INTERDISCIPLINARY PERSPECTIVES LINKING SCIENCE AND LITERACY IN GRADES K-5: IMPLICATIONS FOR POLICY AND PRACTICE

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ABSTRACT

This chapter presents a combination of theoretical perspectives and empirical findings as a foundation for establishing the relevance of elementary science instruction in which reading comprehension and writing are integrated as a major curricular strategy having the potential of providing a curricular solution to systemic problems presently associated with school reform. The evidence-based argument advanced in the chapter is based on a combination of (a) specific interdisciplinary approaches to meaningful school learning drawn from the complementary areas of cognitive science, cognitive psychology, applied learning, instructional design/development, and educational research and (b) research in the literature that has demonstrated the acceleration of achievement in both science and reading comprehension resulting from different models of in-depth science instruction.

[116 words, 9 lines]

INTERDISCIPLINARY PERSPECTIVES LINKING SCIENCE AND LITERACY IN GRADES K-5: IMPLICATIONS FOR POLICY AND PRACTICE

Recent appraisals of interdisciplinary research related to meaningful learning summarized in the report by the National Academy Press, *How People Learn,* (John Bransford et al. 2000) provide a foundation for why and how science as a form of in-depth, content-area instruction can serve as a core element in literacy development (e.g., reading comprehension, writing) in elementary schools. In their overview, Bransford et al. summarized consensus research investigating expert behavior and expertise as a unifying concept for meaningful learning. Such studies have established that, in comparison to novices, experts demonstrate a highly-developed organization of knowledge that emphasizes an in-depth understanding of the core concepts and concept relationships in their discipline (i.e., domain-specific knowledge) that, in turn, they are able to access efficiently and apply with automaticity. Although the instructional implications of such perspectives (discussed below) are highly supportive of the importance of in-depth, content-area learning, these same implications are in direct conflict with the present lack of emphasis on meaningful curricular content in popular approaches to reading and language arts that presently dominate elementary schools (e.g., E. D. Hirsch 1996, 2006; Kate Walsh 2003) and have resulted in a de-emphasis of science instruction (Sam Dillon 2006; Gail Jones et al. 1999). In the following sections, a combination of theoretical perspectives and empirical findings are presented as a foundation for establishing the relevance of elementary science instruction implemented as a form of in-depth, content-area learning to the development of student proficiency in reading comprehension and writing. In doing so, this evidence-based argument provides a rationale for in-depth science instruction within which reading comprehension and writing are integrated as a major curricular strategy that has the potential for providing a curricular solution to systemic problems presently associated with school reform (see Patrick Gonzales et al. 2008; Jihyun Lee et al. 2007; Anthony Lutkus et al. 2006).

INTERDISCIPLINARY RESEARCH UNDERLYING MEANINGFUL LEARNING: KNOWLEDGE-BASED INSTRUCTION MODELS

Interdisciplinary foundations of meaningful school learning draw from the complementary areas of cognitive science, cognitive psychology, applied learning, instructional design/development, and educational research. Although there is a wide variety of such work, several key research-based perspectives represent primary tenets. The first has to do with the architecture of knowledge-based instruction systems (George Luger 2008) originally developed to implement computer-based intelligent tutoring systems. The second (Walter Kintsch 1994, 1998, 2004) has to do with the importance of having a well-structured curricular environment for learning (see also William Schmidt et al. 1997;1999). The third (Bransford et al. 2000) has to do with the role of knowledge as applied in the problem-solving behavior of experts (i.e., expertise) vs. that of novices. And, the fourth has to do with cognitive research dealing with the linkage of declarative knowledge to procedural knowledge and automaticity (John Anderson 1982, 1987, 1992, 1993, 1996).

Cognitive Science Foundations of Knowledge-Based Instruction Models

Implemented originally in computer-based intelligent tutoring systems (ITS), the distinguishing characteristic of knowledge-based instruction is that all aspects of instruction (e.g., teaching strategies, student activities, assessment) are related explicitly to an overall design that represents the logical structure of the concepts in the subject-matter discipline to be taught, a curricular structure that, while grade-appropriate, should parallel the knowledge organization of disciplinary experts. In considering this design characteristic as a key focus for meaningful learning, knowledge-based instruction is best illustrated by the original ITS architecture developed in the early 1980's (e.g., Greg Kearsley 1987; Luger 2008). As Figure 1 shows, in ITS systems the explicit representation of the knowledge to be

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learned serves as an organizational framework for all elements of instruction, including the determination of learning sequences, the selection of teaching methods, the specific activities required of learners, and the evaluative assessment of student learning success. In considering the implications of knowledge-based instruction for education, it is important to recognize that one of the strongest areas of cognitive science methodology focuses on explicitly representing and accessing knowledge (e.g., Luger 2008; Janet Kolodner 1993, 1997; John Sowa 2000).

The research foundations of knowledge-based instruction models are consistent with well-established findings from cognitive science. In particular, Bransford et al. (2000), stressed the principle that explicitly focusing on the core concepts and relationships that reflect the logical structure of the discipline and enhancing the development of prior knowledge are of paramount importance for meaningful learning to occur (see also Schmidt et al. 2001). Closely related to this view is work by Anderson and others (e.g. Anderson 1992, 1993, 1996; Anderson and Jon Fincham 1994; Anderson and Christian Lebiere 1998) who distinguished the "strong" problem solving process of experts as highly knowledge-based and automatic from the "weak" strategies that novices with minimal knowledge are forced to adopt in a heuristically-oriented, trial-and-error fashion. Also directly related are key elements in earlier versions of Anderson's (1996) "ACT" cognitive theory that (a) consider cognitive skills as forms of proficiency that are knowledge-based, (b) distinguish between declarative and procedural knowledge (i.e., knowing about vs. applying knowledge), and (c) identify the conditions in learning environments that determine the transformation of declarative to procedural knowledge.

