Impacts and Implications of Integrated Curricula

by

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A Project Submitted to the Faculty of

The Evergreen State College

In Partial Fulfillment of the Requirements

for the degree

Master in Teaching

2009

This Project for the Master in Teaching Degree

by

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has been approved for

The Evergreen State College

by

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Date

ACKNOWLEDGEMENTS

I am first and always grateful to my beloved mother, Velma Smith. She is a kind, loving, supportive person who brings joy to my life and sees me through difficult times. I am thankful to my sister, Debbi Alioto, who makes me laugh and helps me keep up my spirits. I am grateful to all of my family, biological and chosen, for your love and support.

Thank you to Masao Sugiyama, whose patience, humor, and coffee eased the stresses and challenges of a rigorous program. Thank you to Terry Ford, for your dedication to education, and to George Freeman, for a listening ear and a kind heart. Lastly, I am grateful to Nicole Coots, a wonderful friend and colleague, for innumerable kindnesses and words of wisdom.

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ABSTRACT

Humans live in a world that is not defined by rigid disciplinary boundaries. Exploring the world through the perspectives of academic subjects can be extremely useful; the world is too big and complex to see all at once. Yet there are indissoluble connections in nature, in our lives, that ought not to be ignored. An examination of the history of Western schooling illustrates the dynamic, changing nature of schooling, examining how disciplines and subject areas have risen and fallen in perceived importance over time. A review of the literature shows that there is a broad spectrum of approaches to curriculum, and that interdisciplinary learning happens in many contexts and with varying degrees of connection among subject areas. The research literature suggests that curricula taught in public school classrooms represent a wide spectrum of pedagogical approaches, from strictly subject-based teaching to fully integrated learning that draws on many disciplines. These various approaches to teaching all have advocates and detractors; the purpose of this paper is to highlight and discuss evidence and arguments around interdisciplinarity.

CHAPTER 1: INTRODUCTION

Introduction

Interdisciplinary and subject-based approaches to education are founded on differing philosophies about teaching and learning. Academic disciplines divide the universe into workable portions; many academicians become experts in their individual branches of inquiry, to the exclusion of other ways of knowing. The divides in some cases have become very deep: literature and mathematics departments at universities, for example, have very little to do with one another; they see their subjects, and their methods of exploring the world, as very different. One of the goals of interdisciplinary education is to find the connections among seemingly disparate subjects, to help students see the world as a whole, rather than looking only at fragments.

The spectrum of possibilities for a teacher designing learning experiences ranges widely, and individual teachers' choices are shaped by many factors. There are compelling arguments that can be made in favor of the models at each end of the spectrum, from strict subject-based education to broadly integrated learning. Some claim that discipline-based education is more rigorous, and that certain measures of student achievement may be higher in subject-based programs (Schug & Cross, 1998). Others point to evidence that interdisciplinary approaches are correlated with increased student interest and more positive attitudes about school (Beane, 1992). There may be compelling reasons for educators to draw on a wide variety of approaches to planning and implementing learning experiences.

This paper will examine the research literature to draw conclusions about the impacts of interdisciplinary education on students. What effects do integrated curricula have on student achievement, engagement, and attitudes about school? What are the differences in student outcomes in integrated and in subject-based classrooms? These questions are of enduring importance to teachers and to students. Teachers who strive to help students identify patterns and discover connections through interdisciplinary studies need to be able to back up their teaching practices with research evidence. Students will benefit from having a teacher who has explored the strengths and weaknesses of different approaches to teaching. The questions of how and what to teach are of central importance to the classroom.

Rationale

The Universe is fundamentally connected: everything is composed of the same kinds of particles, and every particle in the Universe exerts a gravitational pull on every other (Hawking, 1988). Organisms in an ecosystem are connected; individuals' actions impact one another. Life is connected. Human lives are not neatly divided into compartments; though we create categories to make sense of the world, the boundaries are blurry, and connections may be found everywhere. The same is true in education. Academic disciplines, developed and specialized over hundreds of years, have value and purpose (Beane, 1992). They are also interconnected with each other, and authentic investigations into the world frequently require a learner to integrate ideas and tools from more than one branch of academic inquiry.

The struggle between subject-focused educators and those who advocate for integrated learning has been playing out for decades, and the debate is still very much alive, though the terms used have changed (Dewey, 1938; National Society for the Study of Education, 1958). As educational trends have come and gone, as the proverbial pendulum has swung through its arc from Progressive to Classical and back, the relative presence or absence of cross-curricular study in public schools has shifted. Chapter two examines these changes in more detail; first, chapter one explores philosophical positions staked out by influential participants in this educational conversation.

Interdisciplinary curricula may be more appealing and feel more natural to elementary teachers, who routinely teach all core subjects, than to secondary teachers, who are more likely to be specialists, experts in one or two academic disciplines (Beane, 1995; Drake, 1998). In the world of elementary education, integrated approaches make sense even within current schooling structures;

using themes to connect ideas among traditionally separate branches of learning can make curricula more engaging for both teacher and students. An interdisciplinary approach also encourages collaboration among teachers, as colleagues may share expertise and lesson ideas, and develop thematic units together. This kind of cooperation is particularly essential for secondary teachers who want to build interdisciplinary connections. Proponents of integrated approaches place high value on student interest and engagement and cooperative learning, as well; these characteristics are supported by interdisciplinary educational practices (Beane, 1991). Students develop a holistic view of the world, which is both more true to life and more interesting than a fractured view.

Making connections is what learning is all about. Humans adapt prior understanding to incorporate new information and experiences into their view of the world. The perspectives humans hold on the world have their foundations in their brains, in the form of physical connections among complex, interconnected networks of neurons (Jensen, 2005). These networks are built by individuals' interactions with the people in their communities and the environments in which they grow and develop. People learn from their first moments by engaging with their surroundings, without regard to any course of study or discrete discipline. Early human experiences with the world have nothing to do with subject areas;

separate subjects are not considered a standard part of learning until adolescence.

Interdisciplinary education also has its share of detractors. Some research evidence suggests that integrated curricula do not raise students' assessment scores in all subjects; in some cases, measures of student achievement remain the same and may drop (Brewer, 2002; Porter & Masingila, 2000). There is also a perception that interdisciplinary studies are less rigorous, that students may miss important content if subjects are always combined. Some discipline purists argue that non-specialists borrow or alter concepts that they don't fully understand, rather than teaching an established course of knowledge, as the experts in secondary and post-secondary schools frequently do (Brewer, 2002; Schug & Cross, 1998). Sowell (1995) dismissed the attempt to create interdisciplinary curricula as "nondisciplinary, in that it simply ignores boundaries between the disciplines" (p. 205). Detractors of interdisciplinary studies insist that academic boundaries exist for a purpose, that humans are unable to make sense of the world as a whole without breaking it into parts (Sowell, 1995).

Even scholars who embrace the underlying principles of integrating curriculum recognize that there are inherent difficulties to this approach. In reporting findings on implementation, Lake (1994) highlighted this common conclusion in the research literature: *"curriculum integration takes time"* [italics in original] (p. 10). Teacher teaming and planning, for example, are valuable aspects of integrated approaches, and a system that allows flexibility and support for teachers to plan together has a greater chance of being successful than a system in which team planning is not supported by administration. They are also potential sticking points. Especially in middle school and high school, teacher collaboration is an essential component of effective curriculum integration, but coordinating planning time and teaching schedules can be a formidable challenge.

There is considerable variety in the approaches taken toward integrating study in public schools. Newell and Green (1982) argued that confusion about different ways of integrating disciplines is unsurprising, as the disciplines themselves are ill defined. They also pointed out that many disciplines are fragmented within themselves, further complicating attempts to develop connections across subject areas.

Detractors of interdisciplinary approaches often fail to cite research showing negative effects of integrated curricula; instead, they point to the paucity of well-crafted research supporting interdisciplinarity. Similarly, proponents of interdisciplinary curricula frequently make scant mention of quantitative research, emphasizing learning theory, especially the experiential approach made famous by John Dewey (1938). Many articles published, from multiple perspectives, focus their arguments around philosophies of learning, or the strengths and importance of traditional domains of knowledge to the experiences of individual teachers and schools. Both advocates and detractors of interdisciplinary education make reasonable arguments. The purpose of this paper is to sift through the arguments and, more significantly, weigh the evidence and consider the implications of integrated education for classroom practice.

Definition of Terms

Interdisciplinary studies draw on multiple disciplines for essential ideas, and attempt to integrate the insights of disparate disciplines.

Multidisciplinary studies incorporate multiple subject areas into one theme or context, but do not necessarily make connections among the insights of the disciplines.

Cross-disciplinary studies apply the principles and practices of one discipline to subject matter of another; this type of study may or may not be interdisciplinary in the sense of integrating important ideas from different areas of inquiry.

Statement of Purpose

This paper examines the evidence from the research regarding the effects of interdisciplinary approaches to education. Integration in the intermediate and middle school levels will be the focus, but the literature review will draw on studies performed in a variety of settings, from elementary through high school. The question of whether to implement an interdisciplinary curriculum or a subject-based program is essential for teachers seeking out best practices. What are the impacts of interdisciplinary education on student achievement, engagement, and attitudes about school?

Summary

Humans live in an interdisciplinary world. The world outside of academia does not run along boundaries imposed by university departments, and real-life problems do not fit themselves neatly into compartments, to be easily solved by practitioners of a single way of doing things. Real life has no respect for disciplinary limits, and educational practices should reflect the blurry boundaries found outside of schools. By involving students with interdisciplinary inquiries, educators have the opportunity to encourage creative thinking and to help students understand the interconnectedness of the world, of the universe.

CHAPTER 2: HISTORICAL BACKGROUND

Introduction

This chapter considers significant historical trends that have influenced American education, with particular attention to the forces shaping the evolution of interdisciplinary approaches to teaching and learning. The origins and development of formal education in the United States will be reviewed, and the fluctuating influence of interdisciplinary studies will be traced.

Historical Goals of Education

The goals of education profoundly affect the content and the teaching methods developed in a society. Historically, common purposes of formal education include the transmission of culture, teaching of survival skills and community responsibilities, preparing elite bureaucrats, soldiers, and priests to fulfill their roles, and indoctrinating people into religious denominations (Ornstein & Levine, 2006). Though additional goals, such as developing experts in mathematics and science or promoting literacy among the general population, have acquired greater importance during the last several hundred years, the earlier aims of education are still influential today (Spring, 2008).

Education in preliterate societies essentially consisted of training for life in the community. Survival skills were taught, as well as cultural traditions, expectations, and taboos. Parents and other family and community members told stories, sang songs, celebrated, and worked with children throughout their lives (Ornstein & Levine, 2006). This enculturation and preparation for adult responsibility cannot reasonably be called interdisciplinary, as there were no disciplinary lines to cross. Rather, this form of cultural and life education might be considered predisciplinary: teaching focused on life and culture, not proprietary boundaries of knowledge.

Early Systems of Schooling

The earliest known systems of schooling arose in China, India, and Egypt around five thousand years ago, not long after the advent of large-scale irrigated agriculture and the subsequent invention of writing (Diamond, 1997; Ford, 2008). The students of these schools were elite males, classic philosophical and religious texts formed the basis of the curriculum, and memorization was the primary method of instruction (Ornstein & Levine, 2006).

Greek city-states and, later, the Romans who admired the Hellenic culture, extended education to male children of citizens; this still excluded most individuals from formal schooling. Greek and Roman philosophers and teachers, including some well-educated slaves who tutored the sons of the wealthy, taught the subjects considered important in the Mediterranean world: reading, writing, rhetoric, poetry, music, military tactics and physical education topped the list. Though the same instructor frequently taught many subjects, divisions of knowledge- the precursors to strictly delineated disciplines- began to appear in ancient Greece and Rome (Ornstein & Levine, 2006).

Aristotle, in particular, had a powerful impact on later Western schools. Aristotelian schools emphasized a "subject-matter curriculum based on scholarly and scientific disciplines" (Ornstein & Levine, 2006, p. 74). Instructors were experts in their subjects, and they worked to develop rational thinking in their students.

