Authentic integration of mathematics and science: a model for integrating Mathematics and Science in 2nd level education

Mr Páraic Treacy & Prof John O’Donoghue
NCE-MSTL at the University of Limerick
Limerick, Rep. of Ireland
paraic.treacy@ul.ie
john.odonoghue@ul.ie

Abstract
Research suggests that hands-on, practical, pupil-centred, authentic activities should form a central element when designing an effective model for the integration of Mathematics and Science. The Authentic Instruction model, developed by Fred Newmann and his associates in the early 1990’s, provides the foundation for a model for the integration of Mathematics and Science as it is integrative in its very nature, and there is considerable empirical evidence backing up its merit. The characteristics of Authentic Instruction fit the needs of an increasingly constructive approach which is being adopted in various education systems (e.g. the new Project Maths syllabus in Ireland) while also ensuring significant learning (which can be implemented in real life contexts) takes place. As the Authentic Instruction model is not explicitly designed for the integration of Mathematics and Science, some adjustment to the model is needed to ensure that all the specific needs of the integration of these two subjects are satisfied. Thus, the author has taken the key elements of Authentic Instruction and modified them to produce a new model entitled Authentic Integration of Mathematics and Science (AIMS).

Keywords
Integration; mathematics; science; model; rich tasks.
1. Introduction – why integrate mathematics and science?

Integrating elements of Mathematics and Science has long been an issue of discussion amongst education groups such as the National Council of Teachers of Mathematics (NCTM), the National Research Council (NRC), the Curriculum Corporation (Australia) and the School Science and Mathematics Association (SSMA), as well as being a practice that has been endorsed by a number of academics (Berlin et al, 1992; Furner et al, 2007; Daniels et al, 2005; Miller et al, 1999). However, the manner in which the subjects are integrated varies from coordinating a school’s Mathematics program with its Science program (NRC, 1996) to integrating material from both subjects in such a way that “it becomes indistinguishable as to whether it is mathematics or science” (Berlin et al, 1992, p.341). In addition to that, no specific curriculum model for integrating Mathematics and Science has been developed to date thus this practice has no definitive direction in which to develop and evolve but rather a cluster of disconnected approaches which endorse various teaching methods.

Having said that, there are certain criteria which various studies recommend when integrating Mathematics and Science, i.e. the need for the content to be contextually based and taught in an authentic manner with plenty of hands-on group work, inquiry and discussion throughout (Frykholm et al, 2005; Daniels et al, 2005; Furner et al, 2007; National Research Council, 1996).

Such an approach would aid in dealing with issues which have affected the quality of students entering higher education e.g. their inability to solve problems. Galbraith and Haines (2000) discovered, when testing 423 beginning Engineering and Mathematics undergraduates, that students develop and depend on translation algorithms that work for textbook problems, thus they struggle when asked to analyse and interpret mathematical information. Application of contextually-based, hands-on group work, with plenty of inquiry and discussion through the integration of Mathematics and Science within secondary education (and higher education) would aid in solving this issue.

This pedagogical approach offers the starting point for the development of a teaching model that integrates Mathematics and Science in a manner which ensures significant learning takes place. After extensive exploration of a wide range of teaching strategies and models, the author concluded that the Authentic Instruction model, developed by Fred Newmann and his associates in the 1990’s, would provide a fine basis from which to develop a model for integrating Mathematics and Science. This was due to the fact that this model is integrative in its very nature and embodies many of the characteristics of effective integration recommended by academics in the field.
2. **Authentic instruction**

The Authentic Instruction model is rooted in constructivism and relies on formative assessment in the same style as Assessment for Learning. Central to this approach is the setting of meaningful, engaging, intellectual tasks which replicate the challenges pupils will deal with in the real world (Ladwig et al, 2007). Particular focus is placed on problem solving and pupils are required to attain and use deep understanding and relevant skills to complete these real world problems or ‘Rich tasks’ as they are commonly referred to within the literature (King et al, 2009). These tasks encourage students to synthesize knowledge and skills from various disciplines to aid them in successfully completing the challenge put to them. The model has proven to be quite effective: it was found that, when the characteristics of Authentic Instruction were adopted, the learning which took place was substantial. Authentic Instruction positively affects pupil performance in Authentic Intellectual Work, knowledge retention, and execution of basic skills and algorithms (Newmann et al, 1996; Newmann et al, 1998; Lee et al, 1995; Newmann et al, 2001).

