The Mathematics, Technology and Science Interface: Implementation in the Middle School

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The concepts of *middle-schooling* and *curriculum integration* were examined in this study, the aim of which was to provide a research base to inform the development and implementation of models of learning in mathematics, technology and science. A number of the case studies of integration conducted with students aged 11 to 15 years are reported, and issues arising from integrated practices are discussed along with their implications for teaching and learning.

Background

In Australia, as in many other parts of the world, the transition of students from primary to secondary school takes place around the age of 12 years. This transition involves a host of changes for students – from the single-teacher, single classroom, continuous curriculum environment of the primary school to that of the secondary school, where the discipline-based, many-teachers system involving discrete lessons taught in a number of classrooms or laboratories prevails. Recent research (Cormack, 1996; Hargreaves, Earl & Ryan, 1996; Speering and Rennie, 1996) has revealed the impact such student lifestyle changes have on student-teacher relationships – changes which have the potential to make these middle years of schooling potentially stressful and alienating for those students.

One of the recommended ways of addressing this problem is to provide a curriculum that is relevant, negotiated and integrated (Cumming, 1996). How to achieve this goal is currently the source of considerable debate among educators as are many other issues related to curriculum integration – for example, whether the curriculum should be primarily discipline-based, issues-based or project-based (Cumming, 1993). Bean's view is that it is incumbent on educators to provide early adolescents with an integrated approach to teaching and learning – that is, one which provides a curriculum that motivates students, where real life questions are posed, and where wholeness and unity are promoted rather than separation and fragmentation (Bean, 1991, p.9).

Why Integrate?

The potential for integrating science, mathematics and technology is well recognised (LaPorte & Sanders, 1993; Wicklein & Schell, 1997). One study (LaPorte & Sanders, 1993) involved middle school teachers integrating these subjects through technology-based projects. The authors concluded that activities depending on students applying science and mathematics knowledge to solve problems in technology offer a practical, meaningful and motivating learning context. Also, a number of case studies of approaches to integrating mathematics, science and technology education (Wicklein & Schell, 1997) found that three primary factors significantly affected the success or failure of the curriculum including "(1) teacher and administration commitment to the integration approach, (2) innovation and effort in curriculum re-design, [and] (3) administration and teachers' co-ordination of the integration plan" (p. 6).

Several authors have classified integrated teaching practice into various models, stages and continua, with a variety of associated terminology. Fogarty (1991), for example, proposed ten models of integration, ranging from the traditional fragmented model to those that connect, sequence, nest, share, web, thread, integrate, network or immerse the learner in curricular integration. Reflecting on the experience of a team of teachers who worked with her on an integrated project, Drake (1991) describes a progression in the process of curriculum development through multidisciplinary, interdisciplinary and transdisciplinary approaches.

Marsh (1993) suggests that the various forms of curriculum integration can be considered as a continuum beginning with "discipline-based options" with separate subjects taught at different times. The first step towards integration is "parallel-disciplines" where content is sequenced to correspond with related content in other disciplines. Marsh then describes "multi-disciplinary thematic approaches" where the various subjects contribute to a central theme and "interdisciplinary concepts and topics" where discipline concepts are chosen because of their direct relevance to the theme. "Internal orientation" encompasses activities which are jointly planned and implemented by students and teachers and the final variation of curriculum integration on the continuum is "whole school integration" which involves a total transformation of the learning environment as practised in Waldorf schools (Barnes, 1991).

Panaritis (1995) advises that teachers should be careful not to be driven by models such as those proposed above because the underlying distinctions are often "either fundamentally irrelevant or hopelessly arcane" (p. 627). Panaritis suggests that it is demoralising for teachers to have their efforts classified as "merely parallel" or "not *truly* interdisciplinary" (p. 627). Another criticism comes from Case (1994), who warns that policies advocating curriculum integration are little more than slogans. The kinds of programs which result can be ill-conceived and disconnected from real academic subjects (Brophy & Alleman, 1991).

There is conflicting evidence about the success of integrated programs. According to Vars (1991), since the 1940s more than 80 normative or comparative studies have reported that students in various forms of integrated programs performed better, or as well, on standardised achievement tests than students enrolled in separate subjects. Marsh (1993) tracked some of the major research studies on integration from the USA, the UK and Asia over the past half century and concluded that although the earlier studies "gave the impression that curriculum integration had many positive elements over single discipline teaching, there is a dearth of evidence of a positive or negative nature over recent years" (p. ii). While some empirical studies have shown that students can learn mathematical and scientific concepts in an integrated manner (Richie & Hampson, 1996; Roth, 1993), there also is evidence that some students have difficulty in grasping the content of integrated courses (Richie & Hampson, 1996; Wicklein & Schell, 1997).

