

Teaching an Integrated  
Science Curriculum:  
Linking Teacher Knowledge  
and Teaching Assignments

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### Introduction

A number of factors affect successful implementation of an integrated science curriculum, including various outputs and inputs related to teacher quality such as professional development experiences, adequate planning periods, and adequate content preparation of teachers with regard to content knowledge associated with the curriculum taught (Huntley, 1998; Knudson, 1937; Leung, 2006; Palmer, 1991; Southern Region Education Board, 1998). Other researchers have examined the relationship between teacher quality and teacher retention (Ingersoll, 2000; National Center for Education Statistics, 1996), and national organizations have defined minimum content preparation standards to improve teaching and learning (Interstate New Teacher Assessment and Support Consortium [ITASC], 2008; National Council for Accreditation of Teacher Educators [NCATE], 2007; National Middle School Association [NMSA], 2008). This study examines factors related to teacher quality inputs (i.e., coursework, grade point average, and teacher test scores). Specifically, the focus is on teacher knowledge related to eighth grade science in Texas, which uses an interdisciplinary science curriculum consisting of topics in life science, chemistry, physics, and Earth science (Texas Education Agency, 2005). To provide a context for viewing the

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data, teacher demographics are presented for gender, ethnicity, years of teaching experience, and degree major. Based on these variables, teacher knowledge factors in the literature, including pedagogical content knowledge, are discussed.

### **Theoretical Foundation and Evolution for an Integrated Science Curriculum**

Integrated curriculum has received considerable support with regard to providing meaningful learning experiences that enhance knowledge and conceptual understanding (Aikin, 1942; Daniels, 1991; Friend, 1984; Jacobs, 1989; Leung, 2006; Lipson, Valencia, Wixson, & Peters, 1993; Vars, 1991; Yager & Lutz, 1994). The rationale for implementation of an integrated curriculum is to show how knowledge across disciplines is interrelated in a natural world, as compared to a program utilizing single-subject courses that narrow the learner's perspective and are less efficient in the learning process (Vars, 1991; Wolf & Brandt, 1998; Yager & Lutz, 1994).

What all integrated curricula have in common is an underlying theoretical foundation rooted in Gestalt psychology. The focus of Gestalt psychology is two-fold: examining the learner as an organic whole and engaging the individual in focused learning experiences that are purposeful and meaningful (Benjafield, 1996). Further, learning is not an additive affair in which concepts are laid down one by one; rather it is a developmental process, characterized by complex and synergistic advances in which interactions between the learner and the environment enable intellectual restructuring and transformation as they relate to the growth and development of the individual.

Because psychological theory is linked to educational practice, it is expected that the curriculum will provide opportunities for the learner to *integrate* knowledge, resulting in the enhancement of the total learning experience. However, it is important to recognize that *integration* takes place internally and that an integrated curriculum does not automatically cause integration within an individual. Rather, to the extent that the curriculum, as an external factor, facilitates assimilation of knowledge, the individual will respond with intellectual restructuring and transformation.

Considerable literature exists on educational reforms involving curriculum integration. Historically, the progressive movement of the 1930s influenced science education, organizing science courses around big ideas. *A Program for Science Teaching* (National Society for the Study of Education, 1932) and *Science for General Education* (American Education Fellowship, 1938) involves science curricula that included factual knowledge about

science as well as involved students in the process of science. This early curriculum reform sought to focus science learning in a natural world context as opposed to within strict content discipline lines. The focus was learning science across disciplines and exploring this knowledge through social contexts, scientific reasoning, and critical thinking.

In 1962, *Science, a Process Approach*, attempted to connect science disciplines by emphasizing process science (Hall, 1978; Livermore, 1964). Continued integration efforts were supported by the National Science Teachers Association (Aldridge, 1989; Crow & Aldridge, 1995), and during the 1990s, the National Research Council (1996) and Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) renewed attempts to develop an integrated curriculum. Curriculum integration remains a broadly-used term, and over the past two decades, a number of *modes* of curriculum integration have been defined in the literature. For purpose of this study, a mode of curriculum integration provides a general conceptual framework as compared to multiple strategies for curriculum integration as described in the literature.

### **Modes of Integration**

Badley (1986) described four modes of integrating the curriculum: fusion, incorporation, correlation, and harmonization. Fusion joins together at least two separate disciplines. For example, physical science joins together the disciplines of physics and chemistry. Incorporation adds or absorbs one curriculum element into another. For example, a unit on oceanography is added to the biology curriculum. Making connections between separately taught subjects, such as timing the study of biomes in world geography and biology so as to overlap, is an example of correlation. Thematic units are examples of this mode of integration. Finally, harmonization takes disparate curricular elements that are compatible and unites them. Teaching higher level thinking skills across the curriculum is an example of harmonization.