Scholasticism and Medieval Europe

These structures of Aristotelian education, interpreted through the lens of a powerful Roman Catholic Church, formed the foundation for Scholasticism in Medieval Europe. Many long-standing patterns continued, though much knowledge was lost, throughout the Dark and Middle Ages (c. 500-1400), as Western learning declined before the intellectual revival of the Renaissance. The majority of the populace, who lived and worked as serfs, never attended formal schools; most learned in their homes or from more experienced craftspeople. The few who did enroll in schools were most frequently men training for religious life, though there were also limited avenues open for men training to become craftsmen or knights. Women learned housewifely skills at home, and a few entered convents to be educated for a life in a religious community (Ornstein & Levine, 2006).

Saint Thomas Aquinas lived and worked in the 13th century AD, at the height of the Scholastic movement. Religious teachers developed this approach over time, affirming the value of both faith and reason as important sources of truth. Aquinas was a major figure of this era who worked to connect Aristotle's philosophy with Christian doctrine.

The Scholastic scheme of schooling mirrored and expanded upon many elements of Aristotelian education. The Scholastics taught formal disciplines such as logic and mathematics, philosophy, and theology. These religious scholars also built bodies of knowledge using deductive reasoning; logical thought combined with faith guided their teaching and other intellectual endeavors.

Medieval scholars organized and codified knowledge and created Universities: these contributions resonate strongly today. Though the subjects have grown, changed, and shifted boundaries over the centuries, modern Western school systems have deep roots in the structures and patterns that dominated Medieval education.

Renaissance and the Reformation

With the Renaissance came a shift in education. While schools in the Middle Ages focused on theology and doctrine, Humanists of the Renaissance emphasized art and literature. Advocates of Humanism during the Renaissance sought a revival of Classical Greek and Roman literature and rhetoric. Reflecting this shift in values, teachers in Humanist schools were frequently writers, poets, or critics, rather than members of the clergy (Ornstein & Levine, 2006). In spite of significant movement away from strictures of Medieval schooling, access to humanist education remained limited to the elite for centuries, and the old strictures persisted in religious schools and continue to persist in many ways.

The Renaissance signaled a change in education, as in many other aspects of life. The attempt to use literature and the arts to make sense of humanity and of the world reflected an important change in thinking: mathematics, logic, and religious doctrine were not the only valid lenses for exploring the world; human ideas, stories, and insights provided a different and valuable view.

Protestant reformers in Europe in the 16th and 17th centuries, including Martin Luther and John Calvin, sought to use schools to advance their cause as they resisted Papal authority. Reformation leaders called for universal literacy, believing that reading the Bible was necessary for salvation; proponents of schools in Colonial America and the early years of the United States made similar, religiously-motivated arguments about the need for basic literacy skills.

The reformers' efforts yielded impressive results: adult literacy rates in England rose from 10% of men and 2% of women in 1500 AD to almost 40% of men and 32% of women by 1700 (Ornstein & Levine, 2006, p. 86). In addition to increasing literacy among the general population, the system of primary schooling instituted during the Reformation substantially raised rates of school attendance for both boys and girls. However, in keeping with prior education systems and the economic and political realities of their era, Protestant reformers continued to reserve secondary schooling for children of the elite.

A dual-track education system emerged from the Renaissance and Reformation, which was carried to the Americas by European colonialists (Spring, 2008), and which may still be seen today. By providing basic schooling to most children while ensuring an elite education to the children of the wealthy—future religious, political, and business leaders—this dual-track system enabled educators to acknowledge a need for universal education while maintaining distinctions of status and rank.

Dual-Track Education in North American Colonies

European colonists in North America established a dual-track system of education based on socioeconomic class. This system limited children of poorer classes to schools that provided basic instruction in reading, writing, mathematics, and religion, while moving sons of the elite up through Latin grammar schools where they learned Latin and Greek to prepare for college; these wealthy sons were groomed to fill their fathers' shoes in government, business, and religious life (Ornstein & Levine, 2006; Spring, 2008).

Despite varied regional and religious influences on schooling in the American colonies, several trends were common throughout schools in European-controlled America. Reading, writing, arithmetic, and religion were the core subjects of most American schools of this era, though some schools taught additional subjects: separate-subject instruction dominated both public and parochial schools (Ornstein & Levine, 2006). Gender and social class discrimination was also endemic in these early American schools; breaking out of culturally determined gender roles and gaining social mobility were severely frowned upon in Colonial society. Though most children of European descent had access to primary schools, the Latin Grammar Schools and colleges were accessible only to boys and men, and those boys and men were overwhelmingly members of the wealthy ruling classes.

Early Education in the United States

Benjamin Franklin and Thomas Jefferson advocated for improvements in American schools in the 18th century. Franklin established an Academy, a private alternative to the then-common Latin Grammar Schools. Franklin's academy provided a secondary education that included English grammar and composition, as well as options for learning French, German, or Spanish alongside the more traditional Latin and Greek. The academy incorporated practical subjects into the curriculum, too, emphasizing the application of mathematics to real-life endeavors as well as teaching skills related to carpentry, printing, and farming (Spring, 2008).

Thomas Jefferson called for quite radical changes to the system as it existed in his time. He strongly advocated for secular, publicly funded schools. Jefferson held that democracy depended upon literate and well-informed citizens, and that extending higher education to academically promising children from lower socioeconomic classes would benefit society (Ornstein & Levine, 2006; Spring, 2008). Jefferson saw few of his hopes for public schools materialize during his lifetime, but hopeful developments were not far in the future.

In 1826, Massachusetts's legislators passed a law requiring every town to establish and support a school to be attended by children of all socioeconomic classes. Massachusetts formed a board of education, the first in the nation, in 1836; Connecticut soon followed suit (Spring, 2008).

Public schooling continued to evolve. Common Schools, hypothetically open to all children, prompted the rise of Normal Schools to educate teachers. One-room schools cropped up in frontier communities as European Americans pressed forward in their conquest of North America (Spring, 2008). The curriculum of these small schools covered basic literacy, mathematics, history, and geography; students memorized and recited lessons to the teacher (Ornstein & Levine, 2006). Throughout the 19th century, considerable variety existed in

American schools, but most remained teacher-centered and kept subjects separate.

The 19th century also saw the rise of public high schools and the National Education Association (NEA) (Ornstein & Levine, 2006). The NEA appointed a Committee of Ten in 1892, which recommended that students receive eight years of elementary education followed by four years of secondary schooling, just as American public schools offer today. The Committee of Ten also called for standardized teaching of subjects, for students who planned to complete their education in secondary schools as well as for the college-bound. The push to teach the same subjects to all students marked a conscious break from the unabashedly dual-track system that had previously dominated American schools (Spring, 2008). Though disparities in educational opportunity and quality of schools were not eliminated, school administrators and politicians began to acknowledge and attempt to address these inequities. As public secondary schools became more common, separate subject structures solidified.

Dewey, Experience, and Progressivism

John Dewey initiated a movement away from many long-standing patterns in schooling during the early 20th century. Rather than emphasizing the transmission of accumulated knowledge from teacher-experts to students, Dewey and other Progressive educators sought to create a fundamentally different kind of school: an environment in which students construct their own understanding of the world based on their lived experiences (Dewey, 1938; Ornstein & Levine, 2006; Spring, 2008). This Progressive approach to education placed students' prior knowledge, interests, and concrete experiences at the center of the curriculum, rather than dividing knowledge into expert-driven categories.

The importance of meaningful, authentic experience was one of the guiding principles of the 8-Year Study; the other focus was the centrality of orienting students to a vision of democracy, which would underlie the acquisition of academic knowledge and skills (Drake, 1998). This longitudinal study, which compared 1,475 matched pairs of students, investigated 18 variables such as academic honors, grade point average, and resourcefulness. The experimental group of students as a whole, which was drawn from 30 different schools, outperformed their control group peers to a small degree; students from the schools with the most innovative Progressive approaches performed better than those from all other schools in the study. Though the 8-Year Study reported significant results, it had surprisingly little impact on educational policy, perhaps in part due to the onset of the Second World War.

War and Global Competition

World War II prompted politicians to turn away from Progressive, interdisciplinary trends in education. Education the 1940s and 1950s was dominated by a drive to develop experts in mathematics and science, experts who could compete with those of other political powers around the world (Spring, 2008). This shift is a good example of an educational pendulum: after a period of time in which the national dialogue around schooling had been strongly influenced by Progressive thinkers, the debate swung to the opposite end of the spectrum, and curriculum was once again dominated by advocates of knowledge-driven, separate-subject schooling.

Summary

The history of schools in the United States is a history of swings of a philosophical pendulum. From strict colonial schools, which taught Bible verses and civic values by rote, to common schools, through a sinuous evolution that has brought American education to where it is today, tension between traditional and progressive educators continues. John Dewey's (1938) advocacy for experience-based education was of huge importance to progressive education; interdisciplinary studies are closely tied to Dewey's ideas about connecting learning to real-life experience. The swinging of the ideological pendulum continues; the increasing dominance of standards-based education has prompted some to abandon progressive ideals for mechanistic, prepackaged approaches to schooling. However, integrated learning has not lost its value, nor its committed core of educators.

CHAPTER 3: REVIEW OF LITERATURE

Introduction

Though detractors of interdisciplinary pedagogy insist that the body of research supporting integrated curriculum is small and incomplete, the last ten years and more have seen a wide variety of studies that involve cross-discipline studies. Interdisciplinary approaches to teaching and learning appeal to educators in many fields, and the research reflects this powerful draw. Research samples range from small case studies focusing closely on qualitative data from six students to ambitious longitudinal assessments collecting quantitative data for over one thousand students.

This chapter will present a review of recent research exploring questions connected to interdisciplinary approaches to teaching and learning. Three different perspectives on the existing research offer pieces of the big picture of the research as a whole. The chapter continues with studies centered in elementary classrooms, and then traces integrated strategies into middle level and secondary schools; multiple configurations of integration are represented in these sections. The final two sections of chapter three will examine research on technology integration and the impacts of interdisciplinarity on teachers.

The body of research reviewed in this paper has, of course, strengths and weaknesses. Weaknesses common in the research include issues such as potential conflicts of interest for authors studying commercial curriculum, problems inherent in studies with small sample sizes, and, in some cases, lack of control or comparison groups. Strengths are found in the wide variety of classroom settings and pedagogical approaches examined in studies of a huge range of sizes and geographical locations. Many different questions are explored in this research, related to achievement, attitude, professional development, conceptual development, classroom communities, and more. Given the frequent claims of the paucity of research supporting integrated curricula, the breadth of the published articles is remarkable.

Meta-Analyses and Integrative Reviews

To develop an understanding of the existing research, this section presents results from an arts-focused literature review, a meta-analysis of quantitative studies of math and science integration, and a study of classroom connections of reading and math.

Brewer (2002) articulated a number of substantial, important critiques of interdisciplinary curricula. In addition to the standard lament for a reported lack of research, Brewer questioned the research methods being used, the personal connections frequently found between authors and the programs they report on, the benefits of interdisciplinarity for certain disciplines, particularly the arts, and the consequences of integrated curriculum for arts education.

In his literature review, Brewer (2002) urged educators to carefully consider the benefits and drawbacks of integrated arts curriculum. He introduced his article with a strong position statement advocating the importance of visual art as a unique discipline, with its own vocabulary, history, tools, and values that make it distinct not only from separate subject areas but also from other arts areas. Brewer vehemently contended that integrated curriculum programs may shortchange the disciplines they integrate by failing to fully explore the tools, methods, or essence of the disciplines.

Brewer (2002) divided his literature review into two sections, with the first focusing on intrinsic approaches to art and the second centering on instrumental approaches to art integration. He cited a number of authors and studies that supported keeping disciplines separate, and reported one writer's view on the vast differences between the arts, which are "affective and participatory," and science, which is "objective, detached, precise, and rational," and the humanities, which "deal with the analysis of moral actions" (p. 32). Brewer argued that these fundamental characteristics of these three academic areas posed a very serious barrier to integration. He concluded that the visual art, like other disciplines, has its own "core and connections" (p. 33) that ought to be respected and maintained when a discipline is included in an integrated framework: the arts have intrinsic value.

