was new to me. Most of all, the fundamental importance of using language as a means of formulating and articulating knowledge became apparent. The need to discuss and share ideas as a means of extending and developing learning is just as important in mathematics as it is in English.

It emerged that students' competency in using language was clearly an influential factor in expressing and communicating their mathematical understanding. If a student could not read and comprehend mathematical language they could not progress in their learning. The specialist terminology was another added impediment to presenting their findings with confidence and understanding.

The importance of writing was emphasised through the requirements to express a hypothesis and present written arguments in support. This seemed the most difficult skill for the students and the one in which the mathematics teacher felt least able to offer support. This problem was identified by my own research evidence across the curriculum, which indicated that the development and extension of students' ideas in writing proved to be a major impediment to both teachers and students. This research has identified the need for competency in using language as a means of learning to be developed in all curriculum subjects.

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