

Adapting a Curriculum Unit to Facilitate Interaction Between Technology, Mathematics and Science in the Elementary Classroom: Identifying Relevant Criteria

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Abstract

Calls for the integration of subjects continue to emanate from a wide range of professional bodies, including governments and subject associations. Yet as some authors suggest, blurring the boundaries between subjects may be one of the most daunting tasks educators face.

The authors have recently begun a research study that will investigate the extent to which (a) relevant mathematics and science can be made explicit in a technology curriculum unit, (b) pupils utilise this mathematics and science learning, and (c) pupils' ability to design is enhanced by making the mathematics and science explicit and useful. This paper reports the results of Phase 1 of the study: an examination of research literature in order to identify criteria to inform the re-writing of an existing technology curriculum (to be used as a research instrument) that previously did not make explicit embedded mathematics and science concepts.

Our reading of the literature has identified two essential criteria that must be met during the re-writing: (a) protecting the integrity of the subjects and (b) identifying the nature and purpose of the intended learning.

Key words interaction, elementary education, technology, mathematics, science, designing

Introduction

What do designers need to know and how do they use what they know? These two questions provide a framework for Bryan Lawson's book *What Designers Know*. Early in the book, Lawson (2004) asks the general question "how do professionals... get from their problems to their solutions?" (p. 8). In beginning to answer this question, Lawson identifies that, "designers bring a great deal into the [design] situation that was not in the original problem" (p. 8). Goel and Pirolli (1992) claimed that, "the kinds of knowledge that may enter into a design solution are practically limitless" (p. 396). Lawson further identifies that, "knowledge that is used in the design process may originate from people and in places far removed from the current project" (p. 21). Both sets of findings, by Lawson and by Goel and Pirolli, are derived from the context of

professional design practice. Indeed, the so-called "novice designers" participating in much of their research were studying the discipline in institutes of higher education or in the early stages of their professional career as designers. To what extent are these findings relevant in the context of elementary pupils learning to design? Do pupils bring to their designing knowledge that does not originate in the technology classroom? Do pupils draw upon a wide range of knowledge originating with other people and in other places?

In technology classrooms, the fledgling designer (Trebell, 2007), working alone or as a member of a team, may be required to utilise knowledge, skills, and understanding from a number of domains without this requirement being made explicit. Further, teaching and learning in other domains may not make explicit the utility of subject knowledge and skills both required and desirable for pupils to design successfully. Welch (2007) has identified some of the issues associated with blurring the boundaries between the three school subjects technology, mathematics, and science. For example: What mathematics and science are likely to be useful for the design task at hand? Have pupils in technology classes learned this science and mathematics? Are pupils able to access and use this as and when required? These questions led the authors to ask three additional questions, including: (a) What is known about the interaction between the three subjects? (b) How can this knowledge inform the development of curriculum materials in technology education? and (c) Will making relevant mathematics and science explicit to pupils enhance their ability to design?

Motivated by these questions, the authors have recently embarked on a two-year research study that has, as its overall goal, the investigation of the extent to which Grade 6 pupils (age 10-11), working in a technology classroom, can and do utilise knowledge which, because of the way school curricula are currently organised, originates with people and places removed from their design activity: namely, in their mathematics and science classrooms. More specifically, the research will investigate the extent to which (a) relevant mathematics and science can be made

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explicit in a technology unit, (b) pupils utilise this mathematics and science learning, and (c) making the mathematics and science explicit enhances pupils' ability to design.

The purpose of this paper is to report the results of Phase 1 of the study that, through a review of relevant literature, identified criteria to inform the re-writing of an existing technology curriculum unit that will be used as a research instrument. This unit has, during the past several years, been used successfully in both Canada and the UK with elementary pupils and with teacher candidates (Department for Education and Skills, 2004). For teachers and pupils, the unit meets statutory requirements. For teacher candidates, the unit exemplifies curriculum materials writing and provides the opportunity to broaden their expertise in both designing and making. However, the mathematics and science concepts embedded in the unit have not, in either context, been made explicit. Classroom teachers made no reference to learning in these two subjects. Pupils were not required to make links between learning in the three subjects. Teacher candidates did not explore the links.

Few empirical studies have investigated the learning that takes place when the boundaries between some combination of the three subjects (technology, mathematics, and science) are blurred. Nevertheless, the authors were able to use the following three criteria to select literature that would inform our work. First, a study must provide either a theoretical or an empirical investigation of interaction between two or more of the three subjects. Second, a study must describe interaction at the elementary level (as defined in North America, i.e. pupils aged 6-13). However, it must be noted that in order to clarify terminology we also examined literature that described interaction at the secondary level. Third, we attempted to locate studies from a wide range of countries.

A total of 77 refereed journal papers were identified, ranging in publication date from 1975 to 2008. Having identified a body of appropriate literature, four questions were used to interrogate each study: (a) Is the nature of the individual subjects described, and if so, in what terms? (b) What terms are used to describe interaction between the subjects? (c) What approaches have been used to enable interaction between technology, mathematics, and science in the school curriculum? and (d) What rationales are presented for justifying interaction between technology, mathematics, and science in the school curriculum?