In the second part of the literature review, Brewer (2002) reported some limited findings for an extensive set of articles. He found that, of 479 published pieces of literature related to integrated arts curricula, 16% were theoretical, 82% addressed or described programming or curriculum, and less than 2% reported actual research. He also discovered that many of these studies focused on results in academic subject areas rather than on the arts, further confounding interpretation of research implications for arts education. Brewer noted that many programs integrating arts with other subject areas used visual art instrumentally, as a tool or enhancement for another subject, rather than teaching art skills or processes as a focus.

Though Brewer (2002) delivered several valid critiques, he also fell somewhat short of the standards he set for others' research. Brewer briefly mentioned reviewing and categorizing hundreds of articles, but provided only very limited details on the findings of those articles, even the 2% he classified as research. The author contended that interdisciplinary curricula tend to undervalue or under-teach one or more disciplines; this is an important caveat for would-be integrators. Brewer's study acted as a needed reminder to interdisciplinary researchers and classroom practitioners that separate disciplines have their own histories, methods, tools, and identities.

Using mixed methods, Hurley (2001) conducted a meta-analysis of thirty-one quantitative studies of student achievement in integrated math and science classrooms and collected qualitative evidence of multiple forms of curriculum integration. She also presented historical evidence, citing research findings over several decades.

Hurley (2001) analyzed studies conducted between 1935 and 1997, which focused variously on core curricula, math-science-technology integrations, and curriculum improvement projects. She created a table to display the thirty-four achievement outcomes reported in the thirty-one studies selected for the meta-analysis; the selected studies had sample sizes that ranged from 32 to 900 students, in grade levels from kindergarten through undergraduate education, and the treatments lasted between two weeks and two years, with one-year interventions being the most common. The author noted that she found a number of unpublished dissertations that documented research in interdisciplinary studies, and suggested that the perceived lack of evidence for curriculum integration may be influenced by the relative difficulty of obtaining these unpublished works.

Hurley (2001) found data from 29 studies that reported student achievement results in mathematics and 21 studies that reported achievement results in science showed that students in treatment groups performed measurably better than their control group peers. The mean effect size for the group of science achievement studies was 0.37, and the mean effect size for mathematics studies was 0.27. These numbers indicated that the interventions had, in general, small to medium positive impacts on student achievement.

Hurley (2001) identified five forms of curriculum integration: sequenced, parallel, partial, enhanced, and total, and examined the results of treatments of these different forms. Parallel integration studies showed a small negative effect size, indicating that the traditional control group achieved higher than the treatment group; the effect sizes of the other approaches were positive for both science and math. Effect sizes for science achievement were larger than for math in all but one category: math effect sizes ranged from -0.11 to 0.85; science effect sizes ranged from -0.09 to 0.96. Though the high numbers for each discipline are close, most integration forms showed moderate impacts on science achievement and small impacts on math achievement. This finding resonates with the frequently mentioned difficulty of balancing disciplines within an integrated program.

Hurley's (2001) analysis provides a fair starting point for the reader interested in interdisciplinary education research. This study is limited to science- and mathematics-focused achievement measures, and it is beginning to be out of date. However, the data Hurley presented do support curriculum integration as a means to promote student achievement in the core areas of math and science.

Wallace and Clark's (2005) review of literature documenting reading and mathematics integration found three distinct stances toward reading in the math classroom: reading was seen as a tool to figure out a written problem, a method for exploring the language of mathematics, or as a way to connect understandings developed in mathematics to societal issues relevant to students' lives. The authors also posited that the ability to read mathematical texts, texts that demand the reader decipher both written words and numerical information, is essential for well-informed members of society in the United States.

Wallace and Clark (2005) reviewed a body of research on reading in mathematics to explore questions of how reading is utilized, perceived, and valued in math classrooms. The authors discovered sharp differences in teaching philosophy that heavily impacted instruction. For example, one teacher believed that students learned math through drill and practice; this belief led the teacher to use reading only as a tool for solving problems, and to spend the bulk of instructional time on completing and reviewing textbook problems. Such an approach, Wallace and Clark concluded, ignored the connection between math and life, and increased students' perceptions of math as an academic endeavor isolated from the real world.

Wallace and Clark (2005) described two other approaches to reading and math integration. They called the first "Reading Mathematics" (p. 71), which entails the use of a variety of texts in addition to the math textbook; this approach brings multiple sources of knowledge into the classroom and supports students in making connections from math to other subjects as well as to life. The "Reading Mathematics" and the "Reading Life" (p. 74) approaches both focus on guiding students as they build conceptual connections between mathematics and the world. Reading Life extends beyond the Reading Mathematics strategy by emphasizing multiple forms of text, including magazines, websites, email, newspapers, contracts, and advertisements. Wallace and Clark found that using life-based mathematical texts can help students develop a genuine sense of the role mathematics plays in life and society. The Reading Life approach "moves beyond the realistic example to actual examples in real time" (p. 76), empowering students to pose problems, understand what their solutions mean, and become active participants in a math-dependent culture.

Wallace and Clark (2005) argued persuasively for the usefulness of environmental texts in a mathematics classroom. However, the conclusions they reached about classroom implications over-reached the scope and findings of their study. They found that integrating Reading Life, in the form of environmental texts, into mathematics classes was beneficial for students' ability to pose and understand problems and to become active, well-informed citizens. With an emphasis on the arts as unique, vibrant disciplines that ought to be taught for themselves, as pure pursuits, Brewer (2002) questioned the benefits of interdisciplinarity for the arts as well as for other subjects. Hurley (2001) identified five different forms of integration and analyzed the impacts of each; she found a small negative impact for one form, and positive effects for the others. In their study on how reading is used and perceived in the context of mathematics, Wallace and Clark (2005) examined the effects of three different approaches to using text to further mathematical understanding. Taken together, these three studies set the stage for a more in-depth exploration of the body of research built around integrated curricula.

Elementary Classrooms

Elementary teachers in the United States are generally expected to teach all core subjects, but surprisingly few research studies focus on elementary classrooms. The three articles reviewed here investigated the effects of an integrated social studies curriculum, the impacts of a four-week unit integrating walking with pedometers across several subject areas, and the effects over time of an integrated curriculum treatment on gifted students.

In a study of implementation of an interdisciplinary social studies unit, Little, Feng, VanTassel-Baska, Rogers and Avery (2007) examined the effects of the unit, based on the Integrated Curriculum Model, on the content learning of students in heterogeneous elementary classrooms. The authors found that the treatment group demonstrated significant gains in content learning compared to the control group, though no significant differences were found for a smaller sub-sample of highly capable students.

Little et al. (2007) used a quasi-experimental design, and reported results from the third year of a three-year project. One thousand two hundred students from second to eighth grade in nine schools in one urban school district comprised the sample; 949 students received the treatment while 251 were in the control group. Little et al. assessed student learning with three instruments: a conceptual thinking test (CNTA), a critical thinking test (CRTA), and content-specific assessments. Researchers administered the CNTA and CRTA to treatment and control groups prior to the treatment, and teachers administered content assessments.

Little et al. (2007) conducted ANCOVA analyses on the pre-tests and post-tests for treatment and control groups; they found statistically significant differences between the two populations in gains in content knowledge, favoring the treatment group, with a moderate eta squared effect size of 0.11, $p < 0.007$.

They did not find statistically significant impacts on conceptual thinking or critical thinking measures.

The disparity in size of the treatment group (949) and the control group (251) warrants a note of caution, which Little et al. (2007) mentioned as a limitation. The study was also impacted by changes resulting from increases in state assessments and accountability reforms, which prompted some principals to withdraw their schools from the ICM study to refocus on more traditional skill- and content-based pedagogy. The authors also mentioned a possible lack of treatment fidelity as a limitation of the study.

One small study focused on the impact of using pedometers as a motivational tool as part of a program integrating physical activity into the core curriculum of children in grades four and five living in New Zealand. Oliver, Schofield, and McEvoy (2006) found that physical activity increased significantly for students with the lowest baseline activity levels, especially female students. However, the effects on the complete sample were nonsignificant. The authors cited recommendations that suggest children should take between 11,000 and 15,000 steps as part of an active, healthy lifestyle; they also noted that young people in Westernized societies tend to be more sedentary than children in other cultures, and may be too inactive to be healthy.

Oliver et al. (2006) described a four-week program integrating pedometers into the curriculum as part of a "virtual walk" around the country. Disciplines connected in this program included English, social studies, mathematics, and statistics. The authors used a "convenience sample" (p. 75) of high socioeconomic status urban elementary school students in Auckland, New Zealand. Participants included 78 children aged eight to ten. The students wore sealed, hip-mounted pedometers while the researchers collected baseline data for three days. During the four-week intervention students wore unsealed pedometers all day, every day, except when sleeping or in water; teachers recorded step counts at the beginning and end of each school day.

Oliver et al. (2006) analyzed data for sixty-one children; sixteen of the original sample had missing data, and one student withdrew. They found that 56% of the students were taking more than 15,000 steps each day. They found that the boys were significantly more active than the girls in the sample, with averages of 18,055 and 14,719 steps, respectively ($p = 0.01$).

Oliver et al. (2006)) also reported that 80% of the sample met or exceeded recommended daily step counts. Boys averaged about 2000 steps more than girls on weekdays, but the difference disappeared on weekend days. On weekend days, average steps of all students dropped dramatically: boys walked about 3,890 steps, girls about 4,042. Students who took the fewest steps for the baseline measure showed the statistically most significant increases in step counts during the intervention. Both boys and girls increased their activity: group A girls boosted their step counts by 14.3%; group B boys and girls increased their counts by 13.3% and 31.4%; group C boys increased 13.3%, and girls in this group increased their step counts by 100%, from 6,323 to 12,655 on average. Boys in group D, the lowest quartile, showed an increase of 21.2%, while girls in the lowest quartile jumped 131.4%. The gains were not highly significant for the sample as a whole, but the students who were least active at the baseline measure, especially girls, experienced significant increases in activity.

Oliver et al. (2006) noted several limitations of their study, including the lack of a control group, short duration, and a sample that was homogenous and was not randomized. Despite these limitations, the authors provided yet another incremental piece to the picture of how integrated curricula impact students and teachers.

In a study of factors that act as supports and obstacles to the implementation of the Integrated Curriculum Model (ICM), VanTassel-Baska and Brown (2007) analyzed the efficacy of different curriculum models in gifted education. VanTassel-Baska and Brown found that implementation of ICM is supported by professional development, leadership, accountability, and research: specifically, data collected over time by practicing teachers to gauge the program's effectiveness. The authors identified "lack of fidelity of implementation" by practicing teachers and an overemphasis on state testing as inhibiting factors to implementation. Using a rubric designed to assess fifteen elements of a curriculum model, such as "Research evidence to support use," "Teacher receptivity," and "Relationship to school-based core curricula" (p. 343-344), the authors examined eleven gifted education models; they determined that research evidence of effectiveness with gifted learners was available for six models, and the authors focused on these. For each model, VanTassel-Baska and Brown reviewed available research, reported on current use and sustainability and identified factors that supported each program, as well as each model's strengths and weaknesses.

In discussing the Integrated Curriculum Model (ICM), the only interdisciplinary model reviewed, the VanTassel-Baska and Brown (2007) reported evidence that the ICM is correlated with gains in linguistic capabilities, persuasive writing skill, and literary analysis, as well as conceptual learning in science. They stated that the units designed with the ICM are aligned with national standards, and thus related well to state standards. They further reported that ICM units are well received by school districts, teachers, and students, and that units are in use in all fifty states.

VanTassel-Baska and Brown (2007) acknowledged the potential bias concomitant with studying a curriculum model created by one of the authors; however, they did not describe any efforts made to account for this issue. They also failed to note that nearly all of the research cited in support of the ICM was co-authored by VanTassel-Baska, diminishing the strength of this study.