This model has three underlying guiding principles: Construction of Knowledge; Disciplined Enquiry; and Value Beyond School. As the Authentic Instruction model is not designed explicitly for the integration of Mathematics and Science, the author has taken these three characteristics and adjusted them to specifically suit the recommendations outlined previously i.e. ensure each lesson is based around tasks which are contextually based or taught in an authentic manner with plenty of hands-on group work, inquiry and discussion throughout. Through this adaptive process, Authentic Instruction evolved into Authentic Integration of Mathematics and Science (AIMS).

3. **Authentic Integration of Mathematics and Science (AIMS)**

AIMS takes on the characteristics of Authentic Instruction due to its success in enhancing learning when implemented but these characteristics have been modified to meet the specific needs of the integration of Mathematics and Science. In all there are 4 criteria that need to be satisfied when creating an integrated lesson of this nature:

1. **Knowledge Development, Synthesis and Application**

Pupils will draw on their previous knowledge (in both Mathematics and Science), assimilate this knowledge and develop it through application to various challenging tasks and scenarios. In other words – they will improve and increase their knowledge in Mathematics and Science (knowledge development) then combine what they have learned in both disciplines (synthesis) so that they may apply it to solve a problem or complete a set task (application). It is vital that pupils identify the connections between the skills and information they have obtained in both disciplines.
2. **Focused Inquiry Resulting in Higher-Order Learning**

Pupils will achieve higher-order learning through inquiry into the elements of the topic(s) being studied in a focussed manner. Pupils should engage in substantial conversation with their teacher and their peers to build a shared understanding. Pupils must display advanced learning through:

- demonstration of their knowledge of the core elements and concepts being studied using the language and procedures relevant to Mathematics and Science;
- coherent approaches to tasks with presentations of results which suit the data obtained and conclusions drawn.

3. **Applicable to Real World Scenarios**

Skills and knowledge obtained, developed and displayed should be useful outside the classroom i.e. in situations which may occur in everyday life. This may pertain to typical domestic challenges, hobbies or tasks to be carried out in further education and/or future jobs.

4. **Rich Tasks**

A task is considered rich when it allows learners to use and develop their Mathematical abilities and awareness, as well as providing opportunities to make significant Mathematical choices (Mason et al, 1991). As such, in this context, tasks must be of an active or experiential nature with pupils central to the planning, implementation and conclusions drawn. The teacher should act as a facilitator offering hints, tips and advice when necessary as well as ensuring that the work carried out is of a high standard.
Pupils will develop their knowledge of energy ratings of household appliances and their ability to perform basic calculations. They will develop their ability to find the cost of running appliances and work out the total cost of typical electricity bills.

Calculating Household Electricity Bill

Applicable to Real World Scenarios

Focused Inquiry Resulting in Higher Order Learning

Rich Tasks

Basic calculations and determining percentages are regular tasks in everyday life that will be enhanced through this work. Understanding and being able to calculate household bills is important for any independent member of society as it is vital when identifying areas in which money can be saved.

Pupils’ knowledge of which appliances use the most electricity will be deepened through analysis and calculations carried out.

Figure 1: AIMS triangle with an example of each element from a sample lesson entitled Household Electricity Lesson.

The AIMS triangle (Figure 1) displays graphically the characteristics of the model. The first two elements “Knowledge Development, Synthesis, and Application” and “Focused Inquiry Resulting in Higher Order Learning” form the foundation of AIMS. These elements are central to how each lesson is constructed and delivered as well as providing the basis for applying the relevant knowledge to real world scenarios. These three elements ensure that the final outcome, the rich task, has the requisite characteristics to elicit meaningful learning.

