Integrating Science and Mathematics Using a Spreadsheet

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Abstract
The paper begins with an examination of the case made for integrating science and mathematics using an approach in which science experiences provide the starting point for developing mathematical concepts and applying schematic knowledge. The project described in this paper began with a design task in which students had to create an economical and healthy food bar which meet certain nutritional specifications. Students were supplied with a table of appropriate nutritional data and an explanation of the way in which it could be used. Students began the task by recalling their knowledge of familiar products, such as muesli bars. This knowledge was used as the basis for an initial formulation which they checked against the specifications using the nutritional data. At this point students were encouraged to set-up a spreadsheet which would make it easy for them to systematically vary the composition of the food bar and thus its price. This proved to be an effective tool for solving this problem in which there were many variables.


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Introduction
The relationship between science and mathematics in schools has been debated for much of this century. There is a number of journals which deal with science and mathematics education including School Science and Mathematics and Journal of Science and Mathematics Education in Southeast Asia which represent this discussion. The relationship between science and mathematics has been viewed from different perspectives. Science providing opportunities for the application and development of mathematical concepts. Mathematics has been considered by some scientists as "both the queen and the servant of the sciences" (Jacobson & Bergman, 1980, p. 118). Some educators have seen science and mathematics as having a synergistic relationship not only because they deal with common topics but also because they share
teaching/learning strategies which depend on a common understanding of the way learners process information (eg. constructivism). Recently, Berlin (1991) published a detailed bibliography of this literature.

Literature Review

Science and mathematics educators have been concerned with the need to make these disciplines appear as relevant to students in schools. For example, Roth (1992) argued that there was a need to integrate science, mathematics and technology in the context of authentic practice. Other writers (eg. Berlin, 1991; Roth, 1992) have stressed the need for science and mathematics to develop problem-solving skills in the context of real-world situations. They have advocated that teachers ensure their students have opportunities for experience in everyday situations leading them towards the development of basic concepts and principles.

Postle (1993) indicated that:

learning from experience generates knowledge. Attending to the whole experience appears to lead to the generation of realistic, useful and relevant knowledge directly supportive of human flourishings. So far as I edit, limit, deny or ignore areas of my experience, this appears to narrow what I learn form it. This restriction may aid my short-term survival, but at the cost of some detachment from reality (p. 33).

It may be argued that education is often concerned with short-term learning. Skills and understandings are fostered through a collection of specific teaching examples that require students to recall information in ways that do not relate to “real-life” or authentic knowledge. Several weeks later students are required to reproduce attained knowledge through assessment techniques that merely reinforce and promote this narrow use of knowledge. Frequently learners are expected only to apply this learned knowledge to artificially constructed and restricted text book exercise "problems." Such problems are not usually drawn from actual examples from the “real world”, thus the knowledge gained from their completion is not practical knowledge.

Practical knowledge was defined by Sternberg and Curuso (1985) as being procedural knowledge relevant to everyday life. Thus, teachers who wish to develop practical knowledge must do more than transmit content knowledge - they must also model thinking and problem-solving in the discipline areas they teach. This means that science and mathematics teachers must not only be well-versed in terms of content but also know how to apply that knowledge in meaningful ways that demonstrate both the practical value of knowledge and the thinking processes involved. Teachers must possess a range of mental strategies and know where to employ them in order to make the optimum use of their academic content knowledge. In other words, teachers need to exhibit practical
Practical intelligence is commonly associated with expertise in a particular domain such as science, mathematics or technology. There has been a great deal of research into the kind of knowledge which experts possess and the way in which they utilise this knowledge (Glaser, 1984; Glaser & Chi, 1988). Tennant and Pogson (1995) summarised the common factors associated with expertise, indicating that experts: a) mainly excel in their own domains; b) perceive large amounts of meaningful patterns in their domains; c) are faster and more economical in their processing of information; d) have superior memory; e) see and represent a problem in their domain at a deeper level than novices; f) spend a great deal of time analysing a problem qualitatively; and g) have strong self-monitoring skills. These ideas should guide the way the curriculum is developed and delivered to ensure that the activities and experiences of students represent authentic practice and permit the development of expertise.

Technology is commonly used as "the generic term for all the technologies people develop and use. It involves the purposeful application of knowledge, experience and resources to create products and processes that meet human needs" (Australian Education Council, 1994. p. 2). The place of technology in the curriculum has varied in emphasis from time to time. Commonly technology has been seen as the application of science and mathematics understandings in the real world. However, technology can be a real world starting point for the development of science and mathematics understandings beginning with a human problem or issue which is relevant to students. The latter was the starting point for the study which is reported in this paper.

