Case Studies of Multidisciplinary Approaches to Integrating Mathematics, Science and TechnologyEducation

Robert C. Wicklein and John W. Schell

Traditionally, school curriculum has been largely based on the concept that instruction should be separated into distinct subjects for ease of understanding and then reassembled when complex applications are required. Although it is assumed that students readily re-connect their school knowledge and then use it in an applied context outside of the classroom, recent research does substantiate this belief (Crohn, 1983; Hawkins, 1982). Here in lies the crux of the matter, the school curricula is a segregated approach to instructional topics which does not adequately address the reassemblage of topics into a coherent body of knowledge to be used by students.

Senge (1990) addresses the fragmented way that we as a culture have been trained to solve problems. He writes:

> From a very early age, we are taught to break apart problems, to fragment the world. This apparently makes complex tasks and subjects more manageable, but we pay a hidden, enormous price. We can no longer see the consequences of our actions; we lose our intrinsic sense of connection to a larger whole. When we try to 'see the big picture,' we try to reassemble the fragments in out minds, to list and organize all the pieces. (p. 3)

The curricular concept of integrating or connecting school subject areas has gained significant attention in recent years as a plausible solution to developing a more relevant approach to teaching and learning (Adelman, 1989; Department of Labor, 1991; Cheek, 1992). Specific attention within the technology education field has been directed at integrating mathematics, science, and technology (LaPorte and Sanders, 1993; Scarborough, 1993). The

Robert C. Wicklein and John W. Shell are Assistant Professors in the Technological Studies Program of the Department of Occupational Studies, University of Georgia, Athens, GA.

integrative or multidisciplinary curricular approach related to technology education seeks to help students learn and appreciate the relevancy of how school subjects are tied together and how each subject builds on the other.

Although this is a noble task, the question of educational worth has not been determined with any degree of accuracy. The question remains, is the integration of mathematics, science, and technology education a step in the right curricular direction or are we again *"jumping on the band wagon of the most current education reform movement?"* There is a need to develop exploratory programs where evaluation can be conducted to determine the value of integrating curriculum. There is also a need to establish a knowledge base that will identify the most current findings related to this curriculum issue.

Therefore, the objectives of this research were to: (1) Review the literature reflecting the main fields of thought pertaining to integration of subject matter, (2) Present actual case studies of multidisciplinary approaches to curriculum planning and implementation at four high schools and draw conclusions regarding the development and implementation of multidisciplinary approaches from four pilot testing sites.

Review of the Related Literature

Recent professional literature in technology education has supported the idea of integrating traditional academic material with technology material (Gray, 1991; Wirt, 1991). However, relatively few authors have provided substantive philosophical and psychological reasons *why* integrating these materials would help modernize or improve education. Upon careful examination of the professional literature on the topic one finds that there are compelling reasons to implement and then evaluate these educational reforms. Germane to this topic are theories of advanced learning and thinking, situated learning (context), transfer of learned knowledge, the nature of problems to be solved, and working in cooperative teams.

Advanced Learning and Thinking

Spiro, Coulson, Feltovich, and Anderson (1988) have defined *advanced learning* as an intermediate stage on a continuum between the introduction of new material and practiced expertise. In this intermediate phase, students learn "what to do" with acquired information. Central to advanced learning is the concept of thinking. Resnick (1987) contends that thinking defies definition within the traditional paradigm of public education. However, she offers several key elements that are descriptive of higher-order thinking. According to her research, higher order thinking is nonalgorithmic, (meaning the path of action is not specified in advance), complex, and often yields multiple rather than simple solutions. Higher-order thinkers demonstrate nuanced judgment and the ability to use more than one criteria when solving complex problems. They also live well with uncertainty, are self-regulated, can impose meaning on apparent disorder, and demonstrate sufficient effort when elaboration and judgment are required.

