Utilising Different Models of Integration to Enhance the Teaching and Learning of Second Level Science and Mathematics

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Abstract
Increasing second level students' uptake and performance in mathematics and science, especially higher level mathematics and the physical sciences, has been identified as national and international priorities. Science and mathematics integration has long been recommended as a way to increase student conceptual understanding of, interest in, and motivation to learn both subjects. Recent interest in STEM education has also lead to calls for increased integration of these areas in order to provide students with the critical tools they need to deal with the multi-faceted and complex problems of sustainability that they will face as citizens. However, attempts to develop a model to integrate just two of the STEM subjects, that is, science and mathematics, have not resulted in a consensus regarding optimal curricular organisation. The integration of mathematics and science teaching and learning facilitates student learning, engagement, motivation, problem-solving, criticality and real-life application. However, the actual implementation of an integrative approach to the teaching and learning of both subjects at a classroom level, with in-service teachers working collaboratively, at second level education, is under-researched due to the complexities of school-based research. In light of this, an evidence-based research project was undertaken at the EPI-STEM National Centre for STEM Education in Ireland, with the aim of investigating the integration of science and mathematics and its impact on teaching and learning in second level education. This paper will report on the design, development and evaluation of three different models of science and mathematics integration that were investigated over a six year period (2009-2015) and will present the key findings that emerged.

1. Introduction
There are many proposed benefits to integrating the teaching and learning of science and mathematics [1], from improvements in students' learning, engagement, motivation, problem-solving, criticality and real-life application. Increasing the uptake and the performance in second level science and mathematics, in particular higher level mathematics and the physical sciences, is both a national and international priority [2]. The drive to improve students' uptake and performance in science and mathematics at second level education has prompted a surge in interest in the integration of STEM teaching and learning [3]. STEM integration is not a new idea; however, internationally it has received an impetus in recent years with the increased emphasis on STEM generally [4, 5].
In 2008 EPI-STEM, National Centre for STEM Education in Ireland [6] was established as an acknowledgement of the importance of the teaching and learning of mathematics and science for Ireland's economic future. The National Centre is a centre for research on national priority issues, conducting best practice and evidence based-research into the teaching and learning of mathematics and science. It was in light of the remit of the National Centre (in which the authors were then working) that the research on the integration of mathematics and science was undertaken. At the time there was very little previous research on science and mathematics integration in the Irish educational system. The aim of the research was to enhance the teaching and learning of science and mathematics at second level education through the use of integration; a particular focus of this research was in-service science and mathematics teachers and their classroom practice. This paper will report on the design, development and evaluation of three different models of science and mathematics integration that were investigated over a six-year period (2009-2015) and it will present some key findings that emerged from the three models of science and mathematics integration.

2. Project development
One of the biggest challenges for second-level education is that few guidelines or models exist for teachers regarding how to teach using STEM integration approaches in their classroom [7]. In the Irish

context both subjects are treated in isolation from one another in the national second level curriculum (approx. age 12-18 years). The mathematics syllabus has undergone major reform recently, with a greater emphasis being placed on the use of contexts and applications that enable students to relate mathematics to everyday experience.

3. Models of science and mathematics integration utilised

A common definition of integration does not exist, and research has utilised and implemented many different models [3, 8 - 11]. Models of integration include content-based approaches, thematic and project-based approaches, synchronised approaches, various continuum models (e.g. mathematics at one end, science at the other, and the centre representing a blended curriculum), and teaching the two subjects in sequence or in parallel, among others [8, 11]. The model of integration utilised in the first cycle (2009-2010) of the project informed the model utilised in second cycle (2010-2011), with cycle 1 and 2 informing the final cycle (2011-2016) where a PhD project [7] was undertaken.
Due to the complexities of school-based research, the authors recognised that for the subjects to be integrated in a meaningful way by the in-service teachers, that the models would have to be based on making connections between the centrally mandated syllabuses of the two disciplines, as teachers are unlikely to adopt integrative strategies that will not speak directly to the concepts students have to learn for subject-specific examinations. Table 1 illustrates the different models of science and mathematics, the methodology and the type of data that was collected throughout the study.