Case (1991) defined and explained the components of integration and its implications for teaching practice. Forms of integration described by Case include integration of content, integration of skills and processes, integration of school and self (intersection of school goals and personal goals), and holistic integration (all formal and informal practices, routines, methods, rules, and school-based influences on learning).

Huntley (1998) attempted to clarify the extent of discipline overlap for mathematics and science via the use of a theoretical framework, the mathematics/science continuum. Huntley defined the integrated curriculum as “one in which a teacher, or teachers, explicitly assimilate concepts from more than one discipline during instruction. It is typified

by approximately equal attention to two (or more) disciplines” (p. 321). Further, Huntley differentiated the integrated from the interdisciplinary curriculum by defining the interdisciplinary curriculum as:

one in which the focus of instruction is on one discipline, and one or more other disciplines are used to support or facilitate content in the first domain (for instance, by establishing relevance or context). In this case, connections between the disciplines are made only implicitly by the teacher(s). (p. 320)

Leung (2006) posited a continuum of integration based on national studies conducted by the Hong Kong Department of Curriculum & Instruction in China. Modes of curriculum integration include a module approach within subjects, cross-curricular approaches, and curriculum integration occurring on particular days or weeks. Results of the survey on teacher challenges to teaching an integrated curriculum indicated that, while 94.9% of teachers support an integrated curriculum, the heavy workload associated with the integrated curriculum and the need for training in this area are of concern for 87% and 93% of teachers, respectively (Leung, 2006).

### **Challenges of the Integrated Curriculum for Educational Policy and Teaching Practice**

Regardless of the mode of integration, severe teacher shortages, especially in the areas of mathematics and science, have left large states such as Texas and California in a continuous struggle to fill classrooms with high quality teachers before the school year begins. Teacher content knowledge is an important factor to consider with regard to effective implementation of an integrated curriculum, and several studies have explored teacher knowledge as measured by completed coursework and teaching assignment.

Bobbitt and McMillan (1994) used the 1987-1988 and 1990-1991 Schools and Staffing Survey data from the National Center for Education Statistics to investigate teacher knowledge. They found that over 97% of teachers reported holding a major, minor, or certification related to their teaching assignment. Monk (1994) examined the relationship between coursework completed and student achievement, demonstrating that students were more likely to have higher achievement gains when their teachers completed coursework equivalent to a major. Ingersoll (1999) reported that 20% of all science teachers held neither a major nor a minor related to their teaching assignment, and Wirt (2004) found that 20% of middle school science teachers did not hold a major, minor, or certification for their teaching assignment.

Data from the National Center for Education Statistics (2004) indicate that 17.2% of middle school teachers have neither a certification nor a major in science and that 33.6% of middle school teachers hold a certification without a major in science, although studies have demonstrated that undergraduate or graduate degrees in the content field are associated with student achievement (Ferguson & Ladd, 1996; Goldhaber & Brewer, 1997; 2000; Rowan, Chiang, & Miller, 1997; Wayne & Youngs, 2003), and national organizations such as INTASC, NCATE, and NMSA call for strong content preparation of middle school teachers. Further, mathematics and science teachers are more likely to leave teaching, as compared to teachers of other disciplines, due to job dissatisfaction or personal reasons, or to pursue other careers (Ingersoll, 2000), creating a revolving door that exacerbates the teacher shortage problem in science and other high-need fields.

Because each state functions as the gatekeeper for teacher certification, policy makers often seek to provide a “temporary fix” for the teacher shortage problem and fill every classroom with a teacher, even when content knowledge is suspect. For example, in Texas, an individual who holds a certification in a single-subject area of science (e.g., biology, chemistry), multiple-science subject (i.e., 4-8 math science, 8-12 science), or multiple-generalist subjects (i.e., K-8, Early Childhood-6, 4-8) can teach grades 6-8 middle school science. In Texas, grades 6-8 middle school science includes biology, chemistry, physics, and Earth science.

To demonstrate content mastery, the requirement of the state of Texas is to pass the state teacher content exam. No transcript analysis is required to determine whether the teacher has formal training in each of areas covered in the teaching assignment or whether the grades that the potential teacher received indicate sufficient mastery of the content. Thus, a Texas teacher may hold a grades K-8 (similar to California multiple-subjects certificate) or grades 4-8 elementary generalist certificate and be assigned to teach a single subject assignment in middle school such as grades 6-8 math or science.

The process for assignment of teachers in California differs substantially from that of Texas in that teacher assignments in California are organized around multiple subjects (e.g., grade 2 multiple-subjects teaching assignment) or single subjects (e.g., grade 5 science or chemistry teaching assignment). In those school assignments organized around a single subject, the teacher must demonstrate content knowledge by passing a state test for the single subject, whereas those school assignments that are organized around multiple subjects require the teacher to pass a multiple-subject state examination.