Ill-structured Workplace Problems

Berryman and Bailey (1992) described an emerging workplace that is dependent on accelerated product and process innovation. Companies must respond to fast-changing markets by rapid delivery of products and services. These "quick response" capabilities are critical to successful international competition. Competitive workplaces require advanced learning and thinking on the part of employees at lower and lower organizational levels. These mental skills are particularly important in situations where complex problems must be solved under volatile conditions. Indeed, throughout their lives vocational graduates will encounter a diverse array of work and personal problems that are complex, ambiguous and cannot be solved using the same solutions every time (D'Ignazio, 1990). Spiro and Jehng (1990) refer to these as "ill-structured" situations or environments. To solve ill-structured problems, workers and learners must be able to adroitly use, or transfer, information often learned in other settings.

Learning Transfer

Educators have traditionally assumed that schooling directly enabled transfer to occupational or life settings. Yet, Berryman (1991) aggressively reports otherwise. She maintains that individuals *do not* predictably use knowledge learned in school in everyday practice, nor do they use everyday knowledge in school settings. Perhaps most importantly, learners do not predictably transfer learning across school subjects. Berryman (1991) writes that context is critical for understanding and thus for learning. "[T]he importance of context lies in the meaning that it gives to learning" (p. 11).

Wittgenstein (1953) postulated that the meaning of information is determined by its intended use. Bransford and Vye (1989) further believe that "students must have the opportunity to actively use this information themselves and to experience its effects on their own performance" (p. 188). If knowledge has no apparent application, it may not be perceived as meaningful nor readily transfer to other learning situations (Bransford, Sherwood, Hasselbring, Kinzer, and Williams, 1990). Brown, Collins, and Duguid (1989) believe that advanced concepts are learned and progressively developed when thought of as "mental tools" to be used in meaningful activities of a "particular culture." However, these tools can only be fully understood through their use in a particular culture which involves changing the user's "view of the world and adopting the belief systems of the culture in which they [the tools] are used" (p. 33). This approach rests on the assumption that there is more to using a tool (*i.e.,* developing an advanced cognitive skill) than mastering a list of explicit knowledge and rules.

Activating Potential Knowledge

To the extent that schooling is isolated from the community, too many concepts are learned in abstract ways. Theorists such as Berryman (1991), Resnick (1987), and Spiro, et al. (1988) believe that transfer of knowledge is inhibited by this condition which does little to activate knowledge for later use. Lave (1988) approaches this problem by advancing the concept of "authentic activity" which she defines as ordinary practices of "just plain folks" within a given culture. Rather than using the educational syntax of the classroom, they propose using everyday activities as a means of providing contextualized or situated learning. This places learners in a free and more relevant classroom shaped by a community of practitioners. Perkins and Salomon (1989) concluded that "to the extent that transfer does take place, it is highly specific and must be cued, primed, and guided; it seldom occurs spontaneously" (p. 19).

In summary, the research suggests several specific areas that must be considered by educators who wish to implement multidisciplinary teaching and learning. This is particularly important when the expectation of higher order thinking and problem solving is adopted as it has been in many suggestions for reform of technology education.

Case Studies of Multidisciplinary Demonstration Projects

To evaluate school programs where multidisciplinary curricula can be measured for effectiveness, it was determined that four (4) pilot high school demonstration sites would be established in four different states within the mid western section of the US. Each school established a multidisciplinary team comprised of teachers from three respective academic disciplines: technology education, science, and mathematics as well as a school administrator and a school counselor. In addition to the high school multidisciplinary team was a resource team to help support the local school integration activities. The resource team was comprised of teacher educators from the academic areas of technology education, science, and mathematics along with the state supervisor for technology education. Each demonstration site team was encouraged to develop a multidisciplinary curriculum that integrated mathematics, science, and technology education that they believed would be workable and effective within their unique educational environment. Although a limited number of curriculum integration criteria were encouraged (e.g., context based learning, learning transfer, working/learning teams, higher-order thinking skills), no effort was directed to specify curriculum models to be used.

