MA THEMA TICS IN THE PRACTICE OF VOCATIONAL SCIENCE

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As a window onto the mathematical practices of science students, a project working alongside people studying vocational science courses (GNVQ Advanced) is currently in progress. Through classroom observation, analysis of course materials, individual interviews and diagnostic tests, a picture of the students work with mathematics-inscience is emerging. The practice of converting between units of measurement has been analysed in depth. Converting is a critical aspect of science, drawing on several mathematical ideas. In this paper we present a summary of our analysis of students converting practices in a test situation, and describe an episode of converting in chemistry.

Introduction

In England and Wales, increasing numbers of 16-19 year old students are choosing to study new vocational qualifications as an alternative to the more academic' A' levels. The qualifications GNVQSl - are a competence-based qualification covering areas such as Leisure and Tourism, Manufacturing and Business Studies and more recently, Science. All students studying for these vocational qualifications must cover the core skills of communication, information technology and application of number as well as their subject studies. Further Education colleges (who are the main providers of vocational courses) differ in their approaches to the integration, or otherwise, of the core skills into the main subject (FEDA, 1995). Traditionally, mathematics has been taught as a separate subject to science students, but with examples often drawn from science. One view influencing teaching of these vocational courses centres around the idea of teaching mathematics in science contexts, sometimes within science lessons. This assumes that if mathematics is taught in this way, students will be more motivated to learn it and more readily able to use it, in science.

We are currently engaged in a project working with two groups of vocational science students with the aims of:-

- characterising the mathematical practices of these science students,
- investigating the advantages and disadvantages of the GNVQ approach to teaching mathematics in context,
- investigating the role of computer-based activities in the development of mathematical competencies the students.

At present, we are studying which mathematical practices the students engage in and how these practices are influenced by the ongoing science activity. From initial analyses of the GNVQ Science 'curriculum', a diagnostic test taken by the students and from extensive observations of classroom

1 GNVQs can be studied at Foundation, Intermediate and Advanced level. An Advanced level GNVQ is equivalent to two 'A' levels.

interactions, several mathematical ideas were identified as pivotal. We started our analysis of mathematical practice with an in-depth study of the area of **converting between units of measurement,** an area where mathematical and scientific ideas are intimately related.

The project is influenced by the work of Vygotsky, Wertsch and Lave. We take a socio-cultural approach to mind, which means we attempt not to separate mental functioning (or action) from the contexts in which this action takes place. The 'agent-acting-with-mediational-means' is taken as our unit of analysis and as Wertsch (1991) has pointed out, "mediational means shape the action in essential ways". In our work, mediational means include laboratory equipment, calculators, graphs, algebraic representations etc. We also draw upon Lave's idea of 'structuring resources' (1988) and take the view that 'mathematics' can give structure to and be structured by, other ongoing activities.

Methodology

The project is being conducted with groups of GNVQ Science students at two Further Education colleges in different English cities.

The first phase ofthe project involved the design and administration of a 'diagnostic' test, as one angle on the mathematical practices students brought to the science course. The test covered several mathematical areas including, ratio and proportion, algebra, trigonometry and converting between units. The test design drew on GCSE Maths, GNVQ application of number criteria and knowledge of the critical mathematical ideas used in science. Questions from past examination papers (GCSE Maths and Science, Scottish '0' grade) and created questions, were presented in a mixture of science and more abstract contexts. Some conversion-related questions were;

A) Circle the larger quantity,

1×10^{-3} kg or 10g

B) Convert the following quantities;

a) 350g into kilograms

d) $5^1/_2$ hours into seconds

e) i) $45cm^2$ into $metres^2$

C) A ball bearing has a mass of 0.44 pounds. Calculate the mass of the ball bearing in kilograms. (1 kg = 2.2 pounds)

D) Write a formula to convert, grams G into kilograms K

K=

Follow-up interviews were conducted to elicit students own explanations for their ways of working on these questions. Phase two of the project involved extensive observation of the vocational science classrooms. Both 'theory' and 'practical' sessions were observed and student's notes and assignment work were also collected and photocopied for analysis. Phase 3 of the project, which will not be discussed here, concerns the design and evaluation of teaching scenarios aimed at supporting students in the development of particular mathematical ideas.