In considering the role of prior knowledge in learning, the consensus research findings presented by Bransford et al. (2000) emphasized that both the conceptual understanding and use of knowledge by experts in application tasks (e.g., analyzing and solving problems) is primarily a matter of accessing and applying prior knowledge (see Kolodner 1993, 1997; Ann Rivet and Joseph Krajcik 2008) under conditions of automaticity. As characteristics of learning processes, the preceding emphasizes that extensive amounts of varied experiences (i.e., practice) focusing on knowledge in the form of the concept relationships to be learned are critical to the development of the different aspects of automaticity associated with expert mastery in any discipline. In related research, Murray Sidman (1994) and others (e.g., Erik Artzen and Per Holth 1997; Michael Dougher and Michael Markham 1994) have explored the conditions under which extensive practice to automaticity focusing on one subset of relationships can result in additional subsets of relationships being learned without explicit instruction. In these studies, the additional relationships were not taught, but, rather, were implied by the original set of relationships that were taught (i.e., formed equivalence relationships). In related work, both Mark Niedelman (1992) and Anderson and others (e.g., Anderson 1996) have offered interpretations of research issues relating to transfer of learning that are consistent with the knowledge-based approach to learning and understanding. Considered together, these findings represent an emerging knowledge-based emphasis on the linkage between the logical structure of what is to be taught with the instructional means for accomplishing meaningful learning.

A Knowledge-Based Framework for Approaching Comprehension through Content-Area Instruction

The well-defined structure of the science knowledge (e.g., NSES Standards) appropriate for in-depth science instruction in K-5 schools fits well with knowledge-based, ITS-type instructional models. However, in order for such in-depth science instruction to be adopted as a primary means for developing student reading comprehension, schools must have an evidence-based rationale as a foundation to justify increased time for science instruction. Because of the strong dependence of the role of prior knowledge in meaningful learning (see Kintsch 1994, 1998, 2004), a knowledge-based approach to reading comprehension would be to consider reading comprehension as a subset of comprehension in general (see Michael Vitale and Nancy Romance 2007b). With this view in mind, all of the instructional strategies for engendering the development of student in-depth science understanding (e.g., hands-on activities, inquiry-oriented questioning, journaling) are, by inference, also applicable to building student proficiency in reading comprehension.

One approach addressing the linkage of comprehension development to a knowledge-based approach to meaningful learning is the construction-integration model developed by Kintsch and his colleagues (e.g., Kintsch 1994, 1998, 2004). Kintsch's model explains the process of reading comprehension (and, by inference, comprehension) by distinguishing between the propositional structure (i.e., semantic meaning) of the conceptual content of a text that is being read and the prior knowledge the reader brings to the process of reading. In this context, meaningful comprehension results when the prior knowledge of the learner can be joined with the propositional structure of the text. If the propositional structure of the text is highly cohesive (i.e., knowledge is explicitly well-organized in propositional form), then there is less demand upon reader prior knowledge. But if the text is not cohesive (i.e., contains significant semantic gaps), then the reader's prior knowledge is critical for understanding. In either case, comprehension consists of the integration of the propositional structure of the text with reader prior knowledge.

Within this framework, much of the research conducted by Kintsch and his colleagues (e.g., Danielle McNamara et al. 2007) has focused on the interplay of meaningful text structure and the prior knowledge of the reader considered as a learner. However, as noted above, the elements of the Kintsch model are readily generalizable to any form of meaningful learning in school settings that involve the interaction of student prior knowledge with a (cohesive) curricular structure that, together, provide the context for meaningful learning. In this sense, Kintsch's model offers an evidence-based framework (e.g., McNamara and Kintsch 1996; Charles Weaver and Kintsch 1995) that is supportive of the appropriateness of in-depth science instruction through knowledge-based models and of the linkage of such knowledge-based models focusing on science to the development of reading comprehension.

Combining the architecture of knowledge-based instruction with the construction-integration model of Kintsch (1994, 1998, 2004) allows a re-interpretation of research in reading comprehension in a manner that is directly relevant to the use of K-5 science curricula that are “coherent” (see Schmidt et al. 2001) as a vehicle for building reading comprehension. Within the field of reading both individual researchers (e.g., Cathy Block and Michael Pressley 2002; Alan Farstrup and Jay Samuels 2002) and research groups (RAND Report, Catherine Snow 2002; National Reading Panel 2000) have investigated and evaluated different aspects of reading comprehension instruction. However, in evaluating such research, the RAND report concluded that present knowledge in the field is not yet adequate to systemically reform reading comprehension instruction, particularly the type of content-area reading comprehension ultimately required for success in textbook-oriented high school courses in science and other areas. In contrast, in recent interdisciplinary-oriented reading comprehension research, McNamara et al. (2007) concluded that skilled comprehenders are more able to actively and efficiently use knowledge (and strategies) to help them comprehend text and, further, that individual differences in reading comprehension depend on the dynamics associated with such knowledge activation. Clearly, the activation of prior knowledge in combination with coherent curricular structure are key components of any instructional environment that focuses on the development of in-depth content-area understanding such as science or reading comprehension.