To protect the confidentiality of the research participants, the demonstration schools are identified as Missouri, Nebraska, Colorado, and Oklahoma County School Districts (CSD's). These cases were studied and analyzed through three primary avenues of inquiry. The first inquiry was based on self-reported qualitative data from each of the demonstration sites. Each demonstration project team was required to explain in narrative form how they addressed or perceived each of the following project issues and concerns: *Goals of Their Project, Curriculum Approach Used in Their Project, Most Successful Aspect of Their Project, and Most Difficult Problem of Their Project*. The second method of inquiry was based on extensive personal interviews with students, teachers, and school administrators. Each project site was visited by a three (3) person team of researchers that conducted systematic interviews. The third inquiry effort was based on an analysis of three (3) open-ended questions that were part of a quantitative survey instrument administered to all student participants of the projects. The three questions provided opportunities for students to describe in their own words what they considered the most successful aspect of the project, the least successful aspect of the project, and how the project could be improved. Based on these three methods of investigation, the following cases are presented.

Missouri County School District

Overview. The mutidisciplinary instructional program at the Missouri CSD involved the use of technology in a Survey of Biology class with the support of the mathematics department. This course was distinct in that students received college level credit on a dual enrollment basis through a local community college. The teachers used a portfolio approach to evaluate the work of students in the class. As part of the portfolio, the students actively worked to supplement their learning through the use of instructional technology, problem solving approaches, and independent investigations. Problem-solving was particularly emphasized to establish, test and assist students to evaluate various hypotheses related to their research. In addition, the multidisciplinary approach was expanded into the agriculture department with the study of genetics and related horticultural areas.

Goals. The primary goal was for the teachers to understand that their particular instructional areas did not stand alone within the curricular offerings. The teachers worked well together in providing the students with an avenue by which they could properly use and discriminate data. It was also a goal that students realize that the realm of instruction is not confined to any constraints set forth by being in an isolated classroom. Students were permitted to move about the high school complex, accessing information, and using the facilities in other instructional areas. In addition to these primary goals, it was determined that an objective of the multidisciplinary project was to improve students ability to critically think and gather information that was pertinent to their research.

Curriculum. Since the *Survey of Biology* class was the focus of this project and was revised, in part, due to the experimentation with a multidisciplinary approach, the teachers in this project worked together to establish the objectives of the course with other instructional areas in mind. Students were instructed that this course would not be using a conventional education approach and that it would deviate from what they were accustomed to receiving in a classroom.

Objectives for the class were established based on a ill-structured problem-solving methodology with expectations that students would work independently and in small cooperative groups. Students were encouraged to access the faculty in the related instructional areas for support and instruction pertaining to their research. Conventional biological concepts were central to the course, however, they addressed these concepts through a research based problem-solving approach. The technology instructor provided students with guidance in the physical design and development of their research projects as well as providing opportunities to use technology laboratory facilities to construct and test their various research projects.

Most Successful Innovation. The most innovative success as described by the faculty was the relationship among the instructional areas. The coordinated efforts by the science and technology education instructors and to a lesser degree the mathematics instructor, created a learning atmosphere that provided students with a unique opportunity to learn in a much broader context. The principal at Missouri County program described this success in the following terms:

> In education, we have established artificial boundaries through Carnegie units and time blocks. These boundaries are inhibitive to learning in context and has established a paradigm of instruction of which these students have grown increasingly accustomed. By breaking down the autonomy among the disciplines, our students were able to realize that there was a relationship between the knowledge gained in one department versus the knowledge gained in another. By examining this relationship our students better understood the applicability of several subject areas in solving science problems. (Principal, Missouri CSD, personal communication, March 18, 1992)

Most Difficult Problem. The same pattern of instruction which is a constraint to teaching in most school programs existed in the program. Students had been trained to dismiss subject matter learned in one classroom as having little or no relevancy to another. This problem of artificial boundaries of school-based learning continued to exist during this project. Students tended to rely upon the immediate learning environment as their source of knowledge and then ceased to carry the learning beyond the classroom when the bell rang and the class ended. Although this problem abated to a degree during the school year, it continued to be a limiting factor for many students.