It is also possible to utilize a transcript analysis to demonstrate

teacher content knowledge for a particular assignment. Recently, the California Commission on Teacher Credentialing (2008) added a single-subject credential, General Science (foundation level), in an attempt to staff science classrooms. This credential is an effort to encourage more individuals to gain science certification for general, introductory, and integrated science courses taught through eighth grade in California schools by taking a test and completing a single course. Although the change will increase the pipeline of science teachers who have completed as few as two or three units of science, the impact of this change on student science achievement is unknown. This credential is a response to changes during 2002 that call for alignment of teacher programs with student content standards.

According to Knudson (1937), teaching an integrated curriculum requires (a) very able teachers, (b) wide and rich selection of materials, and (c) an administration friendly to innovation and experimentation. However, when teachers do not have the prerequisite background needed to implement the curriculum, there is a considerable problem with regard to the development of student knowledge (Palmer, 1991). Additionally, teaching an integrated curriculum may conflict with the teacher's sense of content expertise (Werner, 1991) because most secondary teachers receive training in colleges and universities that use single- or double-field models reflecting the structure and organization of colleges and universities. Academic preparation is an assumption of a successfully delivered integrated curriculum; however, assignment of teachers to deliver content outside their area of expertise will most likely not promote student achievement. Given the importance of the science content knowledge needed to teach an integrated science curriculum, this study seeks to examine the content preparation of eighth grade science Texas teachers implementing an integrated curriculum that includes the content areas of biology, chemistry, physics, and Earth science.

## Method

### Research Question

The following research question was used to guide the research: How well prepared are Texas teachers to deliver a eighth grade integrated science curriculum (i.e., content area coursework, content grade point average, and the diagnostic grades 8-12 Science Texas Examinations of Educator Standards)?

### Participants

Participants were selected from a pool of applicants for a Teacher

Quality Grant Project for eighth grade science teachers over a two-year academic period (2005-2006 and 2006-2007). Criteria for selection included preference for teachers who were working with underrepresented and underserved student groups in high-need schools. The group of 93 eighth grade teachers in Texas was predominantly female (77.9%) and Caucasian (61.1%), with other ethnic groups represented (African American, 23.2%; Hispanic, 12.6%; and Other, 3.0%). Most teachers were certified (84.9%), although certification areas varied considerably, with the largest representation from majors in interdisciplinary/elementary studies (32.3%), followed by biology/chemistry (34.4%) and physical education (8.5%). Degree majors varied widely and included majors in areas such as agriculture, business, communications, computer science, English, geology, psychology, and home economics.

The majority of the teachers (70.5%) earned a certification from a university-based teacher preparation program, although a notable percentage (27.4%) was trained through alternative routes to teaching. There are 151 separate alternative certification teaching routes in Texas, and they include state and commercial providers (State Board for Educator Certification, 2009a). Each alternative route has unique admission and program completion requirements. In Texas, each alternative certification program provider must be approved by the State Board for Educator Certification.

Although grade point average (GPA) admission requirements were recently increased, during the period for this study, admission requirements for these programs ranged from a GPA of 2.0-3.0. All teachers, regardless of preparation route, must pass state teacher examinations. These teachers had a mean of 8.23 years of teaching experience and most taught at public schools rated by the Texas Education Agency as: Exemplary (1%), Academically Acceptable (28.4%), Recognized (47.4%); Academically Unacceptable (7.3%), or Not Rated (2.1%). School ratings in Texas utilize state student achievement scores (i.e., Texas Assessment of Knowledge and Skills [TAKS] or the State Developed Alternative Assessment II), high school completion rates (students complete or continue education four years after entering high school), and dropout rates. These criteria are used to place schools in one of five rating categories. A detailed description of the rating system can be found on the Texas Education Agency website (Texas Education Agency, 2007).

### **Research Design**

Teacher knowledge was examined using participants' transcripts from all of the colleges and universities attended. The course number, title of the course, number of credit hours, and grades were recorded by

the researchers for each course that matched the Texas Examinations for Educator Standards (TExES) test domains for grades 8-12 science. Content areas for Earth science include geology, Earth science, environmental science, and astronomy.

The content area GPA for each content area tested (biology, chemistry, physics, and Earth science) was calculated. GPA was determined by dividing the summation of all grade points for the four science discipline courses taken by the summation of the number of credits earned.

The content knowledge of the teachers in terms of teacher proficiency was measured using the grades 8-12 TExES diagnostic examination. This examination is used to assess the science content knowledge of middle school and high school teachers in grades 8-12. A score of 70 indicates passing.