Internationally, the past decade has seen several influential documents advocating integration of science, mathematics and other content areas. In the USA, *Science for All Americans* (Rutherford & Ahlgren, 1990), *Everybody Counts* (National Research Council, 1989), *Curriculum and Evaluation Standards for School Mathematics* (National Council for Teachers of Mathematics, 1989), and *The National Science Education Standards* (National Research Council, 1996) all stress the interrelatedness of mathematics and science and the implications for curriculum and instruction (Lonning & DeFranco, 1994). In the United Kingdom, the National Curriculum Council distinguishes cross curricular elements in terms of dimensions, skills and themes (Nixon, 1991). Similar trends are evident in Australia, for example, in the recently published draft of the *Curriculum Framework for Western Australia* (Curriculum Council of Western Australia, 1997). The Western Australian framework describes mathematics, science and technology as three of eight separate learning areas and advocates an integrated approach to curriculum delivery:

> While eight learning areas have been identified, knowledge, skills and values should be integrated across all learning areas. Students should be given frequent opportunities to see the connections between different areas of knowledge and endeavour. They should be encouraged to understand the arbitrariness of any division of knowledge into learning areas and subjects or other categories; to appreciate the interconnectedness of all knowledge; and the indissoluble relationship between knowledge and values. (Curriculum Council of Western Australia, p. 27)

While the new Western Australian framework exhorts teachers to teach in a more integrated way, the culture of the middle years of schooling in this State remains predominantly discipline-based in high schools and to some extent in the upper years of elementary or primary schools. There are, however, some interesting exceptions—schools which have managed to incorporate aspects of integration into their programs. It is these exceptions which form the focus of this study of integrated teaching of science, mathematics and technology in Western Australian classrooms in Grades 7-9.

The Study

A number of Western Australian schools which have successfully introduced integrated approaches to curriculum were the subject of this study. This paper examines such innovation and describes the different ways that the integration of mathematics, science and technology has been achieved. In addition, the paper examines five issues raised by teachers during interviews. These include the process of getting started, implications of integrated practice for teachers and students, structural implications, and the breakdown of departmental structures.

Method

The data were collected from 16 schools, including government and independent high schools and primary schools in the metropolitan area and country districts of Western Australia. The schools were selected on the basis of the existence of some integration between mathematics, science and technology in the middle school years, or that teachers were interested in integration. Four of the 16 schools were involved in the research as in-depth case study schools.

Each of the 16 schools was visited by one of the researchers who interviewed teachers about the integration at their school. The researcher questioned the teachers about integration that had occurred or had been attempted at the school, the teachers' opinions about the factors that enabled or inhibited the integration, and the perceived advantages and disadvantages in the process. The researcher also observed mathematics, science or technology lessons. Data were collected by field notes, and a summary of the school visit was compiled. The teachers were sent a copy of the summary and invited to comment and provide feedback.

The four case study schools were involved in more in-depth data collection, including interviews with from three to seven teachers and/or the principal, the collection of related documentation such as school policy documents, teachers' programs and inspection of student work, and the observation of between five and seven lessons. All interviews in the case study schools were tape recorded and transcribed and notes were taken during classroom observations. Each of the four schools was given a copy of the case study account with an invitation to provide feedback. The data from all of the 16 schools, including the four case studies, were analysed to provide the findings for this paper.

Forms of Integration

Different forms of integration were utilised by the 16 schools in this study, each form described briefly below.

Thematic Approach

A thematic approach to integrating mathematics, science and technology and other subjects was observed in two schools. In both schools a theme was used to integrate the curriculum, and the teachers responsible for each of the learning areas developed a program of work complementary to the theme. Examples of the themes used in these two schools included: decision making, the Olympics, relationships, systems, communication, popular culture, co-operation, Earth and people, and resources. Teachers commented on the different levels to which they were able to integrate their learning area topic with the theme, with most teachers expressing the view that they were able to make a number of significant links.

Cross Curricular Approaches

Several schools focused on cross curricular issues such as numeracy, literacy and computing skills, and teachers commented that these issues served as a basis to their integration between learning areas. For example, a technology teacher pointed out that literacy was clearly integrated into the technology course through the interpretation of the design brief and the written assignments, and that mathematics skills were utilised especially with measurement. Computing was also integrated, with students using word processors for the research assignments and programs such as CAD for the design of products.

Technology-Based Projects

One school used a technology-based project system of integration. Students were given a project to work on for 10 to 12 weeks which included a technological, a scientific and a mathematical research component. An example of a technology project brief was to "design and produce an electric powered vehicle that can climb a steeper gradient on the standard test track than anyone else's." The technology research component investigated traction options, materials and construction techniques, motor mounting options and power transmission systems. The mathematics research component investigated the effects of changing variables on standard Lego model hill climbers and recording, presenting and analysing their group's results from the time trials.