Integration imposes a heavy demand on the human information processing system. Students or learners have to keep in mind context, concepts, principles and procedures at the same time. Recent research by Sweller (1994) has indicated that learners are most likely to experience success when the cognitive load (that is, the number of items which must be kept in working memory at any one time) is kept to a comfortable level. This level depends on the familiarity of the task and the level of expertise of the individual in respect of the disciplines concerned. This was used as a basis for planning the instructional procedure investigated in this study.

The instrumental procedure in this study is also a response to recent developments in education in N.S.W. The N.S.W Department of School Education (1995) Annual Report for 1995 contained details of the government's "Computers in Schools" policy. A key feature of this policy is to make computer education integral to all key learning areas. At present there are few accounts of classroom based research concerned with effective practices for integrating computers in the key learning areas of mathematics, science and technology. This study addresses this shortage.

Method
Students in a first year education subject (n=90) at a regional university in Australia were given the task of designing and making a healthy food bar (50 g) which met nutritional requirements consistent with the Australian Standards and was suitable for sale at a school canteen. The development of this process was divided into three distinct teaching/learning components which provided opportunities for students to acquire information about:

1. The use of a spreadsheet.
2. Knowledge and understandings of food composition information and nutritional specifications for the composition of a food bar. Mathematical calculations and ingredient manipulation were carried out with the use of calculators and pencil-and-paper workings.
3. The development of the food bar with the specific use of a spreadsheet (as opposed to pencil-and-paper calculations).

Initial work on the use of spreadsheets was undertaken with the use of a Claris Corporation (1994) training workbook that provided students with opportunities to develop necessary basic skills in the use of spreadsheets. It should be noted that most students were not familiar with spreadsheets before participating in this course. The second teaching/learning component was developed in science tutorials and initially did not involve the use of such computer software. Students were given nutritional information about specifications for a food bar and also provided with a breakdown of the kilojoules, protein, fat and dietary fibre present in many of the foods used in a typical food bar. The nutritional specifications are presented in Table 1.

Table 1
Nutritional Specifications for the Food Bar

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum energy</td>
<td>750KJ</td>
</tr>
<tr>
<td>Minimum protein</td>
<td>4.5g</td>
</tr>
<tr>
<td>Minimum dietary fibre</td>
<td>2.5g</td>
</tr>
<tr>
<td>Maximum fat</td>
<td>8.0g</td>
</tr>
</tbody>
</table>

Table 2 lists the nutritional information which was available to students.

Table 2
Food Composition Information (per 100g)

<table>
<thead>
<tr>
<th>Food</th>
<th>KJ</th>
<th>Protein</th>
<th>Fat</th>
<th>Dietary Fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apricot, dried</td>
<td>820</td>
<td>4.4</td>
<td>0.4</td>
<td>9.2</td>
</tr>
<tr>
<td>Coconut, desiccated</td>
<td>2630</td>
<td>6.3</td>
<td>0.5</td>
<td>14.7</td>
</tr>
<tr>
<td>Apricot</td>
<td>204.40</td>
<td>49.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coconut</td>
<td>2630</td>
<td>365.01</td>
<td>14.7</td>
<td></td>
</tr>
</tbody>
</table>
Date, dried 113 32.00, 110.0
Dried pear 116 02.00, 211.5
Fig, dried 97 03.60, 714.3
Oats, rolled 15 5010, 58.57.0
Peanuts, roasted 26 2025, 152.86.2
Prune, dried 78 02.40, 57.9
Puffed wheat 15 2012, 52.512.5
Sesame seed 24 5022, 355.410.0
Sultanas, dried 12 802.80, 54.4


Students were asked to use their own experience with food bars to suggest an initial formulation and to enter this formulation into a spreadsheet in preparation for refining the formulation by manipulating the quantities and selection of ingredients to meet the specifications. Once these specifications had been met, students made a prototype bar and consumer tested it using appropriate criteria. The prices of the ingredients were also stated in terms of both wholesale and commercial rates to remind students of the context in which commercial production operates. The formulation was guided by consumer research. The prototype was subject to consumer testing and this information was used in the production of the final product.

The Spreadsheet
The third component of the teaching/learning investigation required the students to apply the knowledge they had gained from the previous two activities in a way that was proposed to make the task more efficient and easier to manage. A typical spreadsheet format used by the students is presented in Table 3. When revising their initial formulation using the spreadsheet students needed to consider the factors which would influence the sale of food bars. The factors might include:
1. Composition
2. Nutritional value
3. Cost
4. Appearance
5. Taste
6. Texture
7. Handling (how it holds together and stickiness)
8. Shape/size

Consumer Research
To guide the revision students also surveyed a group of potential clients to establish the relative weighting for the above factors using the following four point scale:
1. Not important
2. Important
3. Very important
4. Imperative.