Because the participants were all eighth grade teachers, this examination was an appropriate measure of teacher science knowledge. Further, the topics covered on the 8-12 Science TExES for teachers (i.e., biology, chemistry, physics, and Earth science) and the topics on the TAKS Science test for students (i.e., biology, chemistry, and physics) are similar, but the depth and breadth of the TExES test given to the teacher is much greater. The 8-12 diagnostic TExES was given on the first day of the grant. For readers who are unfamiliar with teacher testing in Texas, the process used to establish the validity and reliability of the tests and how the passing standards are set are described in Section I of each preparation manual (State Board for Educator Certification, 2009b).

## Results and Conclusions

Descriptive statistics for semester credit hours taken in science content areas are shown in Table 1. Mean content area preparation (semester credit hours) across all subjects taught in the Texas eighth grade science curriculum range from 3.913 in physics to 19.919 in biology. Physics coursework completed represents the least variability of the four subject areas examined ( $SD=4.845$ ).

Figures 1a and 1b present the semester credit hour coursework for 93 participants partitioned according to science subject. As shown in Figures 1a and 1b, large percentages of teachers have little or no training in the content areas associated with eighth grade science. Eleven teachers (11.8%) had no semester credit hours for biology, 24 teachers (25.8%) had no training in chemistry, 46 teachers (50.0%) had no training in physics, and 43 teachers (46.2%) had no training in Earth science. If one considers the most minimal preparation of eight semester credit hours or less, which is indicative of introductory coursework and includes a laboratory, the situation can be understood as grim.

Table 1  
*Descriptive Statistics for Semester Credit Hours Taken  
 for Science Subject Areas (N = 93)*

Subject	Mean	Median	SD	Min SCH	Max SCH
Biology					
Science major	23.900	22	20.45	0	74
nonScience	16.188	14	14.14	0	56
Biology - All	19.919	16	17.811	0	74
Chemistry					
Science major	17.089	16	16.13	0	64
nonScience	6.583	4	7.11	0	24
Chemistry - All	11.667	8	13.344	0	64
Physics					
Science major	4.864	4	5.14	0	19
nonScience	3.042	0	4.44	0	21
Physics - All	3.913	1.5	4.849	0	21
Earth Science					
Science major	3.400	0	5.742	0	24
nonScience	10.583	5.5	16.003	0	60
Earth Science - All	7.108	3	12.635	0	60

Of the teachers, 33 (35.1%) completed eight semester credit hours or less of biology and 55 teachers (58.5%) completed eight semester credit hours or less of chemistry. The most notable lack of training was within the content area of physics, for which only 8 teachers (8.6%) had *more* than eight semester credit hours of physics. Finally, 71 teachers (74.7%) completed less than eight semester credit hours of coursework in Earth science. The importance of training in Earth science should not go unnoticed because the topic comprises 38% of the eighth grade TAKS Science test. The TAKS Science test is given to all eighth grade students as a measure of progress toward the eleventh grade TAKS Science test, a high-stakes exit-level test that must be passed to fulfill Texas high school graduation requirements.

As seen in Table 2, differences between science major and non-science major content coursework were also found. The median number of semester credit hours for biology, chemistry, physics, and Earth science for science majors was 22, 16, 4, and 0 respectively, while the median semester credit hours for non-science majors was 14, 4, 0, and 5, respectively. Statistically significant differences were noted for science majors with regard to biology ( $t=2.102, p=.039$ ) and chemistry ( $t=4.019, p=.000$ ), while non-science majors had significantly more Earth science coursework as compared to science majors ( $t = -2.916, p = .005$ ).

