Integrating mathematics and science in secondary classrooms

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This theoretical paper discusses the value of integrating mathematics and science in the secondary classroom, understanding gained from previous studies in this field, and the means by which lessons of this nature can be effectively designed. Attempts to integrate mathematics and science in the classroom often encounter barriers such as the rigid nature of the school timetable, deficiencies in teacher knowledge of their non-specialist subject, and lack of instructional materials, amongst other issues. A model for integrating mathematics and science in the secondary classroom is presented here which aims to account for these barriers. It is argued that this model will also provide opportunities for students to retrieve previously learned material and explore key concepts from both disciplines in tandem, thereby strengthening retention and understanding. Application of this model should also allow for the development of students' problem-solving skills and the facilitation of meaningful applications of mathematics to other disciplines.

Integration; transdisciplinary lessons; science; interleaving; rich tasks; applications of mathematics.

Introduction

Analyses of the state of mathematics education in the UK have led to recommendations that schools place greater emphasis on problem solving throughout the mathematics curriculum and meaningful application to other subjects (Jerrim & Shure, 2016; Ofsted, 2012). The Royal Society (2014, p.49) stated that science and mathematics education should adjust to accommodate the development of cross-disciplinary skills through "collaboration and open, dynamic dialogue within and across disciplines" as a complement to single-subject teaching. As such, integration of content from mathematics and other subjects within learning experiences has been highlighted as an area of exploration and a means for improvement. Integration is a term which is interpreted variously. Here, it will be defined as the application of knowledge and skills from two or more disciplines to tasks which challenge students to explore phenomena of varying complexities (Honey, Pearson, & Schweingruber, 2014).

Taking advantage of opportunities to integrate mathematics and science at secondary level are clearly supported within the UK national curricula for these subjects. The Department for Education (DfE) (2013a, p.2) recommend that pupils should "apply their mathematical knowledge in science, geography, computing and other subjects". The DfE (2013b, p.2) also highlight the need for pupils to "apply their mathematical knowledge to their understanding of science, including collecting, presenting and analysing data". Allied to that, overlaps within the aims of both curricula are observable, particularly in relation to problem solving (DfE, 2013a, 2013b).

Integrating mathematics and science in the classroom has previously produced encouraging outcomes with small to medium positive effect sizes for both mathematics (ES=0.27; SE=0.09) and science (ES=0.37; SE=0.12) reported by Hurley (2001) when analysing studies which compared an experimental group (integrated approach) to a control group (single subject approach). Recent applications of an integrated approach in Ireland have also been well received, gaining positive feedback from the teachers involved (Treacy & O'Donoghue, 2014). Much of the support for integration of mathematics and other subjects stems from the potential for more relevant and stimulating experiences which promotes problem solving, critical thinking, and retention (Stohlmann, Moore, & Roehrig 2012).

Barriers to Integrating Mathematics and Science

Although there is considerable support for this pedagogical approach, it must be noted that there are distinct barriers to integrating mathematics and science which have been repeatedly encountered. Such obstacles include the need to coordinate students and curricula, the increased time and effort required to implement this change, and the lack of instructional models and curricular materials (Huntley, 1998; Ní Riordáin, Johnston, & Walshe, 2015). While these factors do pose a challenge, a particular aspect which may be of more concern is that of teacher knowledge within both subjects.

Teachers may be open to innovative ideas and dedicate their time to implementing them but inadequate subject matter knowledge can often be the main reason for failure when attempting to implement such a pedagogic approach (Ní Riordáin et al., 2015). In addition, it has been argued that it is vital to maintain the structure of disciplines such as mathematics and science so that subject-specific problems and challenges can be encountered to allow students to develop and improve specialised skills and knowledge (Honey et al., 2014). Similarly, the rigidity of the school timetable and an emphasis on single-subject final examinations have been cited also (Stinson, Harkness, Meyer, & Stallworth, 2009).