Nebraska County School District

Overview. The multidisciplinary program at the Nebraska CSD began by formulating a focus on a new method of instruction. The outcome of this development effort selected the *Principles of Technology* (PT) curriculum as the basis for integrating mathematics, science, and technology. The instructional staff worked together in developing a team teaching arrangement to present this curriculum. The three instructors supplemented the well established PT curriculum with additional material that helped place the learning in a more real world context for their targeted group of *"at-risk"* ninth grade students. These students were identified based on their past educational accomplishments and general attitude regarding education.

Goals. The primary goal was to increase the interest level of "at-risk" students in the instructional fields of mathematics, science, and technology. Through the application of an integrated "hands-on/minds-on" curriculum, students were encouraged to develop an interest in the practical uses of the three instructional areas. Efforts by the project team addressed the needs of these students to actively use the knowledge they were learning in class. By encouraging students to apply their learning outside of the classroom it was believed that greater meaning and retention could be attained.

Curriculum. The instructional sequence for the *Principles of Technology* (PT) course generally included a two hour block of time where the teacher team worked to address the major components of this curriculum. With this instructional design, students received both mathematics and science credit. Teacher-led discussions were followed with video presentations, math skills labs, student learning exercises, and laboratory experiments relating to the major components of the PT curriculum. Each segment of the curriculum was led by the teacher who was most skilled in that topic. This approach proved to be very successful, allowing the other two teachers to have opportunities to interact with individual students who needed additional help. Primarily, students worked in small groups to solve the various problems and experiments that were integral to the curriculum. Students were required to do library research, develop written technical reports, and develop special projects which applied an integrated approach to learning. In addition to the PT curriculum, the teachers provided supplemental instructional topics on solar collectors, barge building and testing, rocketry, and the creation of life sized moving mannequins. Each of these topics were highly motivational for the students.

Most Successful Innovation. The most successful aspect of the program was the improved motivation on the part of the students in this program to attend class and the reduction of discipline problems. This was measured through a comparison of school attendance records and disciplinary reports from the previous school year. In addition, students demonstrated an appreciation for the structured learning activities, an improvement in student self-esteem, and the development of a cooperative team mentality when addressing problems. The teacher team found that the joint teaching environment was both positive and conducive to professional growth. The understanding that no subject discipline exists in isolation was a realization for both the teachers and the students.

Most Difficult Problem. Although there was a perceived improvement in student attitude with regard to learning, several students in the program had difficulty in grasping the instructional content of this team taught course despite adjustments to accommodate their limitations. The teacher team encountered difficulty working together in the team teaching approach including difficulties in interpersonal communication, lack of commitment to the overall project goals, and orchestrating specific integration activities. It is important to note that there was a disparity of perceptions between the school administrator and the teachers regarding the teaching arrangements (i.e., 2 hour block-team teaching). The teachers presented a very positive view of this working arrangement while the administrator identified several negative aspects, primarily attitude and commitment that transpired during the course of the school year. The administrator suggested that the curriculum format was appropriate however, the teacher team was not working together to bring about suitable subject-matter integration.

Colorado County School District

Overview. At the Colorado CSD the integration of the mathematics, science, and technology curricula took on three distinct approaches. Each of the primary subject matter-teachers designed one of their courses to integrate the curriculum (*Algebra 1, Applied Physics*, and *Introduction to Engineering*). The instructional design strategy that the mathematics and science teachers followed was based on the concept of including new content and an alternate system of delivery (e.g., instructional topics from the other school subjects and unique instructional activities developed by the multidisciplinary teacher team) into existing courses. This may seem rather trivial at first glance but the teachers actually taught specific components within the three courses as well as shared ideas, media, and instructional activities. This was accomplished by allowing each of the teachers to rotate into and out of each others classroom.