Table 1. Illustrates the different models of science and mathematics integration utilised in the research

Cycle	Model	Methodology	Data
Cycle 1 (‘09-‘10)	Connected, situated and sequential integration	• Year-long Case Study • Three second level schools in the southwest of Ireland • One mathematics teacher and one science teacher worked in collaboration with each other and with the authors, in each of the participating schools. • The study focused on 1st year students at second level education (approx. aged 12-13 years old)	• Teacher interviews • Focus groups • Observations
Cycle 2 (‘10–‘11)	Teaching and learning network – situated and integrating mathematics into science	• Year-long Case Study • Cycle 2 involved the same three schools and teachers from Cycle 1 • Teachers had increased input into the design of the integrated activities in Cycle 2?	• Teacher interviews • Focus groups • Observations
Cycle 3 (‘11–‘16)	Integrating mathematics into science	• Educational Design Research • Four phases – including the design, development and evaluation of a syllabus map and sequence in order to facilitate integration across science and mathematics, a conceptual framework of lesson units and identification of the affordances and constraints of implementing the curricular model	• Expert, teacher and principal interviews • Observations • Questionnaires • Surveys

Model 1 - Connected, situated and sequential integration

Science and mathematics teachers collaborated on the development of a curricular unit of learning (distance, speed and time), based on connections between mathematics and science. Emphasis was placed on connections being authentic in respect of both mathematics and science, and suitable for student experiences [4]. The authors were central in the design, development and implementation of the unit. It consisted of seven lessons in total (three 70-minute science lessons and four 35-minute mathematics lessons) taught sequentially over a period of three weeks. Technology was chosen as the vehicle to facilitate the integration between both subjects as it allows for the transfer of learning between both science and mathematics classes [12].

Model 2 – Teaching and learning network, connected and situated integration

The model of integration utilised in Cycle 2 was the examination of the mathematics within the science lesson. A Teaching and Learning Network (TLN) was set up to facilitate the design and development of integrative tasks by the science and mathematics teachers, where the mathematics in the science lessons was to be taught explicitly. Four TLN meetings took place throughout the academic year. TLN 1, 2 and 3 focused on the selection of a science topic, developing integrative tasks within the science lessons, teaching through an inquiry based approach and identifying the mathematics within the chosen topic. TLN 4 facilitated feedback and reflection on the classroom implementation of the integrative tasks. The authors supported and facilitated the TLN and the development of the integrative tasks. The classroom implementation took place over three 70-minute science lessons. Again technology was chosen as the vehicle to facilitate the explicit integration of the mathematics within the science lessons.

Model 3 – Integrating the mathematics within the science

Cycle 3 of the research focused on a curricular model of integration to assist teachers to support students to transfer mathematical knowledge and skills into their learning of lower second level science. The theoretical premise of the model in Cycle 3 is that the science curriculum should preserve its disciplinary structures, while acknowledging its interdependencies on mathematics.

The curricular model (the 'CISA Model') consisted of the mathematics syllabus mapped onto the science syllabus at lower second-level, an integrated teaching sequence, a conceptual framework for designing integrated lessons, and three exemplary lesson units. The methodology for this study was Educational Design Research, characterised by iterative design and formative evaluation of interventions in complex real-world settings. By drawing on overlapping concepts, it is theorised that a progression of mathematical knowledge and skills relevant to students' procedural understanding *within science* can be identified. The model supports a process for teacher-based development of integrated curriculum

5. Findings

Table 2 illustrates some key findings from each Cycle

Cycle	Key Findings
Cycle 1 ('09-'10)	While students reacted positively to the experience, teachers need a range of supports to undertake this 'risky' interdisciplinary endeavour in the context of an educational environment focused on subject-specific teaching and high stakes examinations. The teacher perspective, teacher knowledge of the 'other subject' and of TPACK, and teacher collaboration and support are key aspects of practice that impact on the implementation of an integrative approach to mathematics and science education [13, 14].
Cycle 2 ('10–'11)	The research highlighted the requirement for a systematic approach to the identification of overlapping science and mathematics topics in order to support Junior Cycle teachers to integrate these subjects on a wider scale [14].
Cycle 3 ('11–'16)	The findings offer proof of concept that the integrative model is a feasible process for science teachers to follow so that they can develop their own integrated mathematics into science activities [7]. This study also suggests that curricular models for STEM integration needs to take account of the subject subculture, school structure and teacher subject identity issues that impact on the curricular choices that teachers make. Importantly participation in the evaluation process can support both disciplinary and socio-cultural boundary crossing, enhancing the likelihood of professional learning through processes of reflection and identification, leading to reconceptualisation of professional identities.

6. Discussion and Conclusion

Findings from research on integration of science and mathematics indicate that teachers have limited knowledge of integration, have little or no access to integrated materials designed to support integrated teaching [3, 14]. The authors of this study strongly feel that through integrating the teaching, learning and assessment of science and mathematics at post-primary education that it has the potential to enhance the learning experience for students [15]. As with the concern with defining integration, there is mixed evidence regarding the effectiveness of integration for student learning [1]. We conclude that further research is needed to be carried out to investigate the effectiveness of the models of integration for student learning

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