While education has addressed the role of knowledge in meaningful learning and comprehension (e.g., see Doug Carnine 1991; Robert Glaser 1984; Hirsch 1996, 2001; Kintsch 1998), such attention was minimal until the publication of the Bransford et al. (2000) book (see Sean Cavanagh [2004] interview with David Klahr). However, consistent with McNamara et al.’s (2007) conclusions, Bransford et al. (2000) emphasized how conceptual frameworks as a form of prior knowledge facilitated new meaningful learning (i.e., comprehension in learning tasks). When these perspectives are considered together, it is the cognitive science perspective that provides the means to understand the dynamics of the important differences between what the reading comprehension literature has identified as proficient vs. struggling readers, particularly in instructional settings requiring content-area reading (see Snow 2002) and the field of cognitive science.

One additional implication from Bransford et al. (2000) supported by others (e.g., Carnine 1991; Glaser 1984; Kintsch 1998; Vitale and Romance 2000) is that from a knowledge-based perspective, curriculum mastery in schools should be approached as a form of expertise and that student conceptual mastery of academic content should be consistent with how experts perceive the discipline (see also Schmidt et al. 2001). In this regard, emphasizing the in-depth understanding of core concepts and concept relationships in grade-appropriate form is a critical element of general comprehension and, by inference, of reading comprehension as well. In fact, a knowledge-based perspective of reading comprehension that is consistent with the broad idea of meaningful comprehension presented by Bransford et al. (2000) would suggest that the nature of comprehension in both general learning and reading-to-learn settings is equivalent (see Vitale and Romance 2007b), with the exception that the specific learning experiences associated with reading comprehension are text-based.

SUPPORT FOR USING CONTENT-AREA INSTRUCTION IN SCIENCE AS A MEANS OF ENHANCING LITERACY DEVELOPMENT AT THE ELEMENTARY LEVELS

Following from the preceding framework, the question of empirical support for and the relevance of linking in-depth science instruction to literacy development can be addressed. Because the disciplinary structure of science knowledge is highly cohesive, cumulative in-depth instruction in science provides a learning environment well-suited for the development of understanding as expertise. As a focus for meaningful learning in school settings, science conceptual knowledge is grounded on the everyday events students experience on a continuing basis. In developing science knowledge, elementary students are able to (a) link together different events they observe, (b) make predictions about the occurrence of events (or manipulate conditions to produce outcomes), and (c) make meaningful interpretations of events that occur, all of which are key elements of meaningful comprehension (Vitale and Romance 2006a). As discussed in following sections, meaningful learning in science naturally incorporates critical elements associated with the development of curricular-based science expertise by students (e.g., acquisition and organization of conceptual knowledge, experiencing a potentially wide range of application experiences that provide varied practice in learning). In turn, with the active development of such in-depth conceptual understanding in science serving as a foundation, the use of prior knowledge in the comprehension of new learning tasks and in the communication of what knowledge has been learned provides a basis for key aspects of literacy development.

Research Trends Recognizing the Importance of Content-Area Instruction in Science in Primary (K-2) Grades

Because literacy development is a major focus in grades K-2, the lack of informational science materials to which young children are exposed in school settings is an important curricular policy issue. In this regard, David Pearson and Nell Duke (2002) noted that the terms "comprehension instruction" and "primary grades" seldom appear together and, along with others (e.g., Duke et al. 2003; Pressley et al. 1996), reported that primary students experience minimal content-area instruction, despite an extensive research base that provides guidance on how and why such instruction should be pursued. Specifically, Pearson and Duke (2002) listed a series of research-based approaches involving teacher story reading (i.e., read alouds) for building student content-area comprehension as early as kindergarten (e.g., asking meaningful questions about story elements, engaging students in retelling summarizations, using elaboration strategies such as theme identification, intensive text-study through elaborative discussion). All of these approaches are highly knowledge-focused, inquiry-oriented, and result in the development of domain-specific knowledge as long as such knowledge is available to be learned. As a result, such approaches fit well with an in-depth focus upon science and other content in instruction.

In addressing resistance to the use of informational text at the primary grades, Pearson and Duke (2002) also refuted major unsupported beliefs that serve as barriers (e.g., young children cannot handle them and are uninterested, comprehension is best at upper elementary grades). In a complementary analysis, Walsh (2003) noted that current basal reading series at the primary level are unable to engender meaningful knowledge development because they are designed specifically not to contain such knowledge. Walsh also noted that the problems subsequently evidenced by students in content-area text comprehension are due to lack of prior knowledge rather than deficiencies in reading skills or strategies.

In recent years, emerging K-2 curricular trends have emphasized an increased use of both informational texts in science and reading instruction and a more in-depth approach to science instruction in primary grades. In general, K-2 instructional interventions which emphasize the development of meaningful knowledge in science and other content areas are consistent with emerging literacy trends (Rosemary Palmer and Roger Stewart 2003) that emphasize the use of informational text for developing comprehension proficiency at the primary levels (see also William Holliday 2004; Michael Klentschy and Liz Molina-De La Torre 2004; Donna Ogle and Camille Blachowicz 2002; Stephen Gould et al. 2003, for related views).