Goals. The goals of the program were to:

- Provide a knowledge base of mathematics, science, and technology through instruction and application
- Interpret learning through the integration of subject areas
- Transfer learning to unique problems and solve for such problems
- Analyze a given learning situation and adapt to an individual learning style
- Evaluate solutions to problems in order to recognize and develop new problems

Curriculum. The curriculum design for the program followed three separate curricular strategies. The instructional sequence for the *Algebra 1* class was a modified sequence from the standard *Algebra* progression based on the Standards for School Mathematics objectives (National Council of Teachers of Mathematics (NCTM), 1989). Various learning activities were incorporated into the class to help students experience the scientific and technological applications of *Algebra*. The instruction sequence for the *Applied Physics* class was the *Principles of Technology* (PT) curriculum yet, it was modified substantially to fit perceived needs of the students and teachers. The primary modification of this curriculum was a self-paced modular format. The *Introduction to Engineering* course required the largest degree of development. As a new course designed to have integration of subject matter as a core element it required the design and development of an independent sequence of objectives. The objectives for the *Introduction to Engineering* course were to:

- Interpret mathematics and science principles
- Apply technology to solve for natural and man-made problems
- Synthesize mathematics, science, and technological techniques to aid in problem resolution
- Evaluate engineering solutions for appropriateness
- Appreciate the broad spectrum of knowledge and application required in engineering
- Accept responsibility for self-motivation and self-learning of mathematics, science, and technology in the realm of engineering

The use of computer-based-instruction using HyperCard stacks and interactive video provided unique learning experiences for students in both the *Applied Physics* and *Introduction to Engineering* courses.

Most Successful Innovation. The most successful innovation of the program was the development of the *Introduction to Engineering* course and the revision of the *Algebra 1* and *Applied Physics* courses. The coordinated efforts of the teachers to develop activities that supported the multidisciplinary approaches within each course was also viewed as a very positive outcome of this project. Faculty members worked together to collectively create, identify, and develop new instructional strategies for the integration of the curriculum. Positive change in the overall school curriculum was evidenced in that project members used cross-curricular activities in other classes they were teaching and faculty members who were not part of the project team began to consider multidisciplinary ideas for their classes as well. In addition, the use of teacher resources was greatly expanded. The principal remarked that, "In a small school, like [the Colorado CSD], the teacher is the primary resource, and by using the talents of different instructors the dynamics of classes and the instructional quality was greatly enhanced. All staff members recognized that they needed to be good educators, and great teachers in their specific subject area. This integrative approach to instruction aided the faculty to accomplish this goal." In addition to improving staff development, the project allowed students to experience activities that went beyond the traditional abstractness of learning school based concepts. Teachers within this project attempted to take the instructional content beyond the school grounds by allowing students to research, design, develop, and problem solve on topics that were of some avocational interest (i.e., kite design, development, and testing).

In addition to instructional advantages, many positive aspects of the integration project were noted by students. The greatest positive change for students came from those who were in the *Algebra* class. The mathematics instructor, commented that he rarely heard students complain "When are we ever going to use this stuff?" Student were able to see direct applications of *Algebra* in a variety of technology based activities.

Most Difficult Problem. A major concern was the perceived lack of student involvement in deep and meaningful discussion of the links among mathematics, science and technology subjects. This is primarily due to the over reliance on individualized curriculum and instruction and the mind-set of the teacher team (e.g., deep discussion was not high). In addition, access to the technology center laboratory was viewed as a limitation. This facility was used as the primary classroom for each of the teachers in this project and was stretched beyond its capability on several occasions. Many efforts were made to accommodate the student need for laboratory time during the year, both before and after school. Although these efforts were helpful, laboratory availability was viewed as a major limitation.