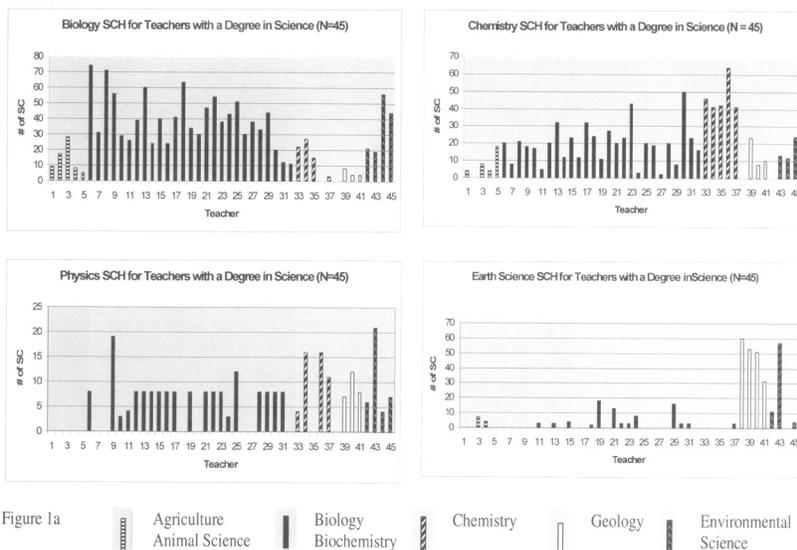


Figure 1a

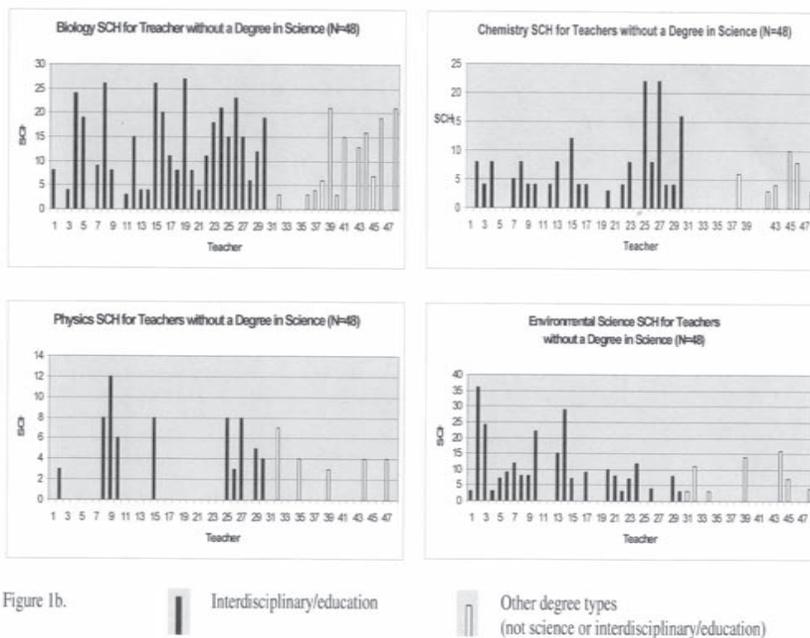


Figure 1b.

Descriptive statistics for the science subject area GPAs are presented in Table 3 and Figures 2a and 2b. Mean GPAs ranged from 1.491 in physics to 2.569 in biology (A = 4.0). An analysis of GPA demonstrates that, even when the eighth grade teachers complete coursework for various disciplines of science, the results indicate poor performance. Except for the area of biology, for which the mean GPA was 2.569, the GPA for all other science disciplines was *below* a grade of C and as low as 1.491 for physics. This is a disturbing finding with regard to eighth grade students' educational experiences, which should prepare them to pass the TAKS. Of the TAKS, 24% tests the teacher candidate's knowledge about Earth science. Further, chemistry and physics represent 12% of the eighth grade TAKS examination.

Table 2  
*T test Results for Science Content Semester Credit Hours Taken (N = 93)*

	Science Degree (N = 45)		Nonscience Degree (N = 48)		df	T	Sig
	M	SD	M	SD			
Biology	23.90	20.45	16.18	14.14	91	2.102	.039
Chemistry	17.09	16.13	6.58	7.11	91	4.019	.000
Earth Sci	3.40	5.74	10.58	16.00	91	-2.916	.005

Table 3  
*Descriptive Statistics for Grade Point Average in Science Subject Areas (N=93)*

Subject	Mean	Median	SD
Biology			
Science major	2.432	2.700	1.143
nonscience	2.699	2.952	1.115
Biology - All	2.569	2.760	1.130
Chemistry			
Science major	2.117	2.350	1.234
nonScience	1.841	2.063	1.421
Chemistry- All	1.977	2.250	1.333
Physics			
Science major	1.608	2.000	1.572
nonScience	1.379	0	1.654
Physics - All	1.491	0	1.609
Earth Science			
Science major	1.469	0	1.666
nonScience	1.641	2.200	1.516
Earth Science - All	1.855	1.855	1.562