We report our findings in the first four parts of this paper. In Part 1, we discuss the nature of the three school subjects: technology, mathematics, and science. Part 2 identifies the wide range of terms used to describe the various ways in which subjects might interact. Part 3 provides an overview of the approaches used for subject interaction. This is followed, in Part 4, with an overview of the rationales for linking subjects. In the fifth and final part of the paper, we discuss how our interrogation of the literature will inform the development of a technology education unit for Grade 6 pupils that incorporates mathematics and science learning.

Technology, mathematics, and science in schools

Most school curricula continue to be conceptualised and organised into traditional subjects based on the archived and valued knowledge of Western scholars (Hipkins, 2004). This organisation is evident in most National and State curriculum documents (e.g. California State Board of Education, 2005; Qualifications and Curriculum Authority, 2008a; Queensland Studies Authority, 2003). Bernstein (1971) argued that, "the boundaries between [traditional school subjects] are closely guarded and carefully maintained... [and] that school subjects socialise all students – including teachers when they were students – into a self-perpetuating subject loyalty" (cited in Hipkins, 2004: 5).

In pursuing an inquiry into the way in which the school subjects technology, mathematics, and science interact, it will be important to be clear about their nature and purpose. Hence we next describe the unique characteristics of the three subjects.

Technology in schools

School technology is titled variously throughout the world: For example, in England as Design and Technology (Qualifications and Curriculum Authority, 2008a), in Ontario as Science and Technology (Ontario Ministry of Education, 2007), in Queensland, Australia as Technology (Queensland Studies Authority, 2003), and in California as Industrial and Technology Education (California State Board of Education, 2005). Despite this variation in title, the subject in most jurisdictions has two main thrusts. First, it engages pupils in designing and making, activities that are both intellectual and practical. Kimbell and Perry (2001) advocate designing and making as an essential aspect of general education, arguing that "the real products of design and technology are... youngsters, capable of tackling projects from inception to delivery... capably integrating knowledge across multiple domains, sensitively optimising the values of those concerned and confidently working alone and in teams" (p. 19).

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Archer, Baynes and Langdon (1976) made a compelling case for design as part of general education in England, arguing for designerly activity to be a way of learning all subjects. Cross (1982) proposed design as a “third area of education” (p. 221) after the sciences and humanities, arguing that pupils learn “designerly ways of knowing” (p. 223), a process in which new ideas are conceived and taken from the mind’s eye into the made world. Important features of this designing are that it: (a) is informed by knowledge, understanding, and skill learned within the school subject, (e.g. Qualifications and Curriculum Authority, 2008b); (b) requires knowledge and understanding of the design problem that is developed as the designing takes place (Lawson, 2004); and (c) makes use of knowledge and understanding from other school subjects, particularly science and mathematics (Sanders, 2005). Barlex (2006) has argued that a useful way of describing the design activity of pupils is to consider it as the making of a series of design decisions and that through a reflective scrutiny of these decisions pupils become aware of, and make progress in, the act of designing.

The second common thrust of technology education aims to engage pupils with the nature of the made world: how it comes into existence, how it was, how it is now, and how it might be in the future. In this way pupils learn about the powerful interaction between technology and society and the influence this has on their lives and the planet. This latter aspect is seen as particularly important in promoting education for sustainable development (Pavlova & Pitt, 2007). Overall, this second thrust is regarded as an essential antidote to a technology curriculum that focuses on the fabrication of artefacts at the expense of developing in pupils a critical awareness of the technologically mediated world they inhabit (Barlex, 2007a; Dakers, 2006; Petrina, 2000).

Although the above represent the curriculum intentions for technology education a recent report from England (Office for Standards in Education, 2008) notes that technology in primary schools is at the margins of the curriculum and there is the need to improve teachers subject knowledge. The report also indicates that attempts should be made to improve creativity and technical rigour in coursework for pupils in secondary school.

Mathematics in schools

Mathematics is a set of tools and processes for thinking through particular types of problems. Mathematics reveals hidden patterns that help pupils understand the world around them (National Research Council, 1989). According to the National Council of Teachers of

Mathematics (2000), “the need to understand and be able to use mathematics in everyday life and in the workplace has never been greater” (p. 1). The US Department of Education (2008) states that, “[a] sound education in mathematics across the population is a national interest” (p. xii).

As a discipline, mathematics deals with data, measurements, and observations from science; with inference, deduction and proof; and with mathematical models of natural phenomena, of human behaviour and of social systems. The Ontario Ministry of Education (2004) states that an effective mathematics education will provide pupils with “conceptual and procedural understanding” (p. 7).