Oklahoma County School District

Overview. The *Principles of Technology* (PT) curriculum was the focus for the Oklahoma CSD project. The faculty team worked together to present a coordinated curriculum where each teacher took responsibility for the specific section of the curriculum that aligned with their particular field of study.

Goals. The goals for the program was to improve mathematics and science skills for students with below average abilities in these areas. In so doing, it was hoped that these same students would develop a greater interest in science and mathematics. A secondary goal was to incorporate other subject areas into the multidisciplinary instructional approach.

Curriculum. A unique approach to implementation was employed. Because the students in each of the three classes (mathematics, science, and technology) were *not* the same, the teachers designed a rotational schedule in which they moved to each of the classrooms to address a particular segment of the curriculum that pertained to their instructional field. In using this approach, specific instructional content could be delivered while maintaining a coordinated integration curriculum that students used to build on their knowledge of mathematics, science, and technology. In addition, student learning teams were created where each team was sub-divided into field experts. That is, each team had a student supervisor, a mathematics expert, a technologist, and two laboratory technicians. It was believed that this type of learning arrangement provided an ideal environment to address the various components in the PT curriculum as well as replicating "real world" strategies for working and solving problems. This approach to the team work concept allowed for excellent cooperative learning, peer teaching, and teamwork responsibilities. The friendly competition between teams within the classes also heightened the interest and learning that was taking place.

Most Successful Innovation. The most successful aspect was the creative use of the teaching staff. By allowing each of the teachers to rotate to the individual classrooms the students were introduced to a coordinated integrative curriculum without the obtrusive restructuring of existing class schedules. Although the coordination efforts were viewed by the instructional staff as a very positive product, it was also perceived as a significant logistical problem which periodically caused confusion for both teachers and students. In addition to the teacher rotation, the creation of the student learning teams was also a very positive experience for most students in this project. Students were able to perceive the importance of working together to solve a common problem as well as, exposure to occupational strategies of modern businesses and industries.

Most Difficult Problem. It was somewhat of a surprise to the teacher team that there were some students who resisted the multidisciplinary approach to the learning process. It was obvious that a number of students wished to be accountable to only one teacher. This resistance was manifested by the reluctance of some students to transfer knowledge from one subject area to another. The staff identified this hesitation to be based on limitations of students, specifically related to student reading ability and computational skills. Efforts are currently being formulated to address these concerns as the project team plans for future integration activities.

Findings

This research sought to develop and implement multidisciplinary approaches to the study of mathematics, science, and technology in the high school and to identify successful factors of those approaches (see Table 1).

After a careful examination of each of the pilot demonstration schools, three primary factors were identified that significantly affected the success or failure of the multidisciplinary curriculum: (1) teacher and administration commitment to the integration approach, (2) innovation and effort in curriculum re-design, (3) administration and teachers coordination of integration plan. Each of these factors are of paramount importance to creating the type of integrated curriculum that will help students learn, apply, and transfer learning beyond the classroom environment.

Commitment to Integration

Teacher and administrator commitment is critically important to a successful multidisciplinary program. Each teacher must understand that the sum of their collective efforts can be more than the simple addition of multiple school subjects. The effort that is needed in planning, coordinating activities, cross-training in other subject areas, making adjustments to teaching styles, making “mid-course” corrections during the school year, and re-designing and planning for future class activities are substantially more than what is experienced by a teacher working alone.

Interpersonal relationships become much more of an issue in the multidisciplinary curriculum environment. Teachers and administrators must be able to work together to accomplish their collective goals; their ability to communicate specific instructional ideas are essential for a smooth coordination of the multidisciplinary curriculum.