Other researchers have extended the notion of linking science with literacy in early childhood (preschool) programs and have identified the benefits thereof. For example, Lucia French (2004) has reported the feasibility of a curricular approach in which science experiences provide a rich learning context for an early childhood curriculum that results in early literacy development as well as science learning. Rochel Gelman and Kimberly Brenneman (2004) have shown from the standpoint of feasibility how a preschool science program which incorporates guided hands-on activities can be used as a framework for instruction that engenders the development of domain-specific knowledge in young children. Working with 3 to 6 year olds, Carol Smith (2001) described how the active involvement of young children in gaining science knowledge is naturally motivating (see also Kathleen Conezio and French 2002) if topics are approached with sufficient depth and time, a position consistent with the 1995 “National Science Education Standards” (NRC 1996). In representative work supporting different facets of science instruction at the primary level, Gould et al. (2003) informally described an approach for early science instruction with gifted students, Russel Tytler and Suzanne Peterson (2001) summarized the meaningful changes in 5-year-old’s explanations of evaporation as a result of extended in-depth science instruction, Jacqueline Jones and Rosalea Courtney (2002) addressed the processes of curricular planning for instruction and assessment in early science learning, Carol Armga et al. (2002) and Laura Colker (2002) suggested guidelines for teaching science in early childhood settings, and Michelle Lee et al. (2000) described the benefits of schoolwide thematically-oriented instruction in science.

In support of the preceding as an emerging trend, an article on a parallel theme by Robert Siegler (2000) discussed a rebirth of attention to children’s learning within developmental psychology. Within this context, Herbert Ginsberg and Susan Golbeck (2004) offered thoughts on the future of research in science learning that encouraged researchers and practitioners to critically examine and be open to the possibilities of unexpected competence in young children (e.g., Glenda Revelle et al. 2002), perspectives related to those of Lynn Newton (2001) and Hilary Asoko (2002) and highly consistent with the importance of in-depth science instruction at the primary level (see also Barbara Sandall 2003).

Research Trends Recognizing the Importance of Instruction in Science for Literacy Development in Upper Elementary (3-5) Grades

There is an expanding number of research initiatives at the upper elementary grades that have linked science instruction and literacy. Gina Cervetti and Pearson (2006) reported results of a series of studies addressing the role of reading in learning science through their “Roots and Seeds” curriculum. Within their model, students first participate in inquiry-based, hands-on experiments to illustrate science concepts which are then followed by science reading assignments. Duke and her colleagues (Duke 2000 b, 2007; Duke and Pearson 2002) conducted series of studies in the use of informational texts at the primary level. These studies addressed an important instructional deficiency identified in earlier work in which Duke (2000 a) reported a scarcity in the use of informational texts at the primary levels. In related work, Duke and Pearson (2002) reported the results of studies addressing use of informational text to build reading comprehension (see also Helen Maniates and Pearson 2008; Pearson and Linda Fielding 1995). In related research, Annemarie Palincsar and her colleagues (Suzanne Hapgood et al. 2004; Hapgood and Palincsar 2007; Shirley Magnusson and Palincsar 2003; Palincsar and Magnusson 2001) conducted studies investigating the interdependency of hands-on activities (first-hand investigations) and related reading focused on the same or similar science concepts (second-hand investigations) on student science and literacy performance.

Another important series of research studies by Guthrie and his colleagues (John Guthrie and Sevgi Ozgungor 2002**;** Guthrie, Allan Wigfield, Pedro Barbosa et al. 2004; Guthrie, Wigfield, and Kathleen Perencevich 2004) demonstrated consistent improvement in student reading comprehension and motivation-to-learn resulting from embedding multi-week, science-focused, instructional modules into traditional reading programs using their Concept-Oriented Reading Instruction (CORI) model. In a broader instructional intervention implemented in classrooms with a majority of K-6 ELL students for whom science instruction replaced traditional reading/language arts, Klentschy (2003, 2006) showed that grade 6 students who participated in the initiative for 4 or more years previously averaged a percentile rank (NPR) of 64 on the nationally-normed Stanford Achievement Test in reading. And, Romance and Vitale (1992, 2001, 2008) found that replacing traditional reading/language arts instruction with in-depth science resulted in both higher reading comprehension and science achievement for students in grades 3-5 using nationally-normed tests. Finally, in complementary work, a series of analyses by Hirsch (1996, 2006) addressed the cumulative learning of academic content as a major systemic deficiency in U.S. elementary schools.

Major Interdisciplinary Implications Linking Science Instruction and Literacy: Grades K-5.

The interdisciplinary perspectives presented in earlier sections have significant implications for educational policy and practice across grades K-5. The idea of knowledge-based instruction in science through a grade-articulated, core-concept oriented curriculum provides a framework for potentially addressing literacy development within science. Such a knowledge-based curricular framework would provide the degree of cohesive structure that is necessary to insure that the science instructional strategies used in classrooms result in cumulative, meaningful learning in a manner that also engenders literacy development. Although these interdisciplinary perspectives are applicable to any curricular content-area, this section summarizes their combined implications in the form of eight "principles" that form the foundation for the linkage of science and literacy instruction. These are:

1. Use the logical structure of concepts in the discipline as the basis for a grade-articulated curricular framework.
2. Insure that the curricular framework provides students with a firm prior knowledge foundation essential for maximizing comprehension of "new" content to be taught.
3. Focus instruction on core disciplinary concepts (and relationships) of a domain and explicitly address prior knowledge and cumulative review.