In a report for the National Research Council, Kilpatrick, Swafford, and Findell (2001) concluded that:

Five attributes are associated with the concept of proficiency in mathematics: (a) conceptual understanding (comprehension of mathematical concepts, operations, and relations); (b) procedural fluency (skills in carrying out procedures flexibly, fluently, and appropriately); (c) strategic competence (ability to formulate, represent, and solve mathematical problems); (d) adaptive reasoning (capacity for logical thought, reflection, explanation, and justification); and (e) productive disposition (habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence in one’s own efficacy). (p. 116).

The National Council of Teachers of Mathematics (2000) identifies number and operations, algebra, geometry, measurement, and data analysis and probability as the essential conceptual knowledge that pupils should know and be able to use. Pupils can learn and apply these concepts by engaging in a variety of processes, including problem solving, reasoning and proof, mathematical communication, making connections, and representing mathematical ideas in a variety of ways, including pictures, tables, graphs and spreadsheets. It is, according to the National Council of Teachers of Mathematics, only when conceptual understanding of mathematical operations and fluent execution of procedures are supported by the commitment of addition, subtraction, multiplication, and subtraction to long-term memory, can pupils engage in effective and efficient mathematical problem solving.

Science in schools

To describe the purposes of science education Hodson (1998) proposed a simple framework in three parts:

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(a) learning scientific concepts and theories, (b) learning *how* to do science, and (c) learning *about* science. The first part of Hodson's framework requires pupils to learn the "products" of scientific knowledge, including scientific concepts, theories, laws, and specialised terms used by the scientific community. This propositional knowledge is what science curricula have historically emphasised, and continue to emphasise, despite the emphasis on inquiry and the nature of science outlined by various reform documents (e.g. American Association for the Advancement of Science, 1998).

Learning *how to do* science engages pupils in (a) the processes of scientific inquiry by asking scientific questions, (b) designing and conducting appropriate investigations, (c) interpreting data, and (d) communicating conclusions. In recent years, argumentation, concerned with justification of scientific evidence and conclusions within the context of a classroom community, has been emphasised as a significant component of scientific inquiry.

Learning *about* science involves understanding the relationship between science, technology, society and the environment, and appreciating science as a social practice embedded in a cultural and historical context. While there are some disagreements among historians and philosophers of science regarding the nature of the *nature of* science, there are some characteristics of scientific knowledge for which there is a reasonable degree of consensus and that are considered accessible to both elementary and secondary pupils (Lederman, 2007). These include an appreciation that scientific knowledge: (a) is tentative or subject to change; (b) is empirically based; (c) is subjective; (d) involves human inference, imagination, and creativity; and (e) is socially and culturally embedded.

Osborne (2007) has identified a fourth purpose of science education, one that includes the social and affective outcomes associated with learning science. This requires facilitating in pupils the ability to work collaboratively and providing them with stimulating, meaningful, and engaging experiences in science class. According to other authors (e.g. Jenkins, 2006; Sjøberg & Schreiner, 2006) enabling pupils to recognise the relevance of science in their lives and their communities and inspiring in them a sense of awe and wonder is proving a considerable challenge to science education.

The confusion with terminology

Early in the examination of literature, the authors identified that there is no universal and commonly understood set

of terminology to describe the nature and extent of interaction between school subjects. As Czerniak, Weber, Sandmann, and Ahern (1999) state, "ambiguity is evident in the sheer number of words used to describe integration: interdisciplinary, multidisciplinary, transdisciplinary, thematic, integrated, connected, nested, sequenced, shared, webbed, threaded, immersed, networked, blended, unified, co-ordinated, and fused" (p. 421). Further, it is clear that authors use the same term differently and, for example, use terms such as "integrated", "interdisciplinary", and "thematic" synonymously. Often, no formal definition is provided by an author, but resides implicitly in the model used to elaborate the dynamic of the relationship between subjects.

For example, "integration" is the most commonly used term, particularly in the areas of mathematics and science education (Ost, 1975). Beane (1995) used the term to describe learning experiences that "[transcend] subject-area and disciplinary identifications" (p. 619). He goes on to state that, "the goal is integrative activities that use knowledge without regard for subject or discipline lines" (p. 619). Banks (1993) used the term to mean, "the extent to which teachers use examples, data, and information from a variety of cultures and groups to illustrate the key concepts, principles, generations, and theories in their subject area or discipline" (p. 26).

Barlex and Pitt (2000), use three terms (co-ordination, collaboration, and integration) to describe the possible relationships between technology and science in schools. A co-ordinated curriculum would involve teachers in each subject scheduling related topics in their respective courses. Collaboration requires sharing some activities between the courses. Integration combines science and technology into a single course.

In this paper we have elected to use the term "interaction" to stand for the range of synonyms identified above. The term "interaction" supports the authors' sense of a two-way effect, rather than a one-way causal effect, when the boundaries between two or more subjects are blurred through curriculum activity. We are drawn to the idea of a reciprocal relationship between subjects.