Integrating mathematics and science as a complement to single-subject instruction

The aforementioned barriers to integrating mathematics and science in the secondary classroom need to be recognised and accounted for within any attempt to establish lessons of this nature in a sustainable manner. Moving away from lessons which focus on one discipline would require a significant transformation in the structure of a typical secondary education system. Allied to that, it is strongly recommended that educators within STEM subjects such as mathematics and science should avoid undermining student learning within these disciplines by attending to learning objectives and progressions specific to that subject (Honey et al., 2014). Similarly, attention needs to be paid to the cognitive demands placed on students when integrating mathematics and science, as making connections between different disciplines within complex problems could overwhelm students and negatively impact on their learning and motivation (Honey et al., 2014; Kirschner, Sweller, & Clark 2006). As such, lessons which integrate mathematics and science need to be applied as a complement to single-subject instruction so that students establish a strong foundation of knowledge and understanding in the individual disciplines before facing the challenge of combining content from both areas.

The author proposes that this can be achieved by implementing lessons which integrate mathematics and science in 4-5 week intervals throughout the school year. Topics and/or concepts from both mathematics and science which students have studied previously should form the focus of these lessons. Such an approach has the value of allowing students to engage in distributed practice, while the inherent need to switch between important ideas and concepts from both mathematics and science within these lessons ensures the constant presence of interleaving. Distributed practice, which is the process of reviewing content on separate occasions across weeks or months, typically leads to better retention of learning (Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006). Interleaving involves the practice of different types of content within a lesson (e.g. concepts and processes from science and mathematics) and has been found to be quite beneficial to student learning and retention in mathematics and other disciplines (Rohrer, Dedrick, & Stershic, 2015; Pashler et al., 2007). A further benefit of this approach to integrating mathematics and science is that, even though prior single-subject instruction of each topic needs to have taken place, such instruction does not need to have occurred at the same time nor does it have to have been recent. This means that teachers of each discipline are not required to closely align the timing of instruction of any particular content in their curricula.

Authentic Integration of Mathematics and Science

A transdisciplinary approach can be defined as instances where "knowledge and skills learned from two or more disciplines are applied to real-world problems and projects, thus helping to shape the learning experience" (English 2016, p.2). The Authentic Integration of Mathematics and Science (AIMS) model (see Fig. 1), adapted from the work of Treacy & O'Donoghue (2014), offers a blueprint for creating effective transdisciplinary lessons based on the principles outlined thus far. Central to these transdisciplinary lessons will be rich tasks which integrate concepts from both mathematics and science simultaneously. Establishing lessons of this nature would place greater emphasis on problem solving and the application of meaningful, cross-curricular activities in the mathematics classroom as recommended by The Royal Society (2014). The key characteristics of the AIMS model include opportunities for students to consolidate and synthesise the knowledge and skills developed in previous single-subject lessons; a focussed, structured approach to inquiry within the rich task so that students don't engage in aimless investigations; and opportunities to engage with tasks within which students apply their knowledge to relatable scenarios. Each of these characteristics will be present in the formulation of a rich task which will be the main element within such a lesson.

Rich Tasks

Rich tasks will form a central element of the lesson so that students may engage in analysing real-world representations of what may otherwise be abstract concepts in mathematics and/or science. Establishing the means to connect and integrate abstract representations of a concept with concrete representations of the same concept have been found to enhance understanding and learning (Richland, Zur, & Holyoak 2007). Rich tasks offer the scope to achieve this. An example of a task of this nature would be the calculation of target heart rate during exercise. This task allows for exploration of the workings of the cardiovascular system while also providing opportunities for application of knowledge of percentages, equations, ratio and proportion. Such tasks should be carefully structured to offer the required guidance and scaffolding for students with explicit identification of concepts from mathematics and science as connecting ideas productively across different disciplines can be quite challenging (Honey et al., 2014).