4. Provide adequate amounts of initial and follow-up instructional time necessary to achieve cumulative conceptual understanding emphasizing “students learning more about what they are learning”.
5. Guide meaningful student conceptual organization of knowledge by linking different types of instructional activities (e.g., hands-on science, reading comprehension, propositional concept mapping, journaling/writing, applications) to those concepts.
6. Provide students with opportunities to represent the structure of conceptual knowledge across cumulative learning experiences as a basis for oral and written communication (e.g., propositional concept mapping, journaling/writing).
7. Reference a variety of conceptually-oriented tasks for the purpose of assessment in order to distinguish between students with and without in-depth understanding (e.g., distinguishing positive vs. negative examples, using IF/THEN principles to predict outcomes, applying abductive reasoning to explain phenomena that occur in terms of science concepts).
8. Recognize how and why in-depth, meaningful, cumulative learning within a content-oriented discipline provides a necessary foundation for developing proficiency in reading comprehension and written communication.

RESEARCH INVESTIGATING THE EFFECT OF INTEGRATING LITERACY WITHIN KNOWLEDGE-BASED SCIENCE INSTRUCTION

While the preceding studies investigated the general linkage between science and literacy, this section reviews in expanded fashion two different multi-year models that have taken a broader approach by replacing (vs. enhancing) regular reading/language arts instruction with in-depth science instruction in which reading comprehension and writing are integrated. These two models are: the *Valle Imperial Project in Science* (Klentschy 2003, 2006; Klentschy and Lori Thompson 2008) and *Science IDEAS* (Romance and Vitale 2001, 2008). Both models have demonstrated that using in-depth science instruction as a means for improving student literacy (reading comprehension, writing) is consistently more effective than the traditional basal reading/language arts programs presently endorsed by the majority of elementary education practitioners, policy makers, (see Reading First Impact Study Interim Report, Beth Gamse et al. 2008) and reading experts in academic settings. Moreover, each of these comprehensive models incorporates the eight major instructional principles based on interdisciplinary perspectives for integrating literacy within science instruction and offers significant implications for curricular policy that would also enhance time allocated to science in K-5 classrooms.

Valle Imperial Project in Science (*VIPS*)

VIPS program overview.

Working with primarily Hispanic students in Imperial County, CA, located in the southeast corner of California along the U.S. border with Mexico in which 50% of students are ELL, the *VIPS* science instructional model emphasizes five interrelated elements necessary for effective systemic reform (National Academy of Science 1997): (a) a high quality curriculum; (b) sustained professional development and support for teachers and school administrators; (c) materials support; (d) community and top level administrative support; and (e) program assessment and evaluation. Within this framework, the design of the *VIPS* model links science and literacy through the use of student science notebooks within an inquiry-based approach to science instruction in which students are provided with an opportunity to develop “voice” in their personal construction of the meaning of science phenomena. In the *VIPS* model, the student “voice” is represented through the science notebooks that students use during their science learning experiences as a repository for reflections and as a knowledge-transforming (vs. story telling) tool for constructing meaning. As a means for engendering significant growth in student achievement in both reading, writing, and science (Olga Amaral et al. 2002; Olaf Jorgenson and Rick Vanosdall 2002; Wendy Saul 2004; Klentschy 2003; Klentschy and Molina-De La Torre 2004), the extensive use of science notebooks linking science and literacy has been a major contributor to the success of the VIPS program.

In order to construct models through the workings of written language, children must necessarily interact with people and objects in their environment. Within the instructional environment established by the *VIPS* model, students use writing (and drawing) as a means for simultaneously constructing and reflecting on their understanding of science phenomena. This general view of the dynamics of student learning establishes a foundation for teaching in which children learn science by doing science and then use writing as part of their science experiences. This suggests that- in the context of science activities- student-produced science notebooks promote the use of literacy while clarifying students’ emerging theories about science phenomena (see also Brian Hand et al. 2004; Lori Norton-Meier et al. 2008). Student science notebooks provide not only stability and permanence to children’s work, but also purpose and form.

VIPS research findings.

A major research focus of the *VIPS* science model has been on documenting the relationship between the levels of student achievement (reading, writing, science) and the number of years of student participation in the *VIPS* science model. Recent studies reported by Klentschy (2003, 2006) consisted of students who had been enrolled in the El Centro School District for a four year period. Students in grade 4 and grade 6 were formed into groups based on the number of years (0-4) they had received *VIPS* science instruction from project-trained teachers using the *VIPS* standards-based instructional science materials. The reading and science achievement measures used in the study were obtained from a districtwide administration of the Stanford Achievement Test (SAT) in Reading and Science. Student achievement in writing (only in grade 6) was assessed through a District-developed Writing Proficiency Test that used prompts requiring specific types of writing.

For reading, the results showed that Stanford Achievement Test (SAT) reading achievement scores increased linearly over years of *VIPS* participation (from 0 through 4 years) for grades 4 and 6 students. Contrary to the achievement drop that is commonly found at the fourth grade level (see Jean Chall and Vicki Jacobs 2003; Hirsch 2003), students in the *VIPS* model for 4 years (i.e., grades 1 through 4, grades 3 through 6) displayed levels of SAT Reading achievement that were above grade level (Grade 4 mean NPR = 57, Grade 6 mean NPR = 67) on national norms. For science, the results showed that Stanford Achievement Test (SAT) science achievement scores also increased linearly over years of *VIPS* participation (from 0 through 4 years) for grades 4 and 6 students. Again, contrary to the achievement drop that is commonly found at the fourth grade level, students in the *VIPS* model for 4 years (i.e., grades 1 through 4, grades 3 through 6) displayed levels of SAT Science achievement that were above grade level (Grade 4 mean NPR = 53, Grade 6 mean NPR = 64) on national norms. Finally, for writing achievement, assessed through a District-developed test, proficiency for students in grade 6 also increased linearly by years of *VIPS* participation. Students in the *VIPS* science model for 3 or for 4 years displayed a high degree of writing proficiency (91 and 89 percent pass-rates, respectively), reflecting the *VIPS* emphasis on meaningful writing.