Approaches to enabling interaction between subjects

Applebee, Burroughs, and Cruz (2000) describe approaches to "interdisciplinary" teaching along a continuum ranging from correlated knowledge (characterised by related concepts), through shared knowledge (characterised by overlapping concepts and emergent patterns), to reconstructed knowledge

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(characterised by the elimination of disciplinary boundaries). Fogarty (1991) identified ten models through which interaction might occur in the curriculum. She grouped these into three sets: (a) within single disciplines, (b) across several disciplines, and (c) within and across learners. Drake (2007) is critical of Fogarty's models, since the components of the third set "were not integration because pupils experienced connections during independent studies" (p. 27) and the elements of the other two sets did not match her team's experience of trying to develop a full-blown curriculum. Overall, she concluded that, "the 10 positions described parts within a whole" (p. 27).

Drake (2007) and her team identified just four approaches to interaction: (a) fusion, in which the focus is embedded into all school life; (b) multidisciplinary, in which the starting points are the concepts and skills of the disciplines; (c) interdisciplinary, in which common concepts and skills across the disciplines are utilised; and (d) transdisciplinary, in which the focus is a real world context and pupils' questions. Drake also identified a significant change in the way curriculum interactions have to be conceptualised. The emergence of subject standards places an accountability burden on the process of interaction, for any curriculum in which subjects interact must show the extent to which the proposed curricula meets the standards for the subjects that are interacting. Berry et al. (2005) provided an example of curriculum developers trying to address this issue by means of a STEM (science, technology, engineering, and mathematics) unit of work in which the designing of earthquake-resistant structures is audited against the US standards for earth science, algebra, and foundations of technology.

Our examination of the literature led to the identification of four permutations of the subjects technology, mathematics, and science: (a) science and mathematics interaction; (b) mathematics and technology interaction; (c) science and technology interaction; and (d) technology, mathematics, and science interaction. A separate subject, engineering, was identified that requires interaction between mathematics, science, and technology (Gattie & Wicklein, 2007; Lewis, 2005). The next parts of the paper explore each of these permutations.

Science and mathematics interaction

In 1994, Berlin and White produced a complex model for the interaction of science with mathematics, that included six aspects: (a) ways of learning, (b) ways of knowing, (c) process and thinking skills, (d) content knowledge, (e)

attitudes and perceptions, and (f) teaching strategies. The authors maintained that the value of the model is that it will enable the identification of "connections" among the six aspects within and across science and mathematics. Their hope was that various combinations of these aspects to different degrees may be useful in framing a common language and developing operational definitions to advance the research base related to the interaction between science and mathematics teaching and learning. Six years later Pang and Good (2000), in reviewing the "integration" of science and mathematics, identified ten issues requiring further exploration and concluded that this "suggests that integration of mathematics and science is one of the most daunting tasks educators face" (p. 76). This is not surprising, as they are two of the most established subjects in the school curriculum and as Hipkins (2004) notes, the boundaries between traditional school subjects are not malleable and are highly resistant to change. Furner and Kumar (2007) argue that a powerful way of overcoming these barriers is to develop a curriculum based on problem solving, with problems that require the use of both science and mathematics. This requires the development of problems that are both engaging and provide specific learning.

Mathematics and technology interaction

Ainley, Pratt, and Hansen (2006), in considering engagement and specific learning in pedagogic task design, develop the powerful idea of learning through a purposeful activity in one subject that is supported by the knowledge, skill, and understanding from other subjects. They cite as an example a task that has both purpose and utility: the designing of a spinner that will stay in the air as long as possible. Taking the length of the wings as a key variable, pupils can experiment with spinners of different wing dimension and record results in a spreadsheet. They report that while pupils had initial difficulty in seeing patterns in the numerical data, by using a scatter graph to display the results pupils were able to identify patterns, make conjectures about the effects of changing wing length, and identify further areas for investigation. Here we have a powerful model for interaction between subjects applied successfully; in this case, the interaction of mathematics with technology.

Science and technology interaction

Garaedts, Boersma, and Eijkelfhof (2006) argue for a coherent science and technology education, but indicate that this coherence must be at three levels across the education system if it is to be successful: (a) at the micro level, in the classroom; (b) at the meso level, involving decisions by local administration such as school boards and school curriculum managers; and (c) at the macro

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level, involving decisions of educational policy made by politicians and supported through curriculum development and educational publishing. Eisenberg, Kipperman, and Dagan (2005) describe a society-technology-science-society (STSS) approach to developing an interaction between science and technology in the school science curriculum. This model is underpinned by four elements: (a) problem solving; (b) the use of social, scientific, and technological knowledge for problem solving and decision-making; (c) the view that science and technology are two distinct but interacting disciplines; and (d) the gap between the needs of society and reality; this gap has the role of a "driving force" for development in both science and technology.