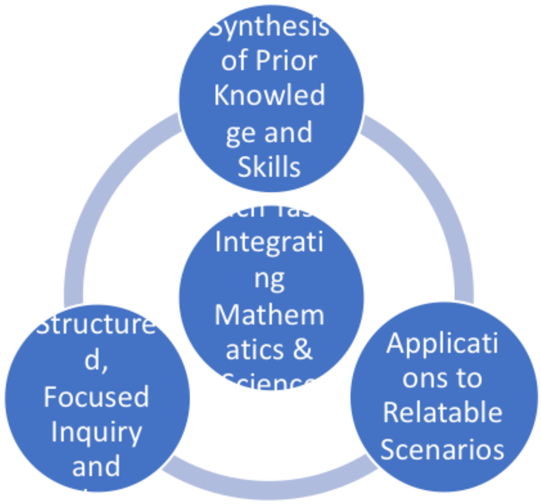

Figure 1: Authentic Integration of Mathematics and Science (AIMS) model.

Synthesis of Prior Knowledge and Skills

Suitable prior knowledge is vital in order for learners to master new ideas and make connections between existing knowledge (Day & Goldstone, 2012). Once a foundation of knowledge and understanding in a particular topic or concept has been established, it is imperative to provide opportunities to make connections between concepts to strengthen understanding and recall. Opportunities to combine previous learning from both mathematics and science also allows for a logical progression through a student's learning pathway as recommended in the revised version of Bloom's Taxonomy (Anderson et al., 2001). Students can potentially progress from challenges of being able to remember, understand, and apply within a single domain towards challenges involving analysis, evaluation and creation across domains of knowledge.

Applications to Relatable Scenarios

Concepts within mathematics and science can often be abstract in nature, thus difficult for students to fully understand. Creating tasks which allow for these concepts to be applied to relatable scenarios can provide enhanced representations of these concepts which can lead to improved understanding. Typically, learning is more effective when students can map a new idea onto one with which they are already familiar, with this being particularly true when considering mathematics (Richland et al., 2007). Incorporating this characteristic into the rich task will aid the learning process during these transdisciplinary lessons.

Structured, Focused Inquiry and Dialogue

Applying previously learned concepts and knowledge to new contexts (i.e. transfer) is quite challenging and is typically most successful when accompanied by careful support and structure from the teacher (Kirschner et al., 2006; Day & Goldstone, 2012). Learners often require explicit cues to recognise opportunities for application of prior learning to new contexts. As such, teachers need to carefully structure rich tasks which integrate mathematics and science so that learners are given sufficient support and guidance to utilise their prior knowledge effectively as they progress. Regular dialogue between teachers and learners is vital in order to provide cues and scaffolding as well as checking for understanding. Similarly, dialogue between learners, where suitable, allows for the development of a shared understanding.

Conclusion

Adopting the AIMS model when integrating mathematics and science provides opportunities to apply and combine prior learning to new contexts in a meaningful manner. Team teaching of these lessons by mathematics and science teachers every 4-5 weeks should be viable, even when considering the restrictions of a typical timetable. Such an approach ensures that any gaps in teacher knowledge within either subject can be overcome in the planning and delivery of these lessons.

The AIMS model also offers opportunities for teachers to assess the learning that has taken place in previous single-subject lessons. The challenge of retrieving previously learned material both tests and strengthens students' retention of that material (Pashler et al., 2007), while the challenge of applying this material in a new context provides the teacher with an insight into the depth of student understanding. Similarly, teachers and students often mistakenly rely upon their performance during acquisition of knowledge and skills as an indicator of the associated long-term learning (Soderstrom & Bjork, 2015). A wealth of empirical evidence indicates that significant changes in performance regularly fail to translate into corresponding variations in learning and, conversely, that substantial learning can occur without the presence of any performance gains (ibid.). It is recommended that learners should be provided with regular opportunities to revisit material previously studied to strengthen retention and understanding as alluded to previously. Integrating mathematics and science in the manner outlined here would provide such opportunities on a regular basis.

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