Conclusions and related findings: *VIPS*

Overall, the results indicate a substantial relationship between years of participation in the *VIPS* science model and achievement in reading, writing, and science. These findings are consistent with those reported by Ted Bredderman (1983) in an analysis of 57 research studies comparing the learning effects of science programs that emphasize in-depth learning to traditional textbook programs. In that study, Bredderman reported a 14-percentile point difference in favor of in-depth (inquiry-based) programs, along with consistent positive effects for females, economically disadvantaged, and minority students. In the *VIP* studies, students who did not participate in *VIPS* science during the years covered by this study (i.e., students with zero (0) years of participation) typically received instruction from science textbooks or from individually developed teacher units. The results of the *VIPS* studies also are consistent with a meta-analysis of 81 research studies by James Shymansky and others (1990) which contrasted the performance of students in hands-on, activity-based programs with that of students in traditional textbook-based programs.

At the same time, in interpreting the results of these meta-analyses, it is important to note that more recent complementary research findings (e.g., Magnusson and Palincsar 2003; Palincsar and Magnusson 2001; Emily Swan and Guthrie 1999) have emphasized that the integration of hands-on science activities with reading and writing rather than hands-on science alone resulted in increased student achievement outcomes. In fact, as a major characteristic of the *VIPS* (and *Science IDEAS*) model, the integration of literacy within science (vs. use of basal reading/language arts programs) explains the combined overall impact of program participation resulting in both improved science achievement and the transfer of the *VIPS* science experiences by students to an overall improvement in reading and writing.

As *VIPS* students advanced through the grade levels, participation in *VIPS* science instruction has had other cumulative effects. For example, Klentschy and Molina-De La Torre (2004) found that more students in the District were enrolled in high school chemistry and physics classes than in any previous year, and that reading achievement at the high school level had improved incrementally with each succeeding high school freshman class over a three-year period. In addition, they found that the cohort of students in high school in 2004 had the highest graduation rate in a decade.

Science IDEAS Model

Science IDEAS program overview

The research on *Science IDEAS* model was conducted in large, and highly diverse, urban school settings in southeastern Florida (e.g., African American = 36%, Caucasian = 38%, Hispanic = 21%, Other: 5%, Free Lunch: 37%). *Science IDEAS* is a cognitive-science-oriented instructional intervention that was initially validated within a grade 4 upper elementary setting (Romance and Vitale 1992). Implemented through a daily 2-hour block of time which replaces regular reading/language arts instruction, *Science IDEAS* is an integrated instructional model that embeds reading and writing within science instruction. In *Science IDEAS,* multi-day science lessons engage students in a variety of instructional activities (e.g., inquiry-based/hands-on science, reading text/trade/internet science materials, writing about science, science projects, journaling, propositional concept mapping as a knowledge representation tool), all of which focus on enhancing science conceptual understanding. As an instructional intervention implemented within a broad inquiry-oriented framework (e.g., all aspects of teaching and learning emphasize learning more about what is being learned through text and non-text modalities), teachers use core science concepts and concept relationships (which students master to develop in-depth science understanding) as curricular guidelines for identifying, organizing, and sequencing all instructional activities. From a curriculum integration standpoint, as students engage in science-based reading activities, teachers guide and support reading comprehension (and writing) in an authentic fashion.

As a simplified illustration of how *Science IDEAS* functions as a strong knowledge-based instruction model, Figure 2 shows how a propositional concept map (see Romance and Vitale 2001) representing the concept of evaporation could serve as a knowledge-based framework for organizing and sequencing complementary instructional activities. Within the knowledge-based curricular framework representing the concept of evaporation, teachers identify additional reading, hands-on projects, and writing activities to expand in-depth science knowledge.

- - - Insert Figure 2 Here - - -

The foundations of the *Science IDEAS* model are well grounded in cognitive science (see Romance and Vitale 2001, 2008). These consider curricular mastery as equivalent to knowledge-based expertise and the cumulative development (and subsequent access) of curricular prior knowledge as the most critical determinant of success in meaningful learning across all varieties of instructional tasks, including reading comprehension.

Using the initial findings (Romance and Vitale 1992) as a foundation, the *Science IDEAS* model subsequently was extended to over 50 classrooms and 1200 students across grades 3-5, which included ethnically diverse student populations and a variety of academic levels ranging from above average to severely at-risk. Most recently, the *Science IDEAS* research group is engaged in a multi-year project funded by the National Science Foundation (NSF) to develop, implement, and study the process of scaling up the model both at the upper elementary level and, in a complementary fashion, adapt the grade 3-5 model to the primary level (grades K-2). Through the present, the *Science IDEAS* model is being implemented in grades K-5 on a schoolwide basis in 12 elementary schools.