In their investigation of the interaction between science and design and technology in secondary schools in England, Barlex and Pitt (2000) noted that there was little, if any, interaction between these school subjects. This is unlike the dynamic relationship between science and technology in the world outside school. From a consideration of the nature of the disciplines concerned they identified and supported two forms of interaction (co-ordination and collaboration), but rejected combination into a single "subject." They argued that the learning of science almost inevitably dominates and distorts the technological activities such that the learning of designing is severely compromised.

Despite claims for interaction between science and technology, it is important to be realistic with regard to the immediate usefulness of scientific knowledge in technological endeavours. Layton (1993) explains that, "the knowledge that is constructed by scientists in their quest for understanding of natural phenomena is not always in a form which enables it to be used directly and effectively in design and technology tasks" (p. 49).

Technology, mathematics, and science interaction

Given the difficulties identified in forging links between two subjects it is not surprising that Satchwell and Loep (2002) report that the development of a standards based "integrated" technology, mathematics, and science curriculum is fraught with many challenges. In reporting on the IMaST (Integrated Mathematics, Science, and Technology) programme they developed over seven years, they describe an approach based on a learning cycle with four phases; (a) exploring the idea, (b) getting the idea, (c) applying the idea, and (d) extending the idea. They used six modules for each of Grade 6, 7, and 8. Their research indicates, as did that of Garaedts, Boersma, and Eijkelhof (2006), that success requires support at national, state, and local levels.

In a curriculum development and implementation project involving school teams of science, mathematics, and technology teachers James, Lamb, Householder, and Bailey (2000) developed 16 units in which science, mathematics, and technology were embedded. The authors reported that, "the problem of integrating mathematics into the curriculum remained unresolved. The teacher teams simply were not giving equal emphasis to mathematics integration, as compared to science or technology" (p. 34). Although the staff tried various ways to overcome the problem, none was particularly successful. This appeared to be because mathematics team members believed that "their curriculum did not allow for the integration of science and technology into mathematics classrooms. They believed that there was neither space nor time" (p. 34).

Engineering design as interaction

Lewis (2005) argues that an engineering design approach to technology education has implications for the use of science and mathematics within technology education. This is echoed by Gattie and Wicklein (2007), who found through a survey of 1063 high school technology teachers in the USA that there was support for an engineering design focus in technology education although this was accompanied by reservations about their professional abilities to provide such a focus.

Sanders (2005) endorses the engineering design approach to the integration of technology, mathematics, and science through the argument that pupils learn to use mathematics and science and "begin to see clear purposes for these subjects that were never apparent before" (p. 26). This has clear resonance with the purpose – utility model proposed by Ainley, Pratt, and Hansen (2006). Sanders also described how an engineering design approach can result in social interactions between pupils with different prior knowledge. Further, he identifies three features that must occur contemporaneously if a combined technology, mathematics, and science curriculum is to take place: (a) well-designed integrated instructional materials; (b) a school infrastructure that truly supports and facilitates integrated instruction, and (c) meaningful, well-designed, and well-executed professional development experiences for the teacher-teams and administrator. This has echoes of the three conditions identified by Garaedts, Boersma, and Eijkelhof (2006).

A rationale for interaction

Appeals for "integration" across technology, mathematics, and science education in schools are not new and have come from a wide range of professional bodies (e.g. American Association for the Advancement of Science,

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1993; National Council of Teachers of Mathematics, 1989; National Research Council, 1996). Why is this the case? What is it about interaction that continues to appeal to policy makers and educators? What rationale is provided in the literature to support interaction between the three subjects as an approach to teaching and learning? Our review has revealed three claims to support interaction: (a) the nature of the disciplines and their relationship, (b) the impact on pupil learning, and (c) enhanced pupil engagement.

The nature of disciplines

As described earlier in the paper, technology, mathematics, and science each serve a unique purpose in the school curriculum. Yet a powerful argument for interaction centres on the nature of the disciplines themselves, the emergence of common procedures and concepts, and the way they interact in the world outside school. This is particularly well captured by Boyer (1983), who stated, "while we recognise the integrity of disciplines we also believe that their current state of splendid isolation give students a narrow and even skewed vision of both knowledge and the realities of the world" (p. 2).

Technology requires pupils to make design decisions (Barlex 2006). Some of those decisions are technical in nature and may be informed by the use of science and mathematics (Barlex, 2007b). The mental modelling required for technology is not dissimilar to that used in science, and both subjects have an interest in developing pupils' ability to reflect on their own practice (Barlex & Pitt, 2000).

Gardner (1994) describes four possible models for analysing the relationship between science and technology: (a) science precedes technology, hence technology is applied science, (b) science and technology as independent domains, (c) technology precedes science, hence science is dependent on technology, and (d) science and technology interact with one another in ways where each informs and challenges the other. This interactionist view of the relationship mirrors, according to Boyer (1983), the "knowledge and realities of the world."

Mathematics relies on processes such as problem solving, reasoning and proving, reflecting, selecting tools and computational strategies, connecting, representing and communicating (Ontario Ministry of Education, 2005). These processes not only facilitate technological and scientific advancements, but also represent activities or tools that are used by technologists and scientists. Modelling is also an activity in mathematics that is evident in technological and scientific activity (Barlex & Pitt, 2000; Moriyama, Suzuki, Miyazaki, & Sakakibara, 2004).