Table 1
Summary Comparison of Cases With Project Components

	Missouri County School District	Nebraska County School District	Colorado County School District	Oklahoma County School District
GOALS	1.Interdependency of subjects 2. Open access to learning 3. Improve critical thinking	1. Increase students (at-risk) interest in mathematics, science, & technology 2. Actively use knowledge & learning transfer	1. Evaluate problem solutions & develop new problems 2. Interpret learning through instruc tional integration 3. Transfer learning beyond classroom 4. Create new learning opportunities	1. Improve math & science skills of students w/ below average abilities 2. Incorporate other subject areas into multidisciplinary approach
CURRICULUM	1. Focus on Survey of Biology Course 2. Original experimentation & portfolio review	1. Focus on Principles of Technology Course 2. Team teaching in two hour block period	1. Focus on 3 courses - Algebra 1 - Applied Physics - Intro. to Engineering 2. Coordination & use of teacher expertise	1. Focus on Principles of Technology Course 2. Rotation of teachers to address specific instruc tional areas
SUCCESS	1. Teacher cooperation & relationships 2. Removal of artificial learning barriers	1. Improved student motivation based on class attendance 2. Team teaching was positive & conducive to professional growth	1. Development of new course of integration - Intro. to Engineering 2. Coordination efforts by teachers 3. Context based learning	1. Creative use of teacher's skills 2. Student learning teams - content experts, peer teaching
PROBLEM	1. Student reliance on specific subject instruction causing limitation of learning transfer	1. Inability of students to grasp instructional content 2. Teacher inter personal relation ships 3. Lack of commitment to project goals	1. Lack of student ability to discuss learning at deep levels 2. Limitations of physical facilities	1. Student resistance to multidisciplinary concept 2. Lack of teacher coordination of curricular content

There is an important link between the need for commitment to multidisciplinary instruction and the recent research on teacher empowerment. Empowerment can be defined as the opportunities a person has for power, choice, autonomy, and responsibility (Lightfoot, 1986). Maton and Rappaport (1984) found that a sense of community and commitment are strongly associated with the empowerment of community leaders. Further, empow- erment of teachers is mostly likely to occur in organizations where partici- pation, innovation, assess to information, and accountability are encouraged (Dobbs, 1993). In the Colorado CSD, we found that multidisciplinary teachers did have opportunities to develop expert organizational power. As a result, these teachers recognized as "experts" were empowered to positively influence their organization along horizontal and vertical axis (Hampton, Summer, and Webber, 1987). With the strong support of the administration, the Colorado County teachers had meaningful license to participate in fundamental curriculum changes. They had unlimited access to technical and pedagogical information which further added to their base of expert power. Perhaps most importantly, the organizational culture at the Colorado CSD were open to innovation and experimentation. Environments that encourage innovation are "hospitable to interesting people with innovative ideas–environments that encourage people to explore new paths and to take meaningful risks at reasonable costs, environments in which curiosity is highly regarded as is technical expertise" (Dobbs, 1993, p. 53).

Innovation and Effort in Curriculum Design

The second major factor effecting multidisciplinary curriculum efforts was the degree of innovation and effort teachers and administrators exercised in the design/re-design of the school subjects. Based on interviews and discussions with student participants, teachers, and administrators, the project sites that approached the goals of multidisciplinary education from a basis of significant curriculum change had more success overall than the project sites that addressed multidisciplinary education as a methodological adjustment to an existing curriculum. The Colorado CSD and to a lesser degree, the Missouri CSD were perceived by the researchers as developing the most extensive integration design/re-design of their curricula. In the Colorado County Program, two courses were re-designed to implement an integrated curriculum that would address aspects of each of the three subject areas. While the focus of each of these courses were aimed at fulfilling specific subject area requirements (i.e., *Algebra 1* and *Applied Physics*) the content of each course was adjusted in order for students to experience the integration of each of the three subject areas. The third course in the Colorado County program *(Introduction to Engineering)* was specifically designed to implement a multidisciplinary approach to teaching and learning. Students learned and applied mathematical formulas, science concepts, and technological applications on a regular basis in order to solve problems and fulfill course requirements. The efforts to innovate and create new and unique ways to teach students the interrelationships of mathematics, science, and technology were perceived by students to be the most rewarding activities in the project.