The longitudinal study carried out by Feng, VanTassel-Baska, Quek, Bai, and O'Neill (2005) examined the impacts on gifted learners of implementing a differentiated curriculum based on the Integrated Curriculum Model (ICM) in one school district over a three-year period. Both qualitative and quantitative techniques were used in analyzing the data to explore pre- and post-achievements in selected academic areas.

Feng et al. (2005) used performance based instrumentation to assess student learning; instruments included: The Diet Cola Test, which assessed students' ability to design experiments; a literary analysis assessment developed prior to this study; and a writing assessment rubric. Feng et al. and collaborating teachers administered pretests and posttests in each of the academic areas selected for this study at the beginning and end of each school year from 1996 to 2002. The authors collected and analyzed data documenting fourth and fifth graders' academic growth over time to investigate the effects of the ICM over the course of a single school year as well as to examine the effects of repeated exposure to curriculum based on the ICM.

Feng et al. (2005) implemented the ICM with 973 students in grades three through nine; this study tracked data for 116 third graders, 106 fourth graders, and 109 fifth graders. The perception surveys were returned by 367 parents, 110 educators, and 732 students. Feng et al. presented data on students' growth. In grade three the authors examined the areas of literary analysis, persuasive writing, and science research; in grades four and five they added data on students' grammar. In each grade level, students made statistically significant gains in these academic areas, with t-scores ranging from 10.77 to 29.23 ($p < 0.001$) and effect sizes (using Cohen's d index) from 0.52 to 1.76.

Feng et al. (2005) analyzed data on student growth from pretest to posttest, paying particular attention to the effects of repeated exposure to the ICM. They found that fifth-grade students who had been exposed to these interdisciplinary units for one school year (that is, only in 5th grade) showed significant growth in Experimental Research Design ($t = 5.76$); students who were in the program for two school years demonstrated even stronger growth ($t = 7.42$), and those who were exposed to the approach for three school years made the greatest gains ($t = 13.75$; $p < 0.001$ for all of these t-scores). Feng et al. reported similar findings for students' growth in language arts after repeated exposure. All fifth grade groups showed growth, and in each area students who received the curriculum three times made the greatest gains. The authors suggested that there is a repeated exposure effect, that students reap more benefits by being exposed to the curriculum multiple times.

Feng et al. (2005) concluded that student achievement is positively impacted by interdisciplinary curriculum implemented with the ICM over the course of one year; they further concluded that the effects increase with repeated exposure to similar curriculum.

Feng et al. (2005) provided detailed information about the instrumentation they used to assess students' learning and students', educators', and parents' perceptions. The authors acknowledged some of the significant limitations of their study: the lack of a control group, relatively low rates of return on parent and teacher surveys, and the lack of available follow-up data for the subjects now in higher grades. However, the article frequently cited articles co-authored by one or more of the authors of the study. This could skew the findings of the article, and is not mentioned as a caveat. The scope of this study is quite narrow; it is limited to one school district's gifted program, and to one approach to integrating curriculum. The study also lacks a control group. Information about the subjects of the study was unclear; though the study spanned six years, the authors appear to have provided numbers for one year. With these limitations in mind, this study does provide additional evidence that student achievement can be significantly positively impacted over time by the implementation of the ICM

The studies reviewed in this section showed positive impacts on students resulting from an integrated social studies program, a physical education integration, and a longitudinal study of gifted students studying a fully integrated curriculum.

Middle Level Classrooms

Many recent studies focused on interdisciplinary programs in middle schools; this section reviews seven research articles. The subjects integrated vary widely; different studies examined conflict resolution, health, and the arts as well as more traditional core subjects like math, reading, writing, and science. These seven studies reported a number of findings that support interdisciplinary pedagogy, and they also offered cautions about the challenges of implementation.

The qualitative case study conducted by Bolak, Bialach, and Dunphy (2005) documented the design and implementation of a pilot project in two sixth grade classes. The authors participated in the design and implementation of an arts-integrated program for a restructured middle school in the Midwest. Student outcomes were measured with rubrics, teacher-made tests, students' individual reflections, and national norm-referenced tests. The researchers worked with school staff, parents, and members of the community to create an interdisciplinary program, in which the arts would be strongly connected to the core curriculum, which supported state standards, drew on the school district's strengths, and addressed Gardener's Multiple Intelligences.

Bolak et al. (2005) studied teachers who collaborated with each other in selecting state standards to address and in choosing a thematic framework to guide their classroom work. The teachers planned guiding questions, formative and summative assessments, and a culminating event in which all students would participate. Teams of teachers cooperatively planned units throughout the year. The school principal provided support by coordinating co-teaching time, space needs, and professional development.

Bolak et al. (2005) found that students and teachers maintained a high level of interest and enthusiasm for arts-integrated, thematic teaching and learning throughout the school year. Parents reported that students' interest in school increased. Many staff members took on leadership roles in making connections with fellow teachers and community members. Student attendance at the culminating events- with one or more family members- was extremely high, reaching 100% for one of the units. Student scores on the Stanford Achievement Test, a national norm-referenced test, increased substantially, rising by 18% in mathematics and 15% in reading over the previous year's scores.

Bolak et al. (2005) examined multiple outcomes, including student interest and participation, test scores, rubrics, and reflections. However, the researchers did not use any formal surveys or other similar instruments. They also did not provide much demographic or outcome data for the students. This study, like many others, demonstrated positive impacts of interdisciplinary pedagogy.

Radcliffe, Caverly, Hand, and Franke (2008) investigated how implementing literacy strategy instruction in a middle school science classroom impacted students' learning in science. The study focused on two groups of sixth grade students, both enrolled in science classes taught by one teacher, a 30-year veteran, in a school of 900. Fifty students were studied; the treatment group was a class of 23, the control group a class of 27. The researchers conducted a quasi-experimental case study, collecting data for two nonequivalent groups, using multiple pre- and post-assessments.

Radcliffe et al. (2008) gave intervention group students five weeks of instruction in the PLAN (Predict-Locate-Add-Note) strategy for reading comprehension as they studied two chapters in a science textbook; control group students studied the same material, without the literacy strategy instruction. All students completed two pre-assessments and two post-assessments, in the form of chapter tests from the textbook. In addition, all students completed reading strategy checklists at the beginning and the end of the study. Pre-assessment averages between the two classes were not statistically significant: the treatment group scored a mean M = 73.5 and the control group's mean was M = 72.2. The post-assessment scores showed a marked difference between the two groups: students who had received literacy strategy instruction scored a mean 68.9 while their control group peers scored a mean 52.8, a statistically significant difference of 16 points on a 100-point assessment. Radcliffe et al. (2008) found similar results when they examined the reading strategies checklist. The difference between the two groups was statistically non-significant on the pre-test, but the post-test revealed that the treatment group's perceptions of their own use of reading strategies had increased: the control group's score on this checklist dropped slightly, from 5.44 to 5.00, while the treatment group's score rose from 5.15 to 6.68; the p-value of the difference in the groups' post-assessment scores is $p = 0.012$.

The very small study by Radcliffe et al. (2008) offered intriguing results, but it also contained significant weaknesses. The small sample size, confined to one school and one teacher, is a real limitation, as is the prior professional relationship between the teacher, who was a graduate student, and the researchers, who were her professors and mentors. The authors explicitly articulated the procedures and data collection and analysis methods used throughout the study, though incorporating more statistical data would have made the article somewhat stronger. Radcliffe et al. contributed a small but compelling addition to the body of research on interdisciplinary pedagogy.

Compton (2002) discussed the findings and implications of the National Curriculum Integration Project (NCIP) on middle school students' perceptions of their learning environment, classroom climate, and the integrated learning process. The NCIP sought to integrate conflict resolution education, civic or law-related education, multicultural and anti-bias education, and social and emotional learning, and to infuse them into classroom teaching across the curriculum. Teachers in seven middle schools incorporated conflict resolution, social and emotional learning, and multicultural and anti-bias education into their classroom instruction. Teachers completed evaluation instruments three times during each year of the two-year study, and they also kept journals of student reactions to the practices and ideas of the aforementioned fields.

Compton (2002) found a significant change in students' perceptions of their learning environment. Students of veteran NCIP teachers perceived their classrooms the most positively, while all students in NCIP classrooms reported more positive impressions of classroom climate than students in control group classes. In interviews, students in NCIP classes indicated that they felt their learning was relevant and connected to their real life experiences; they also reported feeling a sense of classroom community and increased, mutual respect among teacher and students. Compton did not find a significant change in students' emotional competence.

Compton (2002) acknowledged the difficulty for many teachers and administrators trying to find time to train for and implement this curriculum. They also recognized the paucity of practical assessments for the content and skills students were expected to gain through the conflict resolution intervention they received. To the detriment of this article, Compton neglected to include substantial data; he provided summaries of research results without strongly supporting his claims. Like many other studies, small and large, Compton's analysis of the National Curriculum Integration Project provided encouraging but inconclusive evidence in favor of increased interdisciplinarity.

Building on a prior study, which indicated improved performance among students who used the Science Writing Heuristic (SWH) compared with control group peers, Wallace (2004) explored the connections among reading, writing, hands-on experience, and discussion as sources of science knowledge for seventh grade students. The author stated the position that writing to learn in science has value, and she cited several studies to support that claim. She also noted that a careful examination of the myriad factors influencing students' understanding had been lacking; this study attempted to provide some of the missing data.

Wallace (2004) employed an interpretive research approach to this investigation, with the goal of understanding students' own perspectives on how they learned science. Wallace collected data from student interviews, lab reports, and pre- and post-test essay questions. The interviews were designed to: elicit students' views on which classroom activities were useful in learning biology; determine how students approached various aspects of science writing tasks, such as composing questions or explanations; and explore students' ideas about how they would choose to approach an unfamiliar problem in biology. The author also compiled written documents related to students' understanding of the topic of diffusion and osmosis through a cell membrane. Wallace collected data for ten targeted students and reported results for six of these students, whom she stated were evenly distributed in terms of gender, ethnicity, and academic performance.

Wallace (2004) found that three of the six subjects indicated a preference for hands-on learning based on their own senses and experiences; these included one male and one female low achiever and one male average achiever. This group cited their lab experiences most frequently in interviews and in their writing; they also indicated that they viewed their SWH lab reports as important tools for learning. One student in this group explained that writing the SWH lab reports "makes us rethink everything that we've learned and put it into our own words" (p. 73). This statement offered compelling support for the use of writing in the science classroom.

One student, an average achieving female, preferred reading to learn science. She dismissed her own observations, and was unable to connect her lab experiences to the information in the textbook; she appeared to value the authoritative text over first-hand knowledge. Finally, Wallace (2004) categorized two students—the male and female high achievers—as "Integrators," able to connect observation, discussion, writing, and textbook knowledge to arrive at a coherent view of the processes they studied. The male student explicitly stated, "I think you have to make more connections when you're writing things out" (p. 75); the female student described how she developed her understanding of osmosis drawing on her lab experience, internet and textbook research, written comparisons of findings, and class discussions.

After examining the qualitative data generated in this study, Wallace (2004) concluded that science pedagogy would benefit from more explicit teaching of reading and negotiating unfamiliar discourses, such as the language found in textbooks. Wallace particularly recommended that science educators ought to continue using labs to teach science, and that students would benefit from instruction in negotiating multiple written and spoken discourses.

Hsieh (2003) investigated the effects of writing in science on students' knowledge of science; the author closely examined students' writing to determine whether the sixth graders showed evidence of declarative, procedural or constructive/structural knowledge to explore the question of what shifts in student knowledge take place after instruction integrating science and writing. Hsieh found that students' knowledge shifted from predominantly declarative to increasingly procedural and constructive (or structural).

Hsieh (2003) and a cooperating teacher collected and analyzed qualitative data in the form of student writing before, during, and after a four-week science unit. The teacher collected student writing about scientific concepts five times during the four-week study. The preassessment elicited student ideas about a motor; then students observed a magnetic field and the "deflection of a compass needle near a current-carrying wire," and wrote again. Students made an electric magnet and a motor, writing after each project. The postassessment mirrored the preassessment; students wrote about "A motor in daily life." The teacher and two other graduate students analyzed students' writing, looking for examples of declarative, procedural, and structural knowledge in each of the five writing tasks. Hsieh compared the "frequency of knowledge levels" demonstrated in the 6th graders' writing. Thirty 6th grade students participated in this one-class study.