Impact on pupils' learning

Is there evidence to show that blurring the boundaries between subjects has an impact on pupil learning? If so, what impacts does it have? Are they positive, that is, is learning enhanced and if so in what ways? Are there negative impacts, and if so, what are they?

Ainley, Pratt, and Hansen (2006) argue that providing pupils with learning tasks that have purpose, that is, "a meaningful outcome for the pupil" (p. 29) will enhance the utility of the learning, that is, lead to learning that "encompasses not just the ability to carry out procedures, but the construction of meaning for the ways in which those... ideas are useful" (p. 30). In his exploration of a pedagogical model to enable both inquiry learning (science) and designing (technology) Zubrowski (2002) provides an example of the purpose-utility argument in action that leads to enhanced learning in both science and technology. In order to stimulate and enhance an understanding of energy he proposes that pupils design and make model wind turbines. Following the opportunity to explore their own intuitive designs, Zubrowski argues for the presentation to pupils of a "standard model" of a wind turbine, "a model that is suggested by the teacher" and is used by pupils "to carry out systematic testing of essential variables of the system [that provides] knowledge to rebuild and remake a more effective system" (p. 53). Pupils use the results of their investigation into the performance of the standard model to improve their initial designs. And while Zubrowski suggests that his pedagogical model provides one that pupils can use in other design situations, the extent to which this is possible is as yet unreported, but will likely depend on the ingenuity of teachers to develop design proposals from a variety of contexts suitable for pupil adaptation.

In a small study, Norton (2007) showed there were considerable advances in the understanding of science and mathematics through an activity which involved Grades 1-7 pupils designing and making model adventure park rides, a topic of considerable interest (i.e. purpose) to them. Norton concluded that, "cognitive outcomes appeared to be educationally significant... understanding of key mathematical and science concepts had improved" (p. 40). Norton also found that "students developed a more comprehensive view of the nature of mathematics from one dominated by number computations to include aspects of other concepts such as measurement with more practical and applied dimensions" (p. 41). That is, pupils became aware of the "utility" of the subject matter. Ginns, Norton, and McRobbie (2005) identify the considerable science learning that took place when Grade 6 pupils were engaged in the design and construction of

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simple systems and the exploration of more complex ones, as part of technology lessons. They claimed that, "there were important learning outcomes for both technology and science . . . students' learning was enriched because they drew upon their understandings of science to provide more meaningful explanations . . . for example, about the construction of [their] robots". (p. 58).

Some authors suggest that blurring the boundaries between subjects encourages pupils to draw on knowledge from a variety of sources when completing design tasks. For example, Ginns, Norton and McRobbie (2005) described how pupils' "explanations for how the artefacts they had designed worked displayed evidence of the use of the concepts and language of science indicating that they were drawing on prior, or new, understandings" (p. 58). Venville, Rennie, and Wallace (2004) described how pupils in an integrated MST course used "several sources of knowledge to make key decisions that significantly affected the outcome of the technology-based, solar powered boat project". (p. 132). Pupils used "discipline-based theory [taught in science and mathematics lessons] . . . at the beginning of the decision-making process as students referred to concepts from their science and mathematics lessons to help them with the problems they faced while producing their solar boats" (p. 129). At the same time, students outside the class, examples of previous work, and parents were used as sources of knowledge.

These findings resonate with Vygotsky's (1986) view of the interdependence between spontaneous (everyday) and scientific (i.e. taught) concepts:

We believe that the two processes – the development of spontaneous and non-spontaneous concepts – are related and constantly influence each other. They are parts of a single process: the development of concept formation which is affected by varying external and internal conditions but is essentially a unitary process, not a conflict of antagonistic, mutually exclusive forms of thinking. (p. 157)

Other authors argue that in addition to enhanced learning in particular subjects, pupils develop skills and attributes that are not subject specific. For example, Barak (2007) argues that subject interaction enhances the development of problem solving skills.

Note, however, one concern raised about forms of integrated curricula is that they may not lead to enhanced learning and may in fact result in pupils becoming confused. Jacobs (1989) points to the lack of a general

structure in interdisciplinary work, which makes it difficult for teachers to develop appropriate repertoires of teaching. This can lead to pupils becoming confused by a multitude of different approaches. Anderson, Lynne, and Herbert (1996) and Hiebert (1988) argue that the cognitive demand on pupils, when confronted with a complex real world context, is so great that it prevents pupils from gaining conceptual understanding. And as Zubrowski (2002) concludes, "until there is a paring down of [the number of] standards at the state and school district levels . . . teachers will be unable to give students a richer and deeper learning experience" (p. 65).