The results of this survey could also be placed on a spreadsheet to enable members of the class to pool information.

Product Testing
Once the formulation had been completed the students had to prepare a prototype food bar. The prototype bar was then be rated by a panel of five independent judges A, B, C, D, and E on the eight factors described above using the following rating scale:
1. Poor
2. OK
3. Good
4. Excellent

A further refinement to the evaluation of the prototype food bar could be made by using the average weightings obtained in the survey to produce a weighted mean rating for each criterion. It could be useful to set up another spreadsheet for this purpose using the following fields:
1. Factor
2. Rating A
3. Rating B
4. Rating C
5. Rating D
6. Rating E
7. Average Rating
8. Factor Weighting
9. Weighted Rating

The information from this output of the spreadsheet was used to guide the formulations of the final product.

Results and Discussion

The students invariably found that their initial formulations did not meet the nutritional specifications and soon recognised that changing the formula was a tedious task to undertake using pencil, paper and calculator. Generally most students maintained that this method was inefficient and often frustrating. The following responses from students highlight the difficulties often faced when using the calculator and pencil-and-paper format.

This way was tedious, boring and took a long time to come up with the
correct ingredients. It was extremely frustrating and tiring.

The pencil paper calculator formulation was time consuming and also success wasn't high therefore I felt like giving up sometimes. Pencil and paper involved guessing and assuming.

Interestingly, only one student commented that the use of a spreadsheet would have made this task easier. This is despite the fact that all students had recently completed the computer training program that introduced and promoted the use of spreadsheets for similar calculations.

I found the task to be long and tedious and had to use trial and error. As the subject was computers and technology I wondered why we didn't use a spreadsheet.

The authors would argue that this student had already made links between two components of the problem, that is, (a) manipulating the quantities and selection of ingredients and (b) meeting the consumer tested criteria, and, as a consequence, was able to recognise that the use of a spreadsheet would have made such calculations easier to manage. Most students were not yet ready to make this connection.

As previously mentioned, the specific use of a spreadsheet was only introduced after the students had attempted the task manually. The spreadsheet took approximately half an hour to set up but soon proved its worth in enabling rapid reformulation of the composition of the food bar and gradual achievement of success through a series of successive approximations. The set-up used in the spreadsheet enabled the students to enter the general formula =B2*X2/100 for all calculations of mass or cost (where X represents C, E, G, etc) and to "fill down" in the appropriate columns. Students recognised that the use of a spreadsheet made it possible to work like a real food technologist and to use nutritional information and consumer needs and preferences in an authentic context. It also made it clear that students had a working understanding of routine calculations and skill in interpreting information and solving a series of self-identified problems.

The ease with which the task could now be handled ensured that the students not only completed the problem more efficiently but also provided support for the need to use spreadsheets in particular situations.

The spreadsheet allowed us to play around with the figures without doing ten times the amount of work, which was much less frustrating.

Many students felt that the task was now more realistic and authentic.

The spreadsheet added interest and spontaneity to the task and meant
that you could move onto the other task requirement therefore gaining more from your time. The spreadsheet calculations are keeping with the times and crucial to developing the ideas of technology.

Additionally, many of the students could now appreciate that the three-step process actually improved their understanding of the use of spreadsheets.

Now I see the method in your madness. This method - from pencil and paper then moving to spreadsheets once the students are familiar with the problem - is effective.

The use of a spreadsheet was a lot quicker and more effective in doing the same activity. But I now understand things. We first have to work things out the long way in order to be able to understand the short way.

In the process of developing a successful product students gained more than skills in using a spreadsheet; an understanding of the composition of some common foodstuffs; knowledge of proportion and weighted means and appreciation of the way in which individual variables may be manipulated - they gained an interesting understanding of the relationship between and among science, mathematics and technology in an authentic and meaningful context.

Implications

Three points have emerged from this paper that challenge the way problem-solving approaches are fostered in the science, mathematics and technology curricula.

1. Technology which focuses on human needs provides an excellent starting point for establishing authenticity in learning and a context for real-world problem solving.

2. Technology is a useful way of introducing and developing science concepts and understanding and makes use of and develops expertise in mathematics.

3. When considering science, mathematics and technology it is important to keep the cognitive load of the learner to manageable levels. In this study, this was achieved by developing expertise in using spreadsheets prior to their application to the formation of the food bar which placed high demands on scientific understanding and appreciation of mathematical principles.

References