Characterising student's conversion practices

The topic of converting between units of measurement was analysed in depth using all the data sources available. Converting was chosen as the first area to study because of its critical importance in science practice in general and also because the classroom observations and test data showed converting to be of interest in terms of opportunities for studying mathematics-in-practice. Conversions are an integral part of scientific practice for many reasons, for example,

- to allow for ease of data processing
- to enable comparison and standardisation
- to support understanding of physical quantities and processes

The importance of converting arises from the integral role of measurement in science. Often measurements are taken which need to be transformed in some way, for the reasons above amongst others. The role of converting has been recognised as important within the framework of GNVQs and several references are made in the application of number criteria studied by all GNVQ students, not just science students. Thus it is crucial that the science students become competent in this area.

Diagnostic Test

Several important points emerged from analysis of the test data and follow-up interviews. We found that the students approached the solution of conversion problems in many different ways. For example, when asked to convert $5^1/_2$ hours into seconds, some students converted the '5' and the ,1/2, separately, then added the result, whist others worked with the $5^1/_2$ as a whole number. Although both methods generally led students to correct responses, we conjecture that working with parts rather than the whole mitigates against developing any generalised notion of a conversion relationship.

The majority of students were successful at converting single-step metric quantities, for example, 200mI into litres. However, the majority of students were unsuccessful at conversions involving standard form notation and units with indices, for example the questions, *convert* 1 *x* 1 *(jm* into millimetres, and *convert 45cm^2 into m^2*• The most common response to the latter question being $0.45m^2$, that is carrying out the calculation 45 + 100 and not paying attention to the unit dimension. The majority of students also had difficulty in expressing conversion calculations formally, for example, *write an expression to convert millilitres Minto litres L,* although the performance of a specific conversion immediately preceding a request for formalisation did support some students in the formalisation process. Once generated, formal expressions were used by a few students as a resource in the calculation of further specific conversions.

Throughout the test and interviews, it was noted that the students used calculators extensively, and in particular ways. For example, when converting, say 200mI into litres, many students would both multiply and divide the 200 by 1000, and then decide which answer to accept and write down. Access to the calculator allows a student to work in this way but in addition, tacit understandings of qualitative relationships are also drawn upon as resources in the students problem solving processes.

Conversions in classroom practice

The practice of conversions was found to be prevalent in the student's classroom and assignment work. In many ways the students were experiencing converting as a practising scientist would, that is, the science situations encountered created the need for students to engage in conversions due to the large amount of measurement activity and data processing required. Conversions in the student's science experience could also be characterised as *embedded* and *implicit.* That is, the practice of converting was usually a minor element in a much larger, complex science problem and often the actual converting between units was not explicitly drawn attention to. Some of these ideas are illustrated in the following accounts of conversions-in-practice at one particular college. The chemistry lessons at this college are often divided into a 'theory' session, held in a normal classroom, and a 'practical' session where the students move into a chemistry laboratory to conduct experiments. In one 'theory' session the students worked on three questions, on a photocopied hand-out, based around the topic of 'equilibrium constant'.

> The students had laboured over the first two questions. They went on to question 3) on the hand-out. The tutor had pointed out that this question was very relevant to the practical work they were about to do. The students read through the question and the tutor asked them questions relating to the science of the situation, for example, "what is the titration doing ?" He wrote on the board the words,
>
> Amount of NaOH =
> reacted (mol)
>
> He then stated he was fairly sure that they wouldn't 'get this', even though they had done it on previous occasions. He asked "how do we work out how many moles of NaOH have been reacted ?" One student called out, "divide one by the other" to which the tutor replied "no". He continued to write on the board, completing the expression,

$$\underset{\text{reacted (mol)}}{\text{Amount of NaOH}} = \frac{\text{vol. soln}}{1000} \times \underset{(\text{mol dm}^{-3})}{\text{conc}^{\text{n}}}$$

> The tutor asked the students to "work this out".