Science IDEAS research findings

The research completed from 1992 to 2001 consisted of a series of studies conducted in authentic school settings, typically over a school year. In the first study (Romance and Vitale 1992), three average-performing grade 4 classrooms implemented the *Science IDEAS* model over the school year with their end-of-year achievement being measured by the ITBS Reading and the MAT Science. Results showed that *Science IDEAS* students outperformed comparison students by approximately one year's grade equivalent (GE) in science achievement (+.93 GE) and one-third of a GE in reading achievement (+.33 GE). In the second study conducted the following school year, *Science*

IDEAS was again implemented with the same three teachers/classrooms in grade 4. The results of this second year replication obtained similar levels of achievement effects, with *Science IDEAS* students outperforming comparison students by +1.5 GE in science and +.41 GE in reading (Romance and Vitale 2001).

In the third and fourth studies that followed (Romance and Vitale 2001), the robustness of the model was tested by (a) increasing the number of participating schools, (b) broadening the grade levels to grades 4 and 5, and (c) enhancing the diversity of participants by including district-identified at-risk students. Results of the year 3 study (Romance and Vitale 2001) found that low-SES predominantly African-American *Science IDEAS* at-risk students in grade 5 significantly outperformed comparable controls by +2.3 GE in science and by +.51 GE in reading over a 5-month (vs. school year) intervention. However, in contrast with earlier findings, no significant effect was found for the younger grade 4 at-risk students for the 5-month intervention.

In the fourth study, the number of participating schools and teachers/classrooms was increased to 15 school sites and 45 classroom teachers. Results of the fourth study found that *Science IDEAS* students displayed greater overall achievement on both science (+1.11 GE) and reading (+.37 GE). In addition, grade 5 students outperformed grade 4 students while, in a similar fashion, regular students outperformed at-risk students. But, unlike year 3, no interactions were found, indicating that the year-long *Science IDEAS* intervention was consistent across both grade levels (grade 4 and grade 5) and with both regular and at-risk students. In addition, in the final year of the expansion, the study addressed an important equity issue by showing that the differences in rate of achievement growth and affective outcomes in favor of the *Science IDEAS* participants were related only to program participation and not to student demographic characteristics (e.g., at-risk, gender, race).

All of the preceding reported studies (1992-2001) focused on individual teachers/classrooms located in a variety of different school sites. However, beginning with 2002, the *Science IDEAS* research framework (supported by an IERI/NSF grant) was composed of two different initiatives. The primary initiative (Romance and Vitale 2008) involved implementing *Science IDEAS* on a schoolwide basis in grades 3-4-5 in an increasing number of participating schools (from 2 to 12). The increasing number of such schoolwide interventions provided a framework for studying issues relating to scale-up of the *Science IDEAS* model (Romance and Vitale 2007; Vitale and Romance 2005; Vitale et al 2006). The second initiative consisted of two smaller studies embedded within the overall scale-up project that explored extrapolations of the *Science IDEAS* model to grades K-2 (Vitale and Romance 2007a) and as a setting for reading comprehension strategy effectiveness (Romance and Vitale 2006).

Figure 3 shows the cross-sectional effect across grades 3-8 of the *Science IDEAS* model implemented school-wide in grades 3-8 on ITBS science and reading achievement across 12 participating and 12 comparison schools in 2006-2007 (Romance and Vitale 2008). Both groups of schools were comparable demographically (approximately 60% minority, 45% free/reduced lunch). In interpreting these figures, it should be noted that students in grades 6-7-8 (who had previously attended *Science IDEAS* or comparison schools) were categorized as extensions of the *Science IDEAS* or comparison school they attended in grade 5).

----- Insert Figure 3 Here -----

In interpreting achievement trajectories in science in Figure 3, linear models analysis found *Science IDEAS* students obtained higher overall ITBS science achievement than comparison students (adjusted mean difference =

+.38 GE in Science with grade level differences ranging from +.1 GE to +.7 GE). Both Treatment Main Effect and Treatment x Grade Interaction were significant, indicating that the magnitude of the treatment effect increased with grade level. Covariates were Gender and At-Risk Status (Title I Free/Reduced Lunch). In interpreting the achievement trajectories in reading shown in Figure 3, linear models analysis found *Science IDEAS* students obtained higher overall ITBS reading achievement than comparison students (adjusted mean difference = +.32 GE in reading with grade level differences ranging from .0 GE to +.6 GE). While the overall treatment main effect was significant, the treatment x grade level interaction was not. Covariates were Gender and At-Risk Status (Title I Free/Reduced Lunch). Other results of the analyses were (a) the treatment effect was consistent across at-risk and non-at-risk students for both ITBS science and reading, and (b) girls outperformed boys on ITBS Reading (there was no gender effect on science).

The second research initiative consisted of two small-scale studies embedded within the overall NSF scale-up project that explored extrapolations of the *Science IDEAS* model to grades K-2 and explored the effectiveness of in-depth science instruction as a setting for reading comprehension strategies. The objective of the K-2 mini-study (Vitale and Romance 2007a) was to adapt the grade 3-5 *Science IDEAS* model to grades K-2 in two *Science IDEAS* schools (vs. two comparison schools). Within the context of scale-up, the involvement of K-2 teachers/classrooms was designed to transform the implementation of the grade 3-5 model into a more comprehensive, school-wide instructional model. Unlike the grade 3-5 model, however, in grades K-2, teachers only incorporated a 45 minute science instruction block into their daily schedules while continuing their regular daily reading instruction. Results of a year-long study found an overall main effect in favor of *Science IDEAS* students on ITBS science (+.28 GE). However, for ITBS reading achievement, a significant treatment x grade level was found, and subsequent simple effects analysis showed a significant difference of .72 GE in grade 2 on ITBS reading, but no effect in grade 1. Other results found a significant effect of white vs. non-white (+.38 GE), but no treatment x ethnicity interaction.