The subjects were trained in scientific writing for one semester prior to the beginning of the study.

The data showed that students' post-test writing included many more examples of procedural (87 compared to 25) and constructive (25 compared to 2) than the pretest writing. The three writing samples Hsieh (2003) collected during the intervention show a similar shift; the number of examples of procedural and constructive knowledge increased with each successive writing task. Examples of declarative knowledge decreased slightly from pretest to posttest (73 to 70). The author concluded that students' knowledge shifted over the course of the four-week science writing intervention, from predominantly declarative to increasingly procedural and constructive.

Hsieh (2003) included examples of concepts students were expected to write about and examples of student statements that were evaluated as declarative, procedural, and structural knowledge; this was essential, as the terminology used was not immediately self-explanatory, which is often the case in the literature of interdisciplinary studies. This small study needs to be replicated on larger scales to increase confidence in its reliability. The fact that one of the researchers was also the classroom teacher is a weakness as well; further studies would be strengthened by clarifying and separating the roles of teacher and researcher.

Clocksin and Watson (2005) investigated physical education integration. In a study exploring the impact of an integrated health and physical education program on media use and physical activity, students in the intervention group decreased their media use by 18.3%, while those in a control group decreased their media use by 10.3%. Step counts, used as a measure of physical activity, increased by an average of 1,782.86 steps in the intervention group; the average step count in the control decreased by 615.49 steps. Clocksin and Watson concluded that a media literacy-focused health program integrated with a student-centered physical education program had a beneficial impact on adolescent media use and physical activity.

Bernt, Turner, and Bernt (2005) collaborated with three seventh grade teachers, in language arts, science, and math, to conduct a qualitative case study to examining the impacts of an integrated, project-based curriculum on the learning experiences of middle school students. The university researchers and seventh grade teachers worked with students to design and implement a two-month interdisciplinary project to investigate patterns of media use among the students and their peers. Bernt et al. gathered data through classroom observations, students' class work, artifacts and presentations, informal interviews with students, and a debriefing meeting with teachers. The researchers videotaped their observations, students' presentations and interviews; the debriefing meeting was audio recorded and transcribed; they compared information from these sources to clarify their findings.

Bernt et al. (2005) studied three seventh grade teachers, all of whom had computers in classrooms and were comfortable using them, with a common planning time and some experience collaborating with one another, taught 105 seventh grade students at a middle school in the Midwest; 90.4% of students at the school (not just the study) were Caucasian, and 50.6% qualified for free or reduced lunch.

Bernt et al. (2005) found that students not only sustained a high level of interest throughout the project, but they also took responsibility for their learning. The teachers reported that students were willing to take risks, and that their work and learning increased as a result. The teachers also reported that they were fully able to meet curriculum requirements through the project during the two-month period.

Students saw their research project as meaningful, authentic; they asked each day if they could work on the project, and they were enthusiastic about collecting data about something that genuinely interested them. Bernt et al. (2005) found that the multidisciplinary project led to relevant, meaningful student learning; they further stated that the teachers involved in the study showed enthusiasm for the approach. The authors finally concluded that their case study supported advocates of curriculum integration, but also noted that more research is needed. A formal survey for students and one for teachers could have supplied a lot of information about participants' experiences and perceived value of the approach and the project. The study was limited in scope, and the data collected were informal and unstructured. The findings of Bernt et al. resonated with those of other studies: students became actively engaged in classroom activities, took responsibility for their own learning, and developed their group work skills. Because of the higher-level-thinking demands of this type of curriculum, the authors recommended explicit teacher guidance and scaffolding as students learn these thinking skills.

The benefits found in these studies included increased student, teacher, and parent interest and enthusiasm, improved academic achievement, decreased media use and increased physical activity, and positive student perceptions of classroom communities. Challenges highlighted in middle level integration studies included the need for common planning time for teaching teams and the difficulty of balancing integrated subjects, though this last difficulty was more pointed in secondary programs.

Secondary Classrooms

Secondary educators who seek to integrate curriculum face daunting challenges. The eight studies reviewed in this section offer a wide array of findings, but they agree that the obstacles to interdisciplinarity in high schools are substantial: finding common planning time to work with colleagues, meeting subject-area standards within an integrated framework, teaching unfamiliar material, and incorporating disciplines equitably. Each of these research articles, ranging from small case studies to large-scale investigations involving multiple schools, added a piece to the picture of interdisciplinary pedagogy.

In their examination of interdisciplinary curricula in middle schools and high schools, Applebee, Adler, and Flihan (2007) found evidence of significant benefits and drawbacks of integrated studies. Teachers and students demonstrated enthusiasm for exploring new ideas and perspectives, and they reported a shared sense of purpose as they explored authentic questions. Difficulties encountered in this study centered on finding sufficient shared planning time and building compatible teaching teams. The authors concluded that interdisciplinary curricula offer real benefits as well as substantial challenges.

Applebee et al. (2007) collected data for thirty teachers, comprising eleven interdisciplinary teams in public schools in New York and California. These teams were selected for study after an exhaustive process in which the researchers solicited nominations, conducted telephone interviews and visited schools to ensure that the programs studied met the researchers' criteria. The sample was composed of stable, capable teams of teachers whose programs represented a range of "correlated [four programs], shared [five programs], and reconstructed [two programs] curricula" (p. 1008), with consideration given to diverse demographics and school settings. The eleven teams included three groups teaching seventh grade, one at eighth grade, three at ninth grade, and four at eleventh grade. Disciplines incorporated into programs included English, social studies, art, science, math, and philosophy.

Applebee et al. (2007) collected data in eleven schools, and gathered detailed data for at least six students in each class, representing high, medium, and low achievers, equal gender distribution, and mirroring classroom demographics as much as possible. Applebee et al. collected evidence in the form interviews, observation, program artifacts, and student work.

Applebee et al. (2007) performed qualitative analyses throughout the two-year study; they also developed case reports for the eleven schools studied, which documented the "history and functioning of the team, the nature of the interdisciplinary curriculum, the pedagogical approaches of different members of the team, and the students' perceptions" (p. 1012). The researchers collected quantitative data on four classroom practices; they measured the "Emphasis on Integrated Content" on a 0-4 scale, the number of minutes per hour of interdisciplinary content, the frequency of "Envisionment-building activities" on a 0-4 scale, and the number of minutes per hour of open discussion.

Applebee et al. (2007) described a continuum of interdisciplinary curricula and argued that a descriptive scale makes more sense than a sharply delineated either/or model. As mentioned above, the authors categorized the programs they studied into groups they labeled "correlated," "shared," and "reconstructed," with the last showing the most broadly integrated practices. The reconstructed curricula programs showed the highest values for all four quantitative variables measured. The correlated programs averaged 3.63 minutes per hour of interdisciplinary content, while shared programs averaged 13.84 minutes and reconstructed classrooms averaged 26.37 minutes. The other measures followed the same pattern: correlated curricula scored 1.43 on the disciplinary connections scale; shared curricula exceeded that by 0.56 and reconstructed curricula by 1.55. On the scale of envisionment-building activity, correlated curriculum averaged 1.98, shared curriculum averaged 2.48, and reconstructed curriculum averaged 3.61 on the four-point measure. Both correlated and shared curricula averaged few minutes of free discussion in an hour, 2.76 and 6.14 minutes, respectively. Reconstructed curricula, by contrast, averaged 21.07 minutes per hour of open discussion involving three or more individuals. These data showed that these classroom practices increased among teachers of interdisciplinary curricula, and increased more where curricula were more integrated.

Applebee et al. (2007) succinctly reported their general quantitative results, and then provided insightful, detailed case reports for one program of each group. These reports included rich qualitative information as well as detailed quantitative data, which were compared to the rest of the treatment group. The authors noted strengths and limitations of each approach and each team they studied; they found that common planning time is a high priority for interdisciplinary teaching teams, and that there is a danger of a discipline being short-changed. They also found that the flexibility to increase and decrease the level of interdisciplinary focus was important to teachers' success. Where programs allowed room for teachers to choose to focus for a time on disciplinary skills or content, teachers showed more confidence that they were able to balance the needs of their individual disciplines with connections among disciplines.

Applebee et al. (2007) presented a reasonable, balanced view of the benefits and limitations of interdisciplinary pedagogy. They concluded that integrated curriculum involves trade-offs: heavy demands on teachers' time, limited interdisciplinary resources, and challenges facing teaching teams must be weighed against teacher and student enthusiasm, broader perspectives, and a sense of shared purpose.

Pugalee's (2001) study examined student writing in mathematics for evidence of metacognitive frameworks. The author collected written data from a class of twenty-four Algebra I students; he analyzed and reported on the writing of twenty ninth-graders in this study, due to excessive absenteeism and nonparticipation from four students. The ninth graders, who attended a Southern high school with a population of about 1,150, regularly wrote about their problem solving strategies, and began class with a written problem-solving task each day for two weeks prior to the data collection for this study. Pugalee selected six algebra problems—two considered easy, two moderate, and two difficult—and the teacher presented these problems for the opening writing task each day for six consecutive days. Students were instructed to write down everything they thought as they worked through each problem; Pugalee analyzed this qualitative data, classifying statements into four phases of problem solving (orientation, organization, execution, and verification), and, further into categories of metacognitive behavior within those phases (such as "analysis of information and conditions" and "evaluating decisions" (Appendix B)).

Pugalee (2001) discussed the number of data points, student responses, coded in each of the four problem solving phases, quoted sample responses, and interpreted the students' statements as they related to metacognition. In many cases, he argued that student writing constituted evidence of an existing metacognitive framework, but he also claimed that this type of writing task may point to the absence of such a framework. Pugalee argued that, though more research is warranted, his results provide support for reform efforts aimed at improving mathematical understanding and problem solving through the process of writing.

In order to investigate the efficacy of writing to learn mathematics (WTLM) activities, Porter and Masingila (2000) conducted a case study of two groups of introductory calculus students. One group used WTLM activities and then discussed them; the other group used non-writing activities that required students to think and talk about mathematical concepts and procedures. The WTLM treatment group included three female students and twelve male students, and four females and fourteen males comprised the control group; all students took a Calculus Readiness Test at the start of the course, and the mean scores were not statistically significantly different. Students in the treatment group completed a writing activity, either in class or as homework, on seventeen of the thirty-eight days of the course on which there were no exams. Porter and Masingila categorized and analyzed errors made by students on procedural and conceptual problems on three in-class exams and one final exam. The authors conducted MANOVA tests on the error data, and found a statistically significant difference for only one category on one of four exams: the WTLM group averaged 15.40 conceptual errors, significantly more than the 11.28 average of the comparison group.

Porter and Masingila (2000) acknowledged the possibility of bias arising from Porter's dual role as researcher and instructor, and explained how they worked to minimize that bias. They also included sample tasks assigned to the writing and non-writing groups. Importantly, the authors recognized that an absence of errors does not equate to understanding, and they moderately defended their methods of collecting and comparing data. Within these limitations, the authors provided evidence that writing in mathematics may not increase students' understanding, and may, in fact, have an adverse impact.

Porter and Masingila (2000) examined errors made by students in both sections on in-class and final tests to gain information about students' conceptual and procedural understandings. They found no significant differences between the two groups' patterns of error; they suggested that the opportunity to engage in activities that require students to grapple with and communicate their ideas to others may have benefits for learners, whether these activities involve writing or not.

Hand, Hohenshell, and Prain (2004) examined the effects of planned writing experiences on tenth grade biology students at a rural high school in the Midwest. They found that students who engaged in planned writing activities twice, rather than only once, performed better on answering conceptual questions shortly after the experience and still performed better on an exam several weeks later. Four classroom groups completed a writing task that required them to create a student-written textbook section for seventh graders, with two groups performing planned writing (PL) and two groups engaging in delayed-planned writing (DPL). Two of these groups, one PL and one DPL, also performed a second task, which required them to write newspaper articles to be submitted to a local newspaper editor for comment.