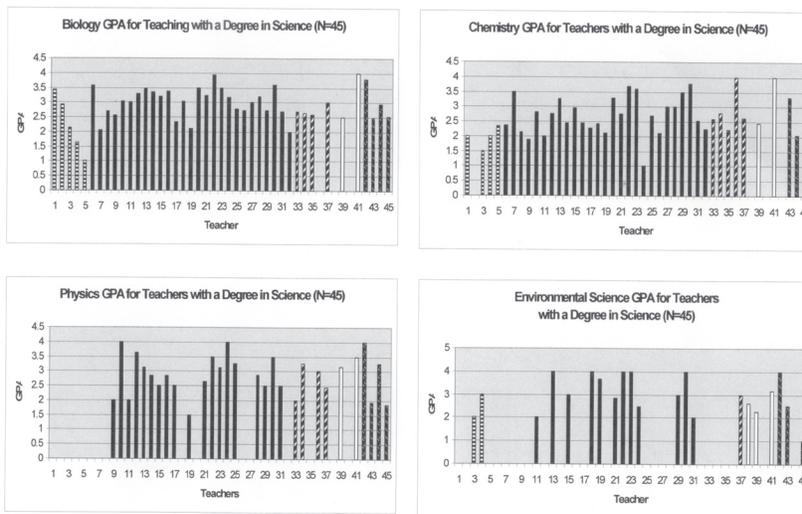


Figure 2a

Agriculture	Animal Science	Biology	Biochemistry	Chemistry	Geology	Environmental Science
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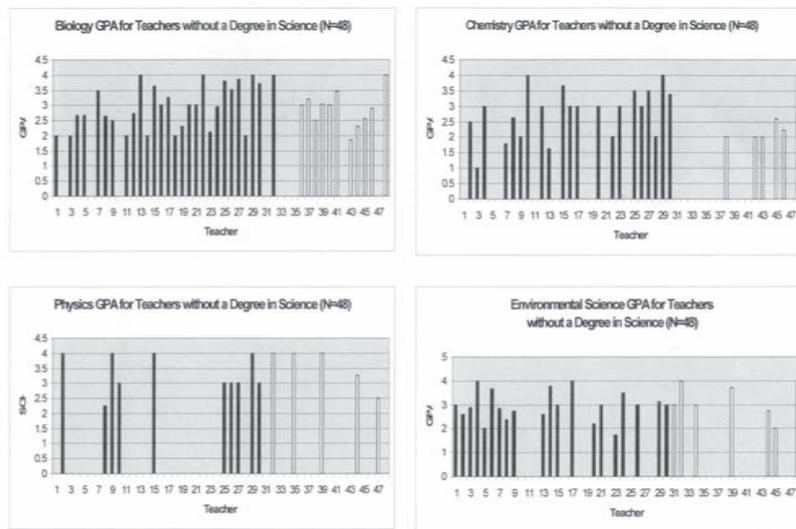


Figure 2b.

Interdisciplinary/Education	Other degree types (not Science or Interdisciplinary/Education)
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The mean GPA for biology, chemistry, physics, and Earth science for science majors was 2.70, 2.35, 2.00, and 0.00, respectively, while the mean GPA for nonscience majors was 2.70, 1.84, 1.38, and 1.64. The *t* tests showed no statistically significant differences between the science and non-science majors for content GPA or grades 8-12 TExES Science scores. In general, there was a clear lack of demonstrated formal content knowledge for eighth grade teachers.

More recently, *No Child Left Behind* legislation promulgated the use of teacher testing in all 50 U.S. states. Because Texas is a large state, instead of using “off-the-shelf” tests such as Praxis I and Praxis II, the state of Texas has contracted with National Evaluation Systems in the past and, in 2007, contracted with the Educational Testing Systems to continue development of teacher content tests aligned with the Texas Essential Knowledge and Skills, the K-12 curriculum in Texas.

Testing is not a new phenomenon in Texas, where teacher testing began in March 1986 (Kain & Singleton, 1996). However, results for the diagnostic grades 8-12 TExES Science test reveal participant scores ranging from 13-84, where 100 is the maximum possible score, and a passing score for the examination is 70 or greater. In this study, only 5 of 93 participants passed the diagnostic examination. This finding is particularly disturbing in that Texas teacher assignments provide a content loophole for eighth grade science teacher assignment. Specifically, teacher knowledge is assumed when one passes a multiple-subject exam designed for elementary teachers working in self-contained classrooms. Further, in Texas, the teacher is not required to pass all content areas for a multiple-subject exam. Rather, a composite score is used to determine mastery.

Only 23% of the grades 4-8 generalist test measures science knowledge. Even the grades 4-8 mathematics/science test measures science knowledge according to the following distribution: 11% physical science; 11% biology; 11% Earth science; 11% process skills; and 6% science learning, instruction, and assessment. Returning to the practice of using a composite score to determine subject mastery, it is possible for the candidate to fail entire subject domains and still pass the exam. Demonstration of content mastery is also undermined when the candidate is allowed unlimited test-taking attempts, which also undermines the validity of the TExES.

In this study, 45 of 93 eighth grade teachers (48.4%) held a degree in any type of science field. The score distribution for all participants is shown in Figures 3a and 3b and is broken down according to the name of the degree awarded, as listed on the teacher’s transcript. Table 4 displays the results for the grades 8-12 TExES Science test, semester

credit hours completed, and GPAs for the five teachers who passed the examination.