Competitions

Teachers at some of the schools mentioned that competitions such as the Solar Car Challenge and Science Talent Search provided good opportunities for integration between science, mathematics and technology. The Solar Car Challenge involved students in making a solar powered car and then racing the car against other students' creations. Students engaged in science through the investigation of solar energy, in technology through the construction and improvement of the vehicle, and in mathematics by working out the most efficient angle for the solar panel and the statistical analysis of racing trials.

Topic Integration

A mathematics teacher and a social science teacher in one school initiated an integrated project completely amalgamating the mathematics topic of Statistics and the social science topic on World Environment. The project ran for three weeks and required groups of students to (i) research a developed and (ii) a developing country and perform various statistical analyses on the data they collected (such as mean, mode, median and standard deviation) and present the results in a graphical form.

Integrated Assignments

Three schools used integrated assignments between learning areas that took between one lesson and two weeks to complete. For example, in one school, the mathematics teacher organised integrated mathematics and science investigation style assignments every five to six weeks. One of these investigations was on pendulums and involved the Year 8 students in developing a hypothesis and experimental procedure, statistically evaluating the data and presenting the results in graphical form.

Synchronised Content and Processes

Many teachers explained that the content in their different learning areas was synchronised as much as possible to allow similar content and processes to be taught at similar times. This involved the teachers in each school writing down everything they hoped to achieve in the year, making a map of the possible links and then rearranging the program where possible. One example of these links involved chi square analysis in mathematics/statistics and Punnett square problem solving in genetics. The teachers were able to synchronise the teaching of these concepts and explicitly link the ideas together.

Local Community Projects

Two schools had been involved in local community projects which integrated skills and content from a number of learning areas. One of these projects involved students, in liaison with a local shopping complex, providing plans for an improved arrangement of parking and pathways prior to major earthworks taking place. A second school said that they had worked with the local council to prepare an inventory of services provided to the community.

Common Teaching Approaches

One form of integration involved using the same framework for designing and writing up investigations in mathematics and science. Teachers said that using the same approach helped students to perceive similarities in the processes involved in working scientifically or working mathematically. One teacher commented that the staff members in her school tried to utilise student-centred teaching strategies as much as possible, and that this common base to their teaching approach provided a catalyst to integration of content and skills across the learning areas.

Natural/Informal Integration

Teachers in four primary schools found that much integration happened naturally because they taught the majority of learning areas to the same students, and "links just cropped up". In one school, technology was promoted as a vital learning tool to extend other subjects. For example, mathematics investigations were used in technology projects and the students explored such things as the cultural value and profit margin of the products. One group of students made a bird feeder by designing a template and then constructed the final product. Students' mathematics skills were assessed through this technology-based project.

Issues Arising from Integrated Practice

Interviews with teachers raised several issues about integration, including the process of getting started, implications for teaching, structural implications, implications for students and the breakdown of departmental structures. Each of these issues is discussed below.

Getting Started

Teachers mentioned several factors that helped initiate the process of integration, including prior planning involving all participating teachers. This created a collective vision and promoted collegiality. The importance of administrative support from people such as the principal was an important factor for motivating change. A caring ethos was regarded by some teachers as a positive factor facilitating the process of integration by encouraging better relationships between students and teachers. Professional development was also highly regarded by teachers who had the opportunity to visit schools where integrated approaches had been implemented.

Implications for Teachers

Teachers felt that commitment and passion were necessary for the challenging and innovative task of integrating across learning areas. The willingness to take risks was seen as a desired quality because of the need for teachers to forego their traditional practices, often established over long teaching careers. The ability to work effectively in teams was considered to be important for integration, especially in high school situations, because of the necessity to work closely with teachers from other learning areas. being recruited into a school knowing that integration was something that would be encountered was said by those in that situation to be an advantage because they 'knew what they were in for'.

Teaching experience in integrated situations and an intimate knowledge of the Westaer Australian *Outcome Statements* were also recognised as factors that facilitated integration. One principal noted that successful integration required teachers to manage a complex and delicate balance between knowing their own learning area deeply and knowing the specifics and commonalities between different learning areas.

Teachers felt they benefited by working in integrated environments because they could choose content to motivate and interest their students; it was a more economical way of achieving the outcomes; it helped them to co-operate and develop professionally, and they enjoyed working with teachers from other learning areas. Some teachers expressed frustration at the slow process of implementing integrated practices, the trial and error nature of the task and the increased work-load on top of their normal teaching duties. These factors could be stressful, especially for those in their first year of teaching.