The chemistry question being attempted was a complex, multi-step chemistry problem which the tutor guided the students through. The formal expression the tutor provided contained an *implicit* conversion from cm^3 to dm^3 signified by the division by 1000'. The expression was written on the board, in it's entirety, and with no accompanying explanation. The students substituted in the values given in the problem statement, calculating an 'amount'. The expression is somewhat complex and the direct question, "how do we work out how many moles of NaOH have been reacted ?" did not seem to offer students any support in reaching it. So, the tutor tells the students the expression they need, that is, he provides the information and structure, and just asks them to carry out the arithmetic. This may be because the expression is only a small part of the larger, important, chemistry problem and in some way he wants to de-emphasise the formal aspect.

The student assignment which followed on from this chemistry lesson was to write up an experiment on 'Determination of Equilibrium Constant for an Esterification Reaction' (an 'A' level textbook problem). The evaluation of equilibrium constant from their experimental data involved a series of calculations which students carried out by following a set of questions similar to those worked on in the theory lesson. The series of ten calculations progressively led to a value for equilibrium constant, using the students own data,

> Heidi worked through the series of calculations and successfully answered the questions, up to number 9 (out of 10). She correctly recorded the expression to find 'concentration' (concentration = amount / volume) and she also recorded the correct units for each quantity. However when carrying out the calculation, she did not account for the fact that her value for 'volume' was measured in cm^3 but the expression is valid only for volumes in dm^3• Consequently she substituted and evaluated an incorrect expression, obtaining concentration values which were incorrect by three orders of magnitude.

9. work out concentration.

$$\text{Conc}^n. / \text{mol dm}^{-3} = \frac{\text{amount of substance}}{\text{Volume of Solution} / \text{dm}^3}$$

ethanol,

$$\frac{0.0822}{10} = 8.22 \times 10^{-3}.$$

$$= 8.22 \times 10^{-3} \text{ mol dm}^{-3}.$$

Heidi had taken the appropriate expression, substituted her own calculated value for 'amount' and the given value for 'volume' but had neglected the conversion aspect of the problem. The complexity of the chemistry situation was such that it was difficult for the student to keep track of all aspects of the problem. Indeed, the series of calculations involved in the analysis of this particular experiment was very complex and it is unlikely that tutors would be able to keep track of such errors in an assignment either.

The expression Heidi used is the 'same' (in a rearranged form) as one she correctly used earlier in the same assignment, and was observed to use during classroom observations. In both the assignment and classroom the expression was presented in the following form,

$$\text{Amount (e.g. of NaOH used)} = \frac{\text{vol cm}^3}{1000} \times \text{conc}^n \text{ mol dm}^{-3}$$

That is, the conversion from cm^3 --> dm^3 was included, but presented in an implicit way. Heidi had no difficulty in her assignment in using the above expression to find 'amount', but when evaluating 'concentration' from the expression, neglected to include the conversion relationship.

The complex nature of chemistry calculations, and the implicit use of conversion factors, is also found in the text book which the students use (Nuffield, 1995), demonstrating that these features are aspects of the science culture in which the student is acting.

Summary

An analysis of responses to conversion questions presented in a test format, and students verbal explanations of their solutions, demonstrated that they made sense of conversion problems in many different ways. The vast majority of students were successful at straightforward metric conversions but were not successful with questions involving standard form notation nor when the units were of dimension >1 (e.g. cm^2). They often drew on qualitative strategies, along with calculator feedback, to make decisions about the quantitative problems.

Converting was observed to be prevalent in GNVQ Science classroom practice, however conversions were usually embedded in complex scientific situations and were often implicit. These points may contribute to the difficulties students were seen to face when trying to make sense of conversions throughout their science work. In the diagnostic test students were usually told to "convert" whereas in the science situation they must realise this for themselves. This recognition comes through an understanding of the science of the problem, not just the mechanics of converting.

Some students who had little success in the diagnostic test were seen to work appropriately within the context of their science work, indicating that the science practice may structure mathematical ideas in ways which do support students. However some students who were successful in the test seemed to have no access to resources to draw on in the science situation, or else utilised resources inappropriately. The challenge of the next stage of the project is to design and evaluate teaching scenarios that aim to support students in appropriating resources, fit for the purpose of their science practice.

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