The diagnostic grades 8-12 TExES Science test confirms the findings of the transcript analysis. That is, teachers are unable to demonstrate mastery of the content knowledge needed to teach eighth grade science in Texas.

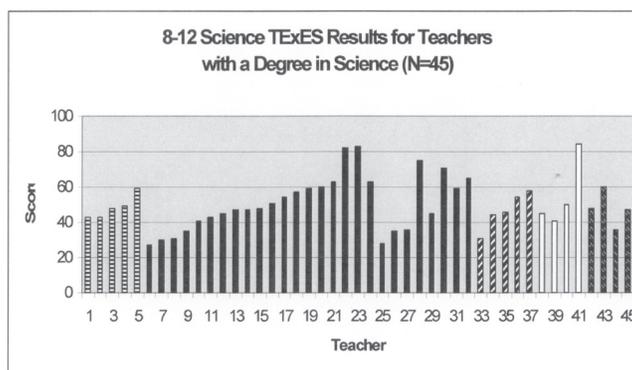


Figure 3a

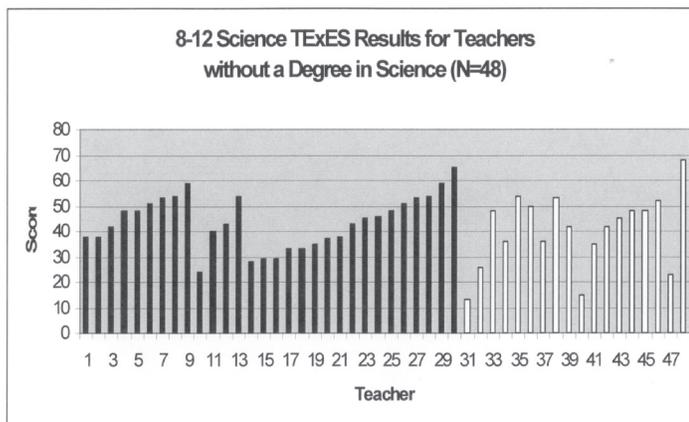


Figure 3b

Table 4  
*8-12 Science TExES Diagnostic Test Scores, Semester Credit Hours,  
 and GPA for Participants Passing the 8-12 Science TExES (N = 45)*

TExES Score	Biology	GPA	Chem.	GPA	Physics	GPA	Earth Science	GPA
71	20	3.60	50	3.76	8	3.50	3	4.00
75	33	3.21	20	3.00	8	2.88	0	0
82	54	3.93	23	3.69	8	3.50	3	4.00
83	38	3.50	43	3.60	8	3.50	3	4.00
84	4	4.00	10	4.00	8	3.50	31	3.17

### Implications

A number of studies have shown the integrated curriculum as a powerful tool to enhance student knowledge. However, successful implementation of an integrated curriculum relies on a number of factors, including adequate preparation of teachers with regard to the content knowledge related to the curriculum taught (Ferguson & Ladd; 1996; Goldhaber & Brewer, 1997; Huntley, 1998; Knudson, 1937; Leung, 2006; Palmer, 1991). The focus of this research was input variables associated with teacher quality (i.e., college coursework, GPA, and teacher content test scores), although process variables (e.g., delivery of the curriculum) and output variables (e.g., student achievement) are also important topics that warrant further research. However, one would not expect that low quality input variables would produce a teacher that could either deliver a science curriculum or increase student achievement (Monk, 1994; Shulman, 1986).

The structure of Texas colleges and universities, increasing numbers of alternatively-trained candidates holding a degree in a single-field subject, and poor alignment between teaching assignment and certification field are also important considerations with regard to successful implementation of an integrated science curriculum. With few exceptions, Texas college and university degree programs remain structured as a single-science discipline. Thus, in general, the teachers themselves have not experienced the benefit of learning science via an integrated curriculum. Single-subject degrees, instead of the broad field training needed to implement an integrated science curriculum, also facilitate the view of the teacher as expert in a particular field. Increasing teacher content knowledge via completion of science coursework in multiple science fields might better prepare teachers to deliver an integrated curriculum.

It is also possible that targeted professional development designed to increase teacher science knowledge is yet another avenue that could increase teacher content knowledge about science. To renew a Texas

teaching license, 150 hours of professional development training are required every five years. Professional development hours, however, are determined by each school district, and the majority of these professional development hours are generic in nature, covering topics such as safety and changes in special education laws. This practice makes it possible to renew the teaching license with no professional development training related to improvement of teacher content knowledge. One way that a state may increase the science teacher pipeline is to “reduce barriers” to teaching by reducing content preparation coursework, lowering GPA requirements, and lowering passing standards for teacher tests. However, all of these attempts to “reduce barriers” will most likely lower teacher quality.