Hand et al. (2004) found that completing writing tasks positively impacted students' performance on conceptual questions on science exams. The effect size was larger for boys than for girls on the first exam (a moderate 0.73), but this disparity diminished on the second test (a small 0.13) and disappeared on the third (to an insignificant 0.06). The authors also reported that effects were larger for students who completed two writing tasks than for those who completed just one; this effect size increased from a small 0.36 on exam one to a moderate 0.70 on exam two and a large 1.09 on exam three. Hand et al. also reported that students' comments demonstrated support for "nontraditional writing tasks" (p. 186), especially when they wrote for an outside audience.

Rather than measuring quantitative student achievement outcomes in an attempt to prove the superiority of integrated pedagogy, Borasi, Siegel, Fonzi, and Smith (1998) conducted a meticulous qualitative analysis of classroom episodes of Reading to Learn Mathematics (RTLM) in order to gain insight into how transactional reading strategies promote sense-making and mathematics discussion in secondary schools. The authors provided a background of psycholinguistic reading approaches, which regard the process of reading as a participatory transaction among author, text, and reader. Drawing on a pool of mathematics teachers that had previously enrolled in graduate coursework for professional development, the authors researched the use of transactional reading strategies in four secondary teachers' classrooms in four different school settings.

Borasi et al. (1998) documented four units lasting from two to six weeks as well as a one semester (eighteen week) course titled *Math Connections* at an alternative urban high school. The researchers' variously played roles of teachers or instructional aides and, at other times, nonparticipant observers. The researchers collected evidence that included field notes written by observers at every class meeting during each unit, audio- and video-tapes of class sessions, audiotapes of researcher meetings, and photocopies of all instructional materials and all student work.

After collecting this substantial set of data, Borasi et al.(1998) identified eighteen *"reading to learn mathematics (RLM) episode[s],"* (p. 282, italics in original) learning experiences in which students engaged with mathematics-related text. Two of the shorter units utilized only one RLM episode each, while the semester-long course incorporated eight of these experiences, which ranged from twenty minutes to seven hours of instructional time. The authors analyzed two of these episodes in depth- one from the geometry unit and one from the *Math Connections* course- and reported detailed findings; they also reviewed the other sixteen episodes to detect discrepant findings or corroborating results. Borasi et al. considered limitations as well as strengths of the reading-math integration that they studied, and they openly articulated the limits and purposes of their study. This research provided a unique qualitative picture of on-the-ground impacts of integrated pedagogy.

McCaffrey et al. (2001) investigated the impacts of standards-based or reform practices, such as those published by the National Council of Teachers of Mathematics, on students' academic achievement. The authors found that teachers' use of reform practices in Integrated Math classes was positively correlated to higher achievement on both multiple choice and open-ended portions of the Stanford Achievement Test.

Using data collected as part of the National Science Foundation's (NSF) Urban System Initiatives (USI), McCaffrey et al. (2001) investigated the effects of curriculum on the relationship between teachers' use of SI reform practices and students' achievement on multiple choice and open-ended problems on the Stanford achievement test. The authors mentioned the National Research Council, the American Association for the Advancement of Science, and the National Council of Teachers of Mathematics as organizations that have published standards or guidelines that encourage educators to engage students to connect them to their learning, and to help them develop cognitive processes. The practices endorsed by the NSF as part of its push for reform include building classroom communities, focusing on logic and problem solving, and exploring connections between science and math.

McCaffrey et al. (2001) gathered data at twenty-six urban high schools for mathematics courses in which the majority of students were tenth graders; 52% of tenth graders studied were enrolled in geometry, 13% each in Algebra I and II, 14% in either the Integrated Mathematics Program (IMP) or College Preparatory Mathematics (CPM), the integrated classes.

The authors collected demographic, questionnaire, and achievement test data; they used students' ninth-grade scores on open-ended Stanford achievement test questions as covariates in their analysis of tenth grade multiple-choice and open ended scores, which McCaffrey et al. (2001) examined as outcome variables.

After collecting and standardizing data, McCaffrey et al. (2001) analyzed and modeled the statistics in a number of ways, exploring relationships among teachers' reported use of reform practices, type of course, and student achievement. They found that reform practices employed in traditional courses (Algebra I, Algebra II, and Geometry) did not correlate with higher (or lower) test scores; reform practices incorporated into integrated courses were correlated with small, statistically significant gains in student achievement.

In a qualitative case study, Venville, Rennie, and Wallace (2004) collected and analyzed data to determine what sources of knowledge grade nine students used as they designed, built and tested solar-powered boats; three teachers coordinated curricular content for this technology-driven multidisciplinary project. Thirteen- and fourteen-year-old students in the Academic Talented Program at a metropolitan high school in Perth, Western Australia, studied Ohm's Law, current, resistance, power, solar energy and solar panels, efficiency, graphs, solving equations, propulsion methods, materials and construction techniques and more during the twelve-week project. Venville et al. collected data on three pairs of students, each of which designed and tested its own working model of a solar-powered boat. The first author conducted research as a participant observer, sitting in on twenty-six class sessions and collecting data in the form of student and teacher interviews, classroom observations, and student portfolios.

Venville et al. (2004) focused their study on the sources of knowledge students used when they made important project decisions. The authors identified five main sources of information: discipline theory (that is, ideas or tools firmly connected to one traditional subject area, such as Ohm's Law); teacher; trials and testing; other students in the same class; and outside students, parents, or family members. The researchers also selected three key moments of the project that required students to draw on knowledge to make design choices. Venville et al. analyzed the compiled data and created diagrams illustrating which knowledge sources were used, and in which order, at each of the previously identified key moments.

Venville et al. (2004) identified several important choices students grappled with. The first big decision students had to make was how to design the hulls of their boats, the second was how to design their circuits; all three pairs consulted three or four different knowledge sources when approaching these open-ended tasks. The third task required students to decide how to mount the solar cell on the boat. This was a less open-ended problem, as there was one orientation that would gather solar energy most efficiently. When making decisions about this closed problem, two groups consulted two knowledge sources each, and the other drew on three sources.

Venville et al. (2004) concluded that the subjects, who were participants in an Academic Talented Program, used multiple sources of knowledge to guide their decisions as they designed their solar-powered boats. They also suggested, tentatively, that more open-ended tasks prompted students to draw on more sources, while closed tasks could be solved with fewer sources. Discipline-based sources appeared to be most useful for closed tasks, problems with a definite answer, while sources such as the classroom teacher, first hand trials, and interactions with other students and family members seemed most helpful when students constructed creative solutions to open-ended, cross-disciplinary tasks. Venville et al. presented interesting and well-documented evidence suggesting that balance between open-ended and closed tasks and access to multiple sources of knowledge are important considerations for teachers working to integrate curricula.

The subjects of Seki and Menon's (2007) math and science integration case study attended an alternative high school for girls in Southern California. All twenty-three students qualified for the free lunch program, and all were considered "at-risk" because of failed classes or expulsion at other schools. Absenteeism and student turnover were high, which the author mentioned as a limitation of the study; however, these challenges would be hard to avoid when working with this important, underserved population.

Seki and Menon (2007) began the four-week study by assigning students the kind of work they were familiar with: reading a section of the textbook and answering the questions in the book. All of the students were able to use either the in-text definition or the glossary to correctly define two science concepts, mechanical advantage and ideal mechanical advantage. However, when students were given a survey during the next class session, only 21% showed a fair understanding, while 79% demonstrated no understanding of mechanical advantage. None showed a good understanding of the concepts.

Following this pre-assessment, the students worked in groups of four to six to construct inclined planes with cardboard, and to calculate the ideal mechanical advantage (IMA) of planes with the same length but varying heights. Groups also created posters of the planes and graphed the relationship between the IMA and the height of the plane. Further study included examining the ratio of the radii of a wheel and an axle and creating individual posters illustrating a simple machine. At the end of the four-week project, the Seki and Menon (2007) administered a post-assessment survey to measure conceptual knowledge, disposition toward math, and understanding of the connection between math and science.

Seki and Menon (2007) found that the subjects initially had a very limited understanding of a concept studied only through reading and transcribing definitions- a practice common in many classrooms- and that many students felt negative about math or believed that it was not important in science. The results of the post-assessment survey indicated that many students gained conceptual understanding through the integrated math and science, hands-on approach: 78% of students (18 of 23) demonstrated some understanding of mechanical advantage. Even more striking was the finding that 61% of students were able to calculate the ideal mechanical advantage of inclined planes on the post-assessment without referring to outside sources. Of particular importance to Seki and Menon's study, post-assessment data showed that 78% of students recognized that math and science are related, and 61% responded that using math in other subjects could improve their math learning.

Seki and Menon (2007) concluded that math is an important component of any science program; they also noted that using math as a tool, as part of a tangible problem, makes mathematics more meaningful to students. The authors found that students' understanding of both math and science was enhanced through this integrated unit. Though the authors expanded their recommendations for integration beyond the scope of their study, their results do offer significant support for the integrated math and sciences courses for students considered "at-risk."

Lewis and Shaha (2003) conducted three case studies to examine the effects of integrated curricula. The English focused study compared three instructional approaches: Traditional English, Applied English, and Integrated English; the mathematics study compared Traditional Algebra instruction with Integrated Mathematics; the science focused study compared Physics, Principles of Technology, and Integrated Physics and Electronics.

Lewis and Shaha (2003) kept subjects blind to the treatment group in which they were placed, and also kept survey responses confidential. Teachers agreed to participate in the study and were assigned to treatment groups based on their own preference. The study applied survey and assessment instruments at the beginning and end of the academic year; attitudinal instruments were developed for this particular study.

Lewis and Shaha's (2003) English study involved eight classrooms in two high schools; subjects were matched for GPA, socioeconomic status, age, and pre-test scores in an effort to increase the validity of the study's results. Ninety-one twelfth grade students studied Traditional English, 56 enrolled in Applied English, and 44 took Integrated English. The mathematics study involved six classroom groups, controlled for age, socioeconomic status, GPA, and pre-test scores. Ninety-one students studied traditional algebra, and 93 studied integrated mathematics. Three distinct approaches to science instruction were implemented in twelve classrooms in four high schools, matched for pre-test scores, age, socioeconomic status, and GPA. Forty-three students studied Physics, 27 studied Principles of Technology, and 42 studied Integrated Physics and Electronics.

Lewis and Shaha (2003) presented data from Likert-scale student attitude surveys, Likert-scale parent survey, and science test scores. Post-test results from the attitudinal survey indicated that the students studying an integrated curriculum valued English more highly, enjoyed the classroom experience more, and rated the skills gained in the course more highly than students in the other two groups. Results for 11 of 14 survey items showed statistically significant differences among the different curricular approaches. The Workplace survey showed that workplace skills were less impacted by the treatment than students' attitudes. Students in integrated studies outperformed their peers in only two of nine categories measured, and the margins, though statistically significant, were not large. The Likert-scale parent survey indicated that parents of students taking Integrated English rated their students' interest and enjoyment of English and their students' learning more highly than parents of students in other courses; the disparity is widest between Integrated and Traditional English.

The authors found no difference in pre-test and post-test scores between groups in Traditional Algebra and Integrated Math courses.

Lewis and Shaha (2003) claimed this as success, noting that traditional expectations would have predicted lower scores for students in Integrated Math. The most significant difference found in the attitudinal survey documented improved attitudes about math abilities and confidence in students in Integrated Math, compared with the Traditional Algebra group.

Lewis and Shaha (2003) found that students' science test scores and self-reported attitudes toward science improved significantly in five out of six survey items for students in Integrated Science courses. The test scores are striking: the increase of scores from pre-test to post-test was.58 for students in Physics, 1.67 for those in Principles of Technology, and a remarkable 8.45 for students in Integrated Physics and Electronics.

Lewis and Shaha (2003) kept their subjects blind to their treatment group; subjects were matched for several variables to improve the validity of the study's results. The researchers studied effects of integration in multiple traditional curriculum areas, offering a broad look at interdisciplinarity through several secondary subject areas.