Teachers in the Nebraska County program and the Oklahoma County program used a pre-designed curriculum as the source of their multidisciplinary effort. In both cases the *Principles of Technology* (PT) course was the source of the curriculum. The PT curriculum provides by its design specific integration and application of mathematics, science, and technology principles. This curriculum however, did not motivate the student participants to be able to discuss technological issues at depth nor did it create an atmosphere where learning would be transferred beyond the classroom. This was a significant problem despite the fact that the teachers in these cases used a variation of the original curriculum design (i.e., team teaching, 2 hour block period, teacher rotation).

Innovation and effort in the design/re-design of the curriculum for multidisciplinary instruction proved to be highly significant in the overall success of this project. Teachers that made more effort and were more creative in their curriculum approaches were rewarded with higher levels of student learning and appreciation. Yet, these efforts alone were insufficient. Although the Missouri and the Colorado projects showed significant innovation in redesigning their curricula, neither appropriately considered the importance of the "learning context." Looking at the problem from a curriculum perspective, Caine and Caine, 1991) suggest that multidisciplinary curricula should be "infused." Perhaps an appropriate metaphor is "blending" a curriculum cake mix. To the extent possible, we believe that blended multidisciplinary learning should occur in realistic and applied settings where the student interacts as a member of a "community of practice" where "authentic" mathematics, science, and technology activities occur as one. We believe that technology and its cultural implications serves as an important curriculum theme where by mathematics and science can be co-investigated. However, curriculum designers should not only focus on integration of hard sciences. Liberal Arts subjects can also be effectively infused.

Coordination of Integration Plan

The third factor that had a notable influence on the overall success of this project was the coordination efforts between teachers and administrators. The pilot demonstration schools that had the most success with their multidisciplinary project were those that were allowed to develop and reorganize class scheduling. Although this factor had mixed results in the pilot schools, by in-large, moderate to substantial changes in teaching loads, class periods, and student scheduling were viewed as important considerations in the overall success of the project. The Colorado CSD allowed the most substantial degree of change to take place in scheduling and curriculum adjustment (e.g., creation of new course, re-design of existing courses, rescheduling of students and teachers) and met with the greatest degree of success based on teacher and student responses. The Nebraska CSD program also made significant adjustments in scheduling of teachers and students (e.g., team teaching, 2 hour block instruction period, rescheduling of students) however, only moderate success of this project was perceived by teachers, administrators, and students.

Experimental efforts made by administrators to allow for scheduling changes were viewed as extremely important to accomplishing meaningful multidisciplinary instruction. Once again, we are reminded of the importance of administrators and teachers who share governmental authority and power. Complex problems such as school scheduling and use of community locations, will only be solved by empowered teams of professionals. These are administrators and teachers who are willing to jointly refocus their organizations on student learning as the first priority, and the retention of tradition as a secondary consideration. In this research, we have found that the Missouri and Colorado County Districts have demonstrated a willingness to “break the traditional mold.” We are reminded of the statement of the Colorado Principal. “In a small school [like ours], the teacher is the primary resource, and by using the talents of different instructors the dynamics of classes and the instructional quality was greatly enhanced.” This is evidence of teacher empowerment that has resulted in effective multidisciplinary instruction.

Conclusions

Stepping back from our research, we believe that we can make the statement that these multidisciplinary projects have made a positive difference in both teachers and students. We have proven that where administrators are open to change and teachers are willing to empower themselves and take individual responsibility, increased student motivation and learning can be effected.

However, these demonstration projects have been subject to many limiting factors. Future research will focus on ways to “situate” integrated learning and teaching and on the importance of building more effective teams of administrators and teachers prior to and concomitant with curriculum reform.

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