Enhanced pupil engagement

There is limited evidence that implementing curricula to blur the boundaries between technology, mathematics, and science enhances motivation and engagement for some pupils. For example, Doppelt, Mehalik, Schunn, Silk, and Krysinski (2008) report enhanced engagement in low ability pupils when they were designing and making a simple burglar alarm as part of a design-based learning activity developed to engage pupils with science understanding. Barak and Zadok (2007) paint a clear picture of enhanced pupil engagement during a Grade 7 and 8 robotics course: "pupils worked independently, . . . remained in the lab until very at [sic] late evening, . . . and arrive[d] at the lab before lessons started" (pp. 416-417).

In 2007 the Department for Children Schools and Families in England introduced *After School Science and Engineering Clubs*. The evaluation of the scheme (Mannion & Caldwell, 2008) revealed that the nature of many of the activities undertaken required interaction between technology and science and, to a lesser extent, between science and mathematics. Data from a pupil survey suggests that club members were more interested in future science and engineering careers when compared to a reference group of pupils who did not attend the clubs.

Discussion

Our examination of literature has revealed a bewildering array of terms used to describe curricular approaches that involve some form and degree of the interaction between school subjects. Despite its frequent use in the literature, we have purposefully chosen not to use the term "integration" since it signifies, in some contexts, such extreme blurring of the boundaries between school subjects that the result is a single course rather than distinct courses that are strategically linked to maximise learning (Barlex & Pitt, 2000). Instead, we use the term "interaction" to portray a reciprocal relationship between subjects and to highlight our expectation that the linking of

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two or more school subjects in a learning experience may lead to multi-rather than unidirectional gains.

We have described a variety of approaches to interaction that involve permutations of the three subjects. The authors of this paper are interested in the interaction between all three: technology and mathematics and science. As described earlier in the paper, our research will investigate the extent to which (a) relevant mathematics and science can be made explicit in a technology unit, (b) pupils utilise this mathematics and science learning, and (c) pupils' ability to design is enhanced by making the mathematics and science explicit.

To accomplish this, a multiple-case study research design (Stake, 2006) will be conducted, beginning in April 2009. One of the data collection instruments will be a Design and Make Activity (DMA), which has been used extensively in technology classrooms, will be re-written to include teaching and learning materials for the previously unacknowledged mathematics and science embedded in the unit. Our reading of the literature, reported in this paper, has identified two criteria that we must meet during this re-writing: (a) protecting the integrity of the subjects and (b) identifying the nature and purpose of the intended learning. Hence, the resultant unit will be, to use Drake's (2007) term "multidisciplinary", in which the starting points are the concepts and skills of the disciplines. At the same time, the unit will build on the work of Ainley, Pratt and Hansen (2006) in which learning is facilitated through a purposeful activity in one subject and supported by the knowledge, skill, and understanding from other subjects.

Our first criterion emphasises that if the integrity of the three interacting subjects is to be maintained, then it is important that the curriculum unit features these subjects in ways that take into account the unique nature of each subject. In the case of technology, the unit will need to promote skills in designing and making and facilitate in pupils the ability to conceptualise new ideas and make these ideas manifest in the real world. Pupils will be required to make a full range of design decisions. To ensure the integrity of technology education, pupils will need to engage in the designing and making of "real products" as opposed to models of products – an approach often used in "design-based science" curricular approaches (e.g., Roth, 2001). At the same time, the contested nature of technology as a discipline must be taken into account when formulating a rationale for interaction. For example, Feenberg (1999) describes four varieties of theory for considering the nature of technology: determinism, instrumentalism, substantivism

and critical theory. In developing technology curricular that intend to discuss with pupils the way in which the made world comes into existence, these different perspectives provided by such theories will need to be considered, albeit in a form that is accessible to pupils.

While learning outcomes related to mathematics education include conceptual understanding of mathematical representations, the development of fluency in recalling facts, and performing mathematical skills, maintaining the integrity of mathematics education will require that pupils investigate mathematical problems, identify diverse problem solving strategies, engage in mathematical reasoning and proof, and communicate their findings using a variety of mathematical representations. Contrived applications of the sort sometimes used to develop fluency in mental arithmetic will be avoided.

Similarly, while a common goal in science education includes learning scientific concepts and theories, maintaining the integrity of science education within the unit will necessarily require pupils to ask scientific questions, design and conduct appropriate investigations, interpret data, justify and then communicate their conclusions. Finally, the curriculum unit will need to help pupils develop an appreciation of the value-laden nature of technology, mathematics and science, their relationship to various aspects of society, and their utility in the world outside school. This approach will preclude the possibility that the research is not able to focus on the use of mathematics and science to support pupils' designing and making and that the technology learning is not subsumed in the service of the other two subjects.

While maintaining the integrity of the interacting subjects must be a feature of the proposed curriculum unit, it will also be essential to capitalise on commonalities, including (a) requiring reflection (Barlex & Pitt, 2000), (b) engaging in modelling (Barlex & Pitt, 2000; Moriyama, Suzuki, Miyazaki, & Sakakibara, 2004), and (c) using problem solving skills (Barak, 2007). In this way the unit will reflect the blurry and dynamic boundaries between technology, mathematics, and science outside the classroom.