Several studies linked integrated curricula to gains in secondary student achievement, while some found no statistically significant differences between treatment and control groups. Some of these studies reported increased student, teacher, and parent interest and enthusiasm, and some documented affective outcomes. As a whole, this collection of studies provides modest support for integrated curricula in secondary schools.

Technology Integration

Technology integration presents unique opportunities and challenges. The four studies critiqued in this section represent distinct approaches to technology integration research. Included here is a study of several hundred students engaged in an interdisciplinary math, science, and technology program, an examination of technology implementation in three urban elementary schools, a case study of technology used in a science classroom, and a case study of technology-integrated science investigation in an urban elementary school.

In a quantitative case study that compared 293 students in a treatment group studying an integrated curriculum to 246 students in classrooms utilizing a traditional curriculum, Satchwell and Loepp (2002) found that the Integrated Mathematics, Science, and Technology (IMaST) curriculum supported student achievement on standardized tests such as the Third International Mathematics and Science Study (TIMSS). These subjects were drawn from eight urban middle schools. Students in the intervention group scored, on average, moderately higher than their control group peers on all four subcategories of this test: math procedures, math problem solving, knowing science, and science process. On the twenty-item mathematics procedures sub-scale, IMaST students scored a mean 17.72, while control group students averaged 16.32; IMaST students scored a mean 13.35 on the 16-point problem solving sub-scale, and students studying a traditional curriculum scored an average of 12.28. On the eighteen-item knowing science sub-scale, traditional students scored a mean of 16.39; treatment group students scored slightly higher, with an average of 17.31. The greatest difference in student achievement occurred on the eighteen-item science process sub-scale, on which IMaST students scored a mean 18.09 and traditional students averaged 15.83. Each of these differences is fairly modest, but the results do show consistently higher scores for IMaST students.

Satchwell and Loepp (2002) acknowledged weaknesses of their study, and explained how they tried to control for them. Though control and treatment groups were not randomly assigned, the researchers did include classrooms in eight different schools, making this one of the largest studies available. The discussion of the statistical analyses of data was rather obscure, and the authors did not explicitly state which of their findings showed statistical significance.

Of further concern is the fact that Satchwell and Loepp (2002) were among the designers of the IMaST curriculum, which they developed, studied, and revised for commercial publication. The authors stated their interest in the curriculum, but the connection remains a note to consider. On the whole, this study of the effects of integrating math, technology, and science provided one more modest piece of evidence in support of interdisciplinary curriculum.

In an effort to relate elements of school culture to the success or failure of technology integration, Staples, Pugach, and Himes (2005) investigated the factors that impacted how technology was used, and how effectively it was used, in three urban elementary schools. The authors described three unique schools: one neighborhood school enrolled 700 students in a year-round, multiple site setting; a second school, with 650 students, adopted a curriculum connected with social justice; the third school housed 350 students in multi-age classroom, and articulated a commitment to project-based learning. The student populations of these schools were demographically similar: between 72% and 85% of students were African Americans, and between two-thirds and 83% qualified for free or reduced lunch.

Staples et al. (2005) sought to identify characteristics of schools and programs that supported successful technology integration. They noted that prior studies of technology implementation frequently focused on individuals or groups of teachers, and stated that they searched for "a cultural view of technology integration in the school ecosystem" (p. 288); furthermore, they conducted a cross-case analysis of implementation in the three school, in search of information that might aid the planning and implementation of educational technology.

Staples et al. (2005) noted that each school receiving the PT[3] technology funding hired a half-time technology specialist; each school also worked with a technology consultant from the partner university one day each week. In addition, teacher candidates at the university were frequently involved at the case study schools gain field experience and for student teaching.

At the outset of their study, which spanned the years from 1999 to 2002, Staples et al. (2005) found that the three schools had an average of five computers in each classroom as well as a computer lab shared by the school; however, each building had only a single internet connection, setting a severe limit on the uses to which teachers could put their classroom computers. The pre-study survey indicated that teachers valued instructional technology and believed its use was important, but the teachers also acknowledged that their practices did not generally align with these beliefs, that they were not making frequent or effective use of technology. When the computers were used, it was primarily for "skill-and-drill or free-time activities" (p. 289), rather than as curricular or instructional supports.

Staples et al. (2005) collected qualitative data: field notes, interviews, timelines, and children's and teacher's artifacts were collected at each site, and then compared and analyzed. They found that instructional technologies and professional development training to support educators in using new tools ought to be planned and implemented together. By considering ways in which technology can be integrated into classrooms and enrich curriculum, careful planning and alignment with curricular goals and teacher trainings are key to effective implementation.

Popejoy (2003) investigated the effects on teaching and learning of integrating computer technology in an elementary science classroom. The participant researcher collected the data for this qualitative case study over a four-month period during which she spent two to three days each week observing in the classroom. Popejoy reported mostly implementation data in this article, along with limited outcome data. The author observed a teacher implement a technology-integrated science project in a fourth and fifth grade class in a coastal community of the Pacific Northwest; six students were fourth graders, and eighteen were fifth graders.

Popejoy (2003) reported that in interviews, students reported that working in pairs or groups of three on the computer was more effective than working independently; the author's observations supported this finding. Though the students in the sample were comfortable using computers for a variety of classroom activities, such as researching and creating presentations, they also all struggled with sifting the massive quantities of information to find data that were reliable and relevant.

Popejoy (2003) found that technology allowed students access to a substantial amount of information about astronomy, a subject for which the school library had few materials; she concluded that incorporating technology into an intermediate science classroom provided opportunities for students to study a challenging topic in meaningful ways. The author also concluded that computer technology enabled students to assemble the data they found on the internet and create polished presentations that they shared with their peers.

Popejoy (2003) stated her role as participant observer, and identified what she perceived as the benefits and limitations of that role. The researcher's familiarity with the practicing teacher and school community could potentially increase the researcher's bias as an observer. Significantly, Popejoy acknowledged the difficulty of measuring the many important variables impacted by technology integration; this challenge of teasing apart important influences on students' classroom experiences is common throughout the literature.

In order to investigate the effects of Geographic Information Systems (GIS) and GoogleEarth technology on students, Bodzin (2008) collaborated with a fourth grade teacher to develop and implement a technology-integrated water quality study for an after school science club at an urban elementary school in Allentown, Pennsylvania. The curriculum also incorporated online photojournals and online databases. Students met for twenty-four 70-minute sessions between June and October; in order to investigate the health of their school's pond, students collected and analyzed data detailing the biotic and abiotic components of the pond over the course of three seasons. The fourth graders used field journals as they observed and posed additional questions about the watershed. Students shared their data through the Center for Improved Engineering and Science Education (CIESE) Bucket Buddies project, an online database through which scientists share and compare their data with the findings of other groups studying ponds around the world.

Bodzin (2008) followed the collaborating teacher who supervised the after school club introduced students to the concept of watersheds with state maps, tracing the routes of major rives in Pennsylvania. The teacher then projected a series of GIS maps that allowed students to see, one piece at a time, their local watershed boundaries and the Lehigh River, tributaries and streams, and then major and local roads. In this way, students gained a sense of their watershed and the human activities that impacted it. The teacher then used GoogleEarth to further explore the local watershed and its connections to other rivers and the Atlantic Ocean.

Bodzin (2008) reported that students' environment attitudes were enhanced, and they gained a sense of environmental stewardship. The author clearly stated his position that outdoor experiences strengthen students' environmental attitudes, and he cited research to support that position. However, he also acknowledge that past research studies have not all come to the same conclusion, and he cited research suggesting that outdoor experiences may not be a decisive factor in developing children's environmental understanding. Bodzin articulated his own perspective, recognized that there are many perspectives on issues of environmental education, outdoor activities, and technology in education, and presented his research openly and without making outrageous claims. Bodzin showed that an environmental science program that integrates technology and outdoor activities can have positive impacts on students.

The technology integration research reviewed here found consistent small gains in student achievement in math and science, identified careful planning and curriculum alignment as important supports, found that sifting and evaluating information gathered on the internet is a challenge for students, and demonstrated positive affective impacts of a program integrating science, technology, and outdoor activities. Integrating technology across the curriculum poses many difficulties, but a successful program yields important benefits.

Impacts on Teachers

The last section of this chapter reviews research focused on the impacts of interdisciplinary curricula on teachers. All three of these studies examined professional development trainings connected with integrated programs. One study investigated the impacts of an interdisciplinary health curriculum on teacher practices, another examined effects of a constructivist, interdisciplinary graduate-level course, and a third followed teachers implementing a math, science, technology integration curriculum funded by the charitable arm of the GTE corporation.

In a professional development study, Haney, Wang, Keil, and Zoffel (2007) investigated the effects of an integrated environmental health curriculum on teaching practice and student performance. Eighteen middle school teachers from six schools participated in a two-year professional development program designed to train educators in developing, implementing, and revising locally relevant, interdisciplinary, problem-based environmental health curricula. Teams of four or more practicing teachers, preservice teachers, and building administrators attended regular meetings and EXCITE summer institutes to develop interdisciplinary environmental health curricula that incorporated best practices such as inquiry-based learning, performance-based assessment, and cooperative learning. Teachers collaborated with each other and with community and university partners over the course of the two-year study, earning a total of 160 professional development hours.

Haney et al. (2007) measured teacher perceptions of factors that would support them as effective science teachers with a Likert-type Context Beliefs About Teaching Science (CBATS) instrument. They assessed teachers' beliefs about self-efficacy with the Science Teaching Efficacy Belief Instrument (STEBI-A), another Likert-type assessment tool. Using Statistical Analysis Software (SAS), the researchers collected teacher data using these four instruments as pre-tests and post-tests at the beginning and end of the two-year study. They performed a multivariate Hotelling T-squared test, and then added scores on each scale to create a composite. They also calculated effect size for each test.

Haney et al. (2007) found that teachers' beliefs about their self-efficacy improved over the course of the study; the mean composite score for this subscale increased a statistically significant 5.94 points, with a $p < 0.001$ and an effect size of 0.83. The authors also found statistically significant changes, with moderate effect sizes, on measures of belief about constructivist teaching practices (mean increased 7.33 points, with $p < 0.032$). Finally, the authors found that teachers' use of traditional strategies decreased (effect size = -0.56, $p < 0.017$) while their use of reform strategies increased (effect size = 0.53, $p < 0.020$).

Haney et al. (2007) examined changes in students' science process skills by administering the Performance of Process Skills (POPS) test before and after the study. They found a statistically significant increase in the mean score for the entire student population. When the authors analyzed the data by quartile, they found significant increases in the scores of students in the three lower-scoring quartiles, with the lowest quartile showing the most growth ($p < 0.001$). The highest-scoring quartile was the only one that did not show significant increase in scores. The researchers also found that students' scores on Ohio State writing, mathematics, and citizenship proficiency tests increased significantly among EXCITE students compared with control group peers.

Haney et al. (2007) acknowledge that the effects of the study on teachers' beliefs and practices could not be attributed to a single causal factor or to one "best practice," though they did claim that the model as a whole had a positive impact on teachers and students. Unfortunately, the researchers provided only brief summaries of student achievement, reporting limited findings without the bulk of the data. They did, however, discuss variables that didn't show significant change, as well as those that did. This study produced significant support for the benefits on teachers' perceptions and limited support for the benefits on student achievement correspondent to interdisciplinary, problem-based instruction.

Foss and Pinchback (1998) reported the effects on fifty practicing teachers enrolled in a graduate-level professional development course titled "K-4 Science, Mathematics, and Reading: An Interdisciplinary Approach." The sample for this qualitative case study included 15 Kindergarten teachers, 16 first grade teachers, four 4 second grade teachers, 9 third grade teachers, and 6 fourth grade teachers. Three course instructors delivered integrated, constructivist lessons to the groups of in-service teachers, following a basic structure of concept exploration, term introduction, and application; this method of graduate-level teaching was designed to reflect the ways in which children learn, and to provide teachers with "images of...integrated lessons" (p. 152).