Structural Implications

Ongoing collaborative planning time was probably the most frequently mentioned factor necessary for integration. A flexible timetable allowed teachers to take students on excursions, to team teach, and swap, extend or shorten lessons when necessary to allow for more integrated practices. Sharing materials with other schools, departments or learning communities and designating responsibilities to individuals in teaching teams was said to help reduce the heavy workload. Principals from two schools with a high number of new teachers each year stressed the necessity of providing induction sessions to orient new staff to integrated curriculum approaches.

Implications for Students

Teachers noted the advantages of integration for their students. The contextualised nature of problem solving was a highly-regarded benefit of integration, especially by mathematics teachers. Some noticed their students had better understanding of mathematics and science concepts when they had applied their knowledge to a practical task in technology and, conversely, the technology products were of a better quality when the students were able to use mathematics and science skills and knowledge to improve their designs. Teachers as well students appreciated the worldly application of the concepts.

To some teachers, an integrated environment meant that students perceived the common threads between the separate learning areas, and could better transfer knowledge and skills between subjects. Teachers were able to reinforce similar ideas in different teaching contexts and could also come to a consensus on how to teach common concepts. Other benefits included the enhancement of group working skills and creativity; increased co-operation and collaborative learning; successful behaviour modification among students; responsibility for their own work, and an increase in the mentoring between students of different ages. Difficulties for students included the lack of ability to plan and manage their time effectively for integrated projects, a lack of enjoyment of the work, and a realisation that other students didn't work hard enough to accomplish set tasks.

Breakdown of Departmental Structure

Frequently mentioned obstacles and difficulties to integrated teaching practice related to the breakdown of traditional departmental structures. Team teachers missed the specialist professional support of the traditional subject departmental groupings. Teaching in integrated situations often meant that teachers were working outside their subject speciality. These teachers said they lacked confidence in their ability to teach in this situation and, most importantly, they raised concerns about the implications for student learning.

The teachers in one primary school were concerned about integration because they valued science, mathematics and technology as different subjects with different orientations including processes, concepts, conventions and attitudes. These teachers believed that teaching in an integrated way might lead to science, mathematics and technology becoming an "amorphous mass". They explained that teachers need to be explicit and clear about what they are teaching and what outcomes are to be achieved.

Secondary teachers, especially those with a mathematics background, expressed concern at the heterogeneous nature of integrated classes and the difficulty of changing from traditional arrangements into homogeneous ability-level groups. Other teachers lamented that the integration they were involved in seemed contrived and imposed, and therefore the links between the subject areas were superficial and unrealistic.

The breakdown of departmental structure did not always have community endorsement either. Parents, teachers and the general community are secure in traditional structures and some teachers commented on a general fear of change.

Discussion and Conclusions

All forms of integration observed in the 16 Western Australian schools in this study maintained the discrete subject disciplines and integrated by means of themes, projects, assignments, synchronised content, cross curricular issues, competitions, school specialities, and teaching approaches. Synchronised content, or "parallel discipline design" (Marsh, 1993, p. 4), together with multidisciplinary thematic approaches which involve various subjects making contributions to a central theme, are small steps from traditional discipline based approaches (Marsh, 1993). The identity of each subject was maintained and subject teachers devoted varying amounts of time directly related to the theme. Marsh (1993) is of the view that it is very difficult to get teachers to undertake themes based on interdisciplinary concepts and topics where the disciplines become secondary to the theme. Many would argue that the integration of concepts in this way leads to more meaningful contexts for students and therefore enhanced learning possibilities (Bean, 1991). It is noteworthy that none of the schools in this study was involved in more consummate forms of integration such as interdisciplinary themes, student planned and implemented themes or whole school curriculum integration.

The results of this study highlight the nature of integration as a double-edged sword. On one hand teachers observed many benefits of integration for their students, including better understanding of mathematics and science concepts when applied to contextualised technology tasks. On the other hand, teachers raised concerns about departmental structure, their own insecurities, and the depth of content in each of the respective disciplines. Some teachers felt insecure when removed from their subject departments because they felt the robustness of the content was lost. It is pertinent that some of the primary teachers interviewed in this study raised concerns about mathematics, science and technology becoming an "amorphous mass" through integration. For many teachers, it threatened existing structures of power and control

Curriculum integration is not an end in itself, but a means of achieving basic educational goals. A fundamental goal of education in the middle school years is to deliver a curriculum which is relevant to students entering early adolescence. This is a difficult task for even the most motivated of teachers. This study identified several ways that teachers have been able to achieve this goal using several different forms of curriculum integration. While integration may not provide the ideal, nor the only way to solve the vexing problems associated with middle schooling, the evidence from this study suggests that some forms of realignment and reinvention of subject boundaries can provide enhanced opportunities for students experiencing this important stage of their schooling.

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