We also acknowledge that a crucial requirement of curricula in which subjects interact is that the statutory requirements of the individual subjects be met (Berry, et al., 2005; Drake, 2007). This has implications for the curriculum unit to be used for research in that it must take into account the Grade-specific Ontario requirements for technology, mathematics, and science. The more flexible approach in England, where the statutory requirements are not grade specific, will help to facilitate this requirement.

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Our second criterion attends to the impact of interaction on pupils' learning. As reported, several authors quote enhanced learning when the curriculum experience is organised to promote interaction between subjects, although there are some voices raised in caution that this may not always be the case. Our rewritten curriculum unit will make explicit where the interacting subjects make their individual contributions and the research will investigate the extent to which this interaction enhances pupil learning. Barlex (1992), for example, has described how when pupils are designing a nutcracker, they could use scientific knowledge and understanding concerning force and energy. Barlex cites the work of Brook and Driver (1984) to acknowledge the reluctance of pupils to apply scientific principles and it is worth noting the need for pupils to reconstruct their understanding of science in response to using that science. The re-written Design and Make Activity should therefore provide pupils with opportunities to make their thinking explicit, hear alternate perspectives that challenge their thinking, and formulate new conceptions based on their observations and experiences. It is possible that this reconstruction requires pupils to challenge their alternative frameworks (Driver, 1983), hence leading to deeper understanding.

Whilst some authors claim that interaction between subjects enhances pupils' engagement (Barak & Zadok, 2007; Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008) they offer no explanation as to why this is the case. While the evidence to support the view that interaction promotes enhanced motivation and engagement is sparse, clearly this is an important aspect of any classroom activities that promote learning. The research design, and hence the revised curriculum unit, must attend to this.

The authors are acutely aware that success in developing programmes in which technology, mathematics, and science interact has been limited (James, Lamb, Householder, & Bailey, 2000; Satchwell & Loepf, 2002). Although there have been appeals to engineering design as the means of promoting interaction between technology, science, and mathematics (Lewis, 2005), Gattie and Wicklein (2007) report that teachers had reservations about their professional abilities to provide such a focus. This literature indicates that developing a curriculum unit in which there is useful interaction between technology, mathematics, and science will not be a trivial task. It will have to meet challenges at three levels identified by Geraedts, Boersma, and Eijkelhof (2006): micro, meso, and macro. To facilitate the successful implementation of the unit during the research phase of this study, we have concentrated on the micro level. Expert teachers in technology, mathematics, and science

education played a key role in identifying the assumptions underpinning the set of guidelines we present in the discussion part of this paper. We anticipate that the involvement of these subject experts will continue to play an important role in formulating the curriculum unit before it is taught, analysing data that emerges from the implementation, and making appropriate modifications to the unit based on this data. In this way we not only explore the needs of the teacher from the micro perspective but may also be able to make recommendations as to requirements at the meso and macro levels.

Conclusion

Calls for the "integration" of subjects continue to emanate from a wide range of professional bodies, including governments and subject associations. Yet as Pang and Good (2000) suggest, blurring the boundaries between subjects may be "one of the most daunting tasks educators face" (p. 78). A review of relevant literature has identified some issues that need further exploration. Not least of these issues is the lack of a clear definition of terms, a difficulty that hinders a valid and reliable comparison between research studies. There is a paucity of empirical evidence that demonstrates the effect of interaction on pupils' learning. There are few clearly articulated curriculum models to support interaction.

The authors of this paper have recently begun a research study that will investigate the extent to which (a) relevant mathematics and science can be made explicit in a technology curriculum unit, (b) pupils utilise this mathematics and science learning, and (c) pupils' ability to design is enhanced by making the mathematics and science explicit and useful. Phase 1 of the study has involved an examination of research literature in order to identify criteria to inform the re-writing of an existing technology curriculum unit that will be used as a research instrument.

Based on this examination of literature, the authors have determined that the curriculum unit must meet seven criteria. First, it must respect the integrity of the subjects and ensure that the central purposes of each subject are not compromised by the interaction. Second, it must utilise the commonalities of process and content shared by the interacting subjects. Third, it must reflect a constructivist theory of learning. Fourth, the task set for pupils must be purposeful if it is to engage and motivate them. Fifth, the task must provide opportunities for pupils to use learning from mathematics and science to support learning in technology in such a way that learning in all three subjects is enhanced. Sixth, it must enable pupils to

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recognise and use learning from mathematics and science to enhance their learning in technology. Seventh, the content of the unit must meet statutory requirements.

The authors have concluded that blurring the boundaries between subjects through interaction requires, first and foremost, (a) clarity about the subject disciplines and what is to be learned from their study, and (b) an understanding of how this might inform and be used in purposeful tasks that promote rich learning environments. To blur the boundaries it is essential to sharpen the focus.

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