This model is best explained through a sample lesson. With this in mind, included in the graphic (Fig. 1) is an example of how each of the criteria is satisfied for a lesson entitled ‘Household Electricity’ (created by the author) which can be summarised thusly:

_Pupils will investigate and apply the methods for computing electricity usage and cost by completing calculations for electricity usage in a typical home. The pupils will figure out the cost of running each appliance, add up these amounts to find the total cost and factor in VAT to compute the final bill._

_Pupils will develop their knowledge of energy ratings of household appliances and their ability to perform basic calculations. They will develop their ability to find the cost of running appliances and work out the total cost of typical electricity bills._

Topics pertaining to both Mathematics (Mixed Operations & Percentages) and Science (Electricity) are integrated and applied in this lesson in a manner which ensures that enhanced learning takes place within both disciplines through a hands-on, pupil-centred, meaningful, engaging, intellectual task that replicates a real world challenge.
3.1 The Task

In this lesson, the pupils are placed in groups of two, three, or four and given a scenario for electricity usage in a household over the course of one month (see Fig. 2). They compute the number of kilowatt-hours needed to run each appliance and then calculate the cost to run each appliance at €0.13 per kilowatt-hour. The kilowatt-hour (symbolized kWh) is a unit of energy equivalent to one kilowatt (1 kW = 1,000 watts) of power expended for one hour (1 h) of time.

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Wattage</th>
<th>Number of Hours of Usage</th>
<th>kWh</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee Maker</td>
<td>1165</td>
<td>4</td>
<td>4.7</td>
<td>€0.61</td>
</tr>
<tr>
<td>Computer</td>
<td>365</td>
<td>75</td>
<td>27.4</td>
<td>€3.56</td>
</tr>
<tr>
<td>Convection Oven</td>
<td>1500</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heater (Portable)</td>
<td>1500</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TV</td>
<td>200</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microwave Oven</td>
<td>1500</td>
<td>11.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toaster</td>
<td>1400</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clothes Dryer</td>
<td>5000</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigerator/Freezer</td>
<td>450</td>
<td>333</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Sample electricity use in a home over the course of one month

For example: The coffee maker has a wattage of 1165 watts (1.165 kilowatts), it was used for a total of 4 hours that month. To find the number of kilowatt-hours, the pupils would multiply the number of kilowatts by the number of hours it was used for:

\[
1.165 \times 4 = 4.66 \text{ kWh} \approx 4.7 \text{ kWh}
\]

To get the cost of running the appliance during that month, the pupils would then multiply the number of kilowatt-hours by €0.13 (cost of 1 kWh). Finally, they would add up the cost of running each appliance and then add on 21% of the total to account for VAT. It is important to note at this point that the onus is on the pupils to work together as a group to figure out what to do rather than the teacher completing an example and asking the pupils to repeat it in their own calculations. The teacher should act as a facilitator, guiding the pupils as they progress through the task.
3.2 Conducting Discussions

As mentioned previously, discussion comes highly recommended when implementing lessons of an integrative nature. Group, teacher-group, and teacher-pupil discussions can be conducted throughout the lesson while whole class discussions could easily be carried out on completion of the task e.g. discuss results obtained, how they were obtained, and what implications they have. In the example given, the teacher could conduct a discussion based around how a person knows which appliances use most electricity; how they can reduce the amount of electricity used; and the discussion could branch out into topics such as renewable energy and non-renewable energy as well as the effects that an increase in VAT would have on a household budget.

4. Conclusion

Lessons which integrate Mathematics and Science require the content to be contextually based and taught in an authentic manner with plenty of hands-on group work, inquiry, and discussion throughout. As Authentic Instruction embodied many of these characteristics, the author took inspiration from this tried-and-tested model to create a model specific to the integration of Mathematics and Science: Authentic Integration of Mathematics and Science (AIMS). This model was designed with secondary education in mind but can be adopted within a higher education setting. It is based around four characteristics: Knowledge Development, Synthesis and Application; Focused Inquiry Resulting in Higher-Order Learning; Applicable to Real World Scenarios; and Rich Tasks.

Satisfying these four characteristics produces a lesson which is pupil-centred and provides opportunities for meaningful learning through active, focused participation in group tasks which relate to real world challenges.

5. References