Foss and Pinchback (1998) assessed the effects of the course by analyzing data documenting subjects' content knowledge in the areas of reading, science and mathematics; they also examined subjects' portfolios, journals, presentations and questionnaires to asses teachers' implementation of integrated lessons. The authors found that the subjects increased their content knowledge and demonstrated improved understanding of implementing interdisciplinary curriculum. Foss and Pinchback further concluded that providing teachers with appropriate materials, instruction in using the materials, and opportunities to learn in an interdisciplinary, constructivist setting—in this case, in the same manner as they are being encouraged to teach—enables teachers to design and implement integrated experiential curricula. One finding, which echoes the results of many other studies, suggested that teachers benefit by having time to collaborate with colleagues.

Potential confounding factors in Foss and Pinchback's (1998) study included the sample, which was likely predisposed toward supporting approaches taught in the course they enrolled in. Foss and Pinchback also reported increases in students' content knowledge and described the statistical analysis they performed, but they did not provide the data to which they referred. This weakness did not, however, negate the evidence of the positive impacts of interdisciplinary, constructivist professional development.

What happens when a team of educators designs and implements an integrated curriculum in middle school math, science, and technology courses? The GTECH project, funded by a philanthropic organization connected with the GTE Corporation, offered training, professional development, and technical support to seven teaching teams working in public schools in Texas. James, Lamb, Householder, and Bailey (2000) prepared a report utilizing both quantitative and qualitative data collected during the first two years of implementation of the GTECH project. Participating educators worked in groups of one math teacher, one science teacher, one technology teacher, and one administrator from each school. These teams attended three workshop days during the course of a school year; the educators set goals that matched the needs of their schools as well as the aims of the curriculum integration GTCH project. Teachers also attended a two to three week summer institute designed to help them develop deeper understanding of key concepts as well as master technical skills.

James et al. (2000) drew on two iterations of a Stages of Concerns Questionnaire (SoCQ); participating teachers first completed this affective measure during the Spring of Year One. This survey, which may be viewed as a formative assessment, indicated that most of the GTECH project teachers' concerns centered on personal, information, and management issues. The authors stated that this finding suggested that many teachers had not yet begun implementing integrated curricula or instructional technology into their classrooms; they further stated that this lack of implementation was confirmed with on-site observations. The results of this first administration of the survey guided GTECH staff to shift the focus of the summer institute toward providing information about educational technology and how technology can be effectively used in the classroom.

James et al. (2000) reported that year two of the GTECH project began with GTECH staff visiting each site to ensure that the provided software (HyperStudio 3.0 and Microsoft PowerPoint) was installed and functioning on the necessary computers; in many cases, the software had not been in use, and technical troubleshooting sessions became a part of the implementation of the project. Increased on-site visits also revealed that only about one third of teachers were actively using the GTECH materials and integration ideas generated with the teaching teams; in many cases, only the science teacher appeared to be using the new strategies. James et al. perceived this as a positive place to start, stating that the initial goal was to put the project in place in each participating school, not necessarily in each participating classroom.

James et al. (2000) administered the second iteration of the Stages of Concern Questionnaire during year two of the study. The researchers found that informational, personal, and management concerns remained substantial, while collaboration and consequence concerns remained low, but refocusing concerns rose, suggesting that teachers were feeling more comfortable with the GTECH approach and were becoming interested in modifying aspects of the project to better suit their schools.

Of special importance, however, was the observational finding, which persisted throughout the study, that math was not being consistently integrated with the other subject areas. James et al. (2000) noticed this lack of balance in curriculum integration early on in the project, and multiple efforts were made by teachers at various sites to correct the problem, with little success. They attributed this difficulty in large part to the highly structured Texas state mathematics standards. Individual schools' report cards placed heavy emphasis on test scores, and the mathematics teachers participating in the study seemed to believe that their curriculum was not flexible enough to integrate science or technology into their classrooms frequently.

The corporate philanthropy source of the GTECH projects funding was a potential weakness of this study, but James et al. (2000) frankly acknowledged the source and the long-term goals of the project, which included the development of a commercial integrated curriculum model. The data were presented without excessive value statements or qualifiers; positive findings were presented in a moderate manner, and project weaknesses were delineated openly.

James et al. (2000) shared two findings that may prove to be challenging for advocates of integrated curriculum: instructional technology has many potential pitfalls and requires substantial support, and some disciplines, such as mathematics may pose serious challenges to teachers working to integrate curricula.

These technology-focused studies emphasized the importance of opportunities for teachers to plan and collaborate; they also shared the finding that professional development is essential for teachers integrating curriculum.

One of the studies found that teachers' content knowledge increased; another found that mathematics was not consistently integrated with the other subjects. The research showed evidence of positive impacts on teachers as well as substantial challenges.

Summary

One persistent problem highlighted in the body of research is the lack of common definitions. Every author's and every teacher's idea of integration is unique. Many terms are used, apparently interchangeably, without clear definitions or explicit connections to language used by others. This is not an insurmountable problem; indeed, the flexibility of some interdisciplinary approaches and their potential for differentiated instruction—that is, tailoring curricula to individual students' needs and developmental levels—are among the most promising characteristics of integrated teaching and learning.

The uniqueness of each study and the frequent fuzziness of terms do, however, create obstacles for the researcher. Studies with close parallels, which ask similar questions or measure similar results, are difficult to find; many studies are entirely qualitative; and many more blend multiple variables within one research project, further complicating the interpretation of results.

CHAPTER 4: CONCLUSION

Introduction

This paper has investigated the impacts of integrated curricula on students and teachers. Chapter One described the current context of the debate surrounding interdisciplinary program; Chapter Two outlined the historical antecedents of the issue. The professional dialogue between those who advocate for interdisciplinary curricula and those who maintain that subject-based curricula are more valuable is ongoing, and may be traced back to ancient Greek ideas of how citizens ought to be educated. Progressive educational reforms in the United States in the 1920s and again in the 1960s and 1970s led to brief, though vigorous, proliferation of interdisciplinary programs at all levels of schooling. Each time interdisciplinarity has gained a foothold, however, curriculum traditionalists have steered public schools back toward a narrow role of disseminating accumulated knowledge and training students in basic skills. Chapter Four will summarize the research findings detailed in Chapter Three, consider implications for the classroom, and suggest areas for further research.

Summary of Findings

Chapter three critiqued recent research investigating the impacts of integrated curricula. Literature reviews and meta-analyses were examined, followed by studies conducted in elementary, middle, and secondary schools. The chapter concluded with sections on technology and teacher impacts.

In a literature review of arts integration research, Brewer (2002) questioned the benefits of interdisciplinary pedagogy, arguing that there are profound differences among disciplines that hamper meaningful integration. Brewer (2002) found that only 2% of reviewed research reported research, while 16% of published articles were primarily theoretical and 82% described programs or curricula. Hurley (2001) conducted a meta-analysis of quantitative math and science integration studies; she found positive impacts on student achievement, with a small effect size of 0.27 for mathematics and a moderate 0.37 for science studies. Wallace and Clark (2005) examined math and reading integration, finding that a teacher's philosophy had a weighty impact on instruction.

Interdisciplinary studies can have positive impacts in elementary schools. Two articles reported achievement gains among students in interdisciplinary intervention groups. The curricula impacted both heterogeneous classrooms and populations of gifted students. Another study, from New Zealand, found that infusing physical education across the curricula increased daily activity levels of elementary schools students.

Studies of interdisciplinary programs in middle schools provided substantial evidence supporting integrated pedagogy. Researchers reported increases in student performance in mathematics and science on the Stanford achievement test (Bolak et al., 2005), increased student interest and enthusiasm (Bernt et al., 2005), and positive student perceptions of the classroom (Compton, 2002). Many middle school educators appear to be embracing interdisciplinary teaching and learning.

There are a few common themes in the literature centered on interdisciplinary programs in secondary schools. Integrated pedagogy entails many challenges, and some of these challenges may be overcome with collaborative team planning time and administrative support. Some studies showed small to moderate gains in student achievement, while others documented qualitative changes in conceptual understandings. The secondary research is, on the whole, modest but positive.

Technology integration poses its own challenges and rewards. Teachers need training on the use of technology in the classroom, and they need time and support to gain skills and confidence (Popejoy, 2003; Staples, et al., 2005). Careful planning is essential for successful implementation of technology programs in schools (Staples et al., 2005). Most importantly for this paper, student achievement and engagement are positively impacted through the use of technology integrated into learning activities (Bodzin, 2008; Popejoy, 2003; Satchwell & Loepp, 2002).

Teachers' beliefs and practices can be positively impacted through the implementation of interdisciplinary curricula; there are significant obstacles for effective implementation. Teachers shifting toward interdisciplinarity need flexible planning time and administrative support to be successful.

Classroom Implications

The implications for the classroom teacher are clear: interdisciplinary study has the potential to increase students' achievement and raise the quality of their educational experience by improving their engagement and attitudes. There are caveats, too; a teacher's commitment to the interdisciplinary approach to curricula, the time available to a teacher for planning and collaboration, and the support of administrators are important variables impacting the success of any interdisciplinary curriculum.

Classroom teachers and school communities searching for ways to improve the quality and authenticity of their students' education ought to give strong consideration to developing an integrated approach to curriculum. Teaching teams, flexible scheduling, support from fellow educators and administrators, and a willingness to invest time and energy into creating and adapting relevant learning experiences are essential elements of a successful integrative program.

The research reviewed in this paper supports the use of interdisciplinary curricula, but the integrated approach is not necessarily for everyone. Many teachers, especially in secondary schools, tend to be specialists, experts in their subject areas. One point essential to keep in mind is that a teacher's educational and life philosophy impact how she or he teaches. A teacher who identifies as an expert in her field may prefer a purely discipline-based approach, while an educator who sees herself as a guide for students finding connections in the world and among areas of study may embrace interdisciplinary pedagogy.

Integrated approaches to teaching and learning have exciting potential, but they are not a panacea, and they are far from one-size-fits-all. The integrated programs detailed in the research vary enormously, blending many different subjects in myriad ways, and part of the beauty of integrated models is their adaptability: the possibilities that exist for a teacher and a group of students to explore ideas through many lenses and create new understandings. This entails a great deal of work, but the rewards may be well worth the effort.

Suggestions for Further Research

Many available research studies of interdisciplinary curricula are in the form of case studies; many of these case studies compare only a few classrooms, and most do not compare multiple schools. Some of the studies do not make use of control groups, and some are written from an advocacy standpoint rather than the perspective of a dispassionate researcher. These are difficulties that are easy to understand, given the context of the research: many of the researchers are practicing teachers, who do not have the time, resources, or connections to replicate their research on a larger scale.

Researchers who have the resources to conduct larger studies may remedy this primary weakness in the research, the small-scale nature of the majority of the studies. Large-scale studies that control for variables such as socioeconomic status, rural, suburban or urban context of schools studied, and baseline attitude and achievement data for student subjects, would add reliability to the conclusions of existing research.

Conclusion

Proponents of interdisciplinary curriculum and advocates of traditional subject-based education draw on distinct philosophies of learning. Educators who see their role as facilitators of educational experiences, who view the world as a fundamentally connected place and view life as a journey of interconnected experiences, value the constructivist, experiential philosophy that underpins integrated curriculum theory. Educators who see themselves as specialists or experts, who see their role as purveyors of information, who view the world and life as divided or compartmentalized, emphasize the importance of specific knowledge and skills, and value the perspectives underlying traditional subject-based education.

This division among educators is nothing new: teachers have been debating the relative value of different approaches to education for thousands of years, and there does not appear to be a definitive answer on the horizon. The research examined in Chapter Three suggests that interdisciplinary curricula often benefit and rarely, if ever, harm students' attitudes and achievement in academia. There is also ample evidence that interdisciplinary curricula are challenging to create and implement, and that educators who do this work need support in the form of flexible scheduling and team and administrative support. The primary weakness in the research documenting integrated curricula is the relative dearth of large-scale studies, which could verify the reliability of existing findings.

Interdisciplinary study is no magic bullet for educational woes, but it has the potential to improve the experiences of students in public schools. School communities dedicated to implementing interdisciplinary curricula have wonderful incentives to help them through the tough work of making education interesting and relevant; with strong institutional structures and the support of administrators and colleagues, educators can help their students connect their learning and connect to their world.

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