Another concern with regard to implementation of the integrated curriculum is the practice of policy makers who legislate teacher assignments to allow a poor match between teaching assignments and teacher certification fields. The current Texas assignment structure allows an individual who holds any secondary-science certificate to teach eighth grade science. In this study, 26% of teachers had no coursework in chemistry, and 45.7% of the teachers had no coursework in physics. Similarly, 48.9% of the teachers had no coursework in Earth science, which comprises 24% of the eighth grade science curriculum. The mean GPA for chemistry, physics, and Earth science was a “D,” and 95.7% of teachers failed the diagnostic grades 8-12 TExES Science test. Clearly, these individuals require significant professional development and/or university coursework to teach the Texas eighth grade science curriculum. Nevertheless, in an effort to fill classrooms with teachers, Texas assignment structure permits the lack of content preparation to continue. This practice means that teachers fall short of meeting any national organization standards (e.g., INTASC, NCATE, NMSA) for preparation of new teachers. Thus, why should lower standards be acceptable for teachers who already hold a credential?

In Texas, addressing the teacher shortage problems in high-need fields such as science and mathematics has resulted in over 151 different alternative routes to teaching. Typically, these individuals hold single-subject degrees and are not trained to teach broad-field science (i.e., biology, chemistry, physics, and Earth science). As previously discussed, this practice is problematic in that the grades 4-8 multiple-subject exams are utilized to assign teachers to single-subject classrooms (e.g., 6-8 grade science), the candidates need not display competency in all test domains because a composite score is used to determine a passing score, and the candidate is offered unlimited test-taking attempts, which undermines the validity of the test.

In California, a new certificate, General Science (foundation level) was recently added in an effort to address teacher shortage problems in science (California Commission on Teacher Credentialing, 2008). The General Science (foundation level) certificate requires the bearer of a multiple-subject credential to gain a General Science (foundation level) credential by passing two California Subject Examinations for Teachers subtests (#118 and #119) and completing one course in single-subject pedagogy. This route to a credential raises more questions about the role of testing as a gatekeeper purported to measure teacher content knowledge, particularly knowledge sufficient for teaching an integrated science curriculum. Unlike Texas, California does not link teacher characteristics to student scores, making it difficult to determine how well the state standards, teacher tests, curriculum, and student achievement are aligned.

The use of an integrated curriculum is a powerful way to communicate scientific knowledge. Unfortunately, the failure to assure that teachers have acquired broad scientific knowledge in biology, chemistry, physics, and Earth science prior to an attempt to implement an integrated curriculum will perpetuate science misconceptions and result in the creation of gaps in that scientific knowledge that is needed to achieve scientific literacy and to function in a global society. Additionally, until policy makers discontinue allowing a poor match between teaching assignments and teacher certification fields and move away from sole reliance on teacher tests as a measure of teacher knowledge, it is unlikely that student achievement will increase above the level of a teacher who lacks the content knowledge needed to deliver an interdisciplinary science curriculum.

### Limitations of the Study

There are various limitations to the study, which include the age of the transcript data. Some teachers were in the workforce for many years and may have learned material as they taught it or engaged in professional development in an effort to increase content knowledge about interdisciplinary science subjects. Teachers may not have taken the test seriously and, as such, not performed to the greatest extent their knowledge might allow or the teachers may have believed that the test is unimportant and not aligned with what they teach (although the test *is* aligned with what should be taught). It is also possible that teachers who possess any or all of the variables used in this study (i.e., coursework, grades, or a passing score on the TExES) may poorly deliver the curriculum. Thus, although not the focus of this study, research on

curriculum delivery or direct impact on student achievement is warranted.

The grades 8-12 diagnostic TExES was given on the first day of the grant. The content of this test is aligned with what teachers should know to teach the Texas state curriculum. No direct incentive other than those associated with participation in the grant (e.g., stipend, laptop, science resources, training) was provided. The candidates were provided six hours to take the examination.

The implementation of an integrated science curriculum provides a powerful learning experience designed to enhance knowledge and conceptual understanding. The teacher's science content knowledge is generally acquired through formal training and/or content specific professional development. Assessment of this knowledge is performed using teacher tests that function as gatekeepers to teacher licensure. This study suggests that (a) Texas teachers of eighth grade science have little formal training in chemistry, physics, or Earth Science, although 38% of the eighth grade curriculum includes topics for Earth Science; (b) science content knowledge as measured using GPA is low; (c) more than half of eighth grade science teachers do not have a degree in science; and (d) interdisciplinary degrees and single-subject content degrees are not statistically significantly related to the grades 8-12 Science TExES exam. As policy makers create new teaching certificates in response to the science teacher shortage, they may also want to examine the impact of changing teacher knowledge standards on student achievement.

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