The objective of the grade 5 mini-study (Vitale and Romance 2006b) was to explore whether research-validated reading comprehension strategies (see Vitale and Romance 2007b) would be differentially effective in the cumulative meaningful learning setting established by *Science IDEAS* classrooms in comparison to a basal reading classrooms emphasizing narrative, non-fiction reading. After a 7-week intervention in which reading comprehension strategies were implemented in *Science IDEAS* classrooms and basal reading classrooms in accordance with a 2 x 2 factorial design (with prior state-administered FCAT reading as a covariate), the results showed that *Science IDEAS* students performed significantly higher than basal students on both ITBS science (+.38 GE) and reading (+.34 GE). Although the main effect of reading comprehension strategy use was not significant, the instructional setting x strategy use was significant. Specifically, simple effects analysis showed the use of the reading comprehension strategy by *Science IDEAS* students improved their overall performance in both science (+.17 GE) and reading (+.53 GE) , but strategy use had no effect in basal classrooms.

Conclusions and related findings: Science IDEAS

The major conclusion from the multi-year pattern of findings is that *Science IDEAS*, as an integrated instructional model, is effective in accelerating student achievement in both science and reading in grades 3-4-5.

More importantly, the magnitude of the effects expressed in grade equivalents on nationally-normed tests (ITBS, SAT, MAT) is educationally meaningful. Because in grades 3-4-5, *Science IDEAS* replaces regular basal reading instruction, the effectiveness of the *Science IDEAS* model which emphasizes in-depth, cumulative, conceptual learning offers major implications for curricular policy at the elementary levels (see Vitale et al. 2006). Of parallel importance is the finding that the effects of *Science IDEAS* in grades 3-4-5 were transferable to grades 6-7-8. Although this finding is presently being replicated, it has important implications for elementary curricular policy as well.

Complementing the preceding are other supportive findings. These include the findings that (a) the effect of *Science IDEAS* is consistent for both regular and at-risk students, (b) the adaptation of the model for use in grades K-2 is feasible and (c) *Science IDEAS*, in emphasizing in-depth, conceptual learning, provides a more effective context for reading comprehension enhancement strategies than narrative-oriented basal reading materials. Overall, the multi-year research initiative involving *Science IDEAS* provides a strong pattern of evidence of the effectiveness of the *Science IDEAS* model, in particular, and the natural linkage of science and literacy, in general (Romance and Vitale 2006, 2008).

TOWARD AN INTERDISCIPLINARY RATIONALE FOR EXPANDING THE ROLE OF IN-DEPTH SCIENCE INSTRUCTION IN ELEMENTARY SCHOOLS

The preceding is suggestive of implications for policy and practice that would broaden the role of in-depth science instruction in elementary schools. These implications are counter to those of present school reform initiatives which, despite their limited success (e.g., Gonzales et al. 2008; Lee et al. 2007; Lutkus et al. 2006), continue to emphasize increased instructional time for traditional reading/language arts at the expense of science instruction (Dillon 2006; Jones et al. 1999). As noted in this chapter, there is an expanding consensus research base from science and literacy educators that linking in-depth science and traditional reading/language arts instruction jointly improves student achievement in both literacy and in science. As also presented here, the interdisciplinary research foundations for such combined achievement results are well established. Yet, despite consistent positive outcomes, the impact of interventions which only augment reading/language arts instruction with in-depth science are necessarily limited. Rather, consistent with interdisciplinary research foundations, comprehensive knowledge-based models which developmentally integrate reading/language arts within in-depth science instruction would promise to provide an instructional environment that is far more powerful.

In fact, the *VIPS* and *Science IDEAS* models overviewed here have accomplished such integration in demonstrating both immediate and long-term achievement effects. In terms of immediate findings, both models have shown consistently that replacing traditional reading/language arts with in-depth science learning results in substantial student achievement acceleration in science, reading comprehension, and writing. Moreover, both have reported positive transfer effects of in-depth science instruction from the elementary to secondary levels. Specifically, *Science IDEAS* found that grade 3-5 students displayed greater achievement in science and reading comprehension in grade 6-7-8. And, *VIPS* findings demonstrated that increased enrollment of students in high school science courses and subsequent graduation rates. In fact, such positive transfer effects from elementary-level instruction to secondary level performance are contrary to findings reported in the literature (e.g., Megan Dolan 2005). Building on a foundation of interdisciplinary research perspectives and findings, science education researchers and practitioners alike may have a opportunity to argue for systemic changes in present curricular policy to substantially increase the instructional emphasis on in-depth science instruction in grades K-5.

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References

Amaral, O., Garrison, L., & Klentschy, M. (2002). Helping English learners increase achievement through inquiry-based science instruction. *Bilingual Research Journal, 26,* 213-239.

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review*, *89*, 369-403.

Anderson, J. R. (1987). Skill acquisition: Compilation of weak-method problem solutions. *Psychological Review, 94*, 192-210.

Anderson, J. R. (1992). Automaticity and the ACT theory. *American Journal of Psychology, 105,* 15-180.

Anderson, J. R. (1993). Problem solving and learning. *American Psychologist*, *48,* 35-44.

Anderson, J. R. (1996). ACT: A simple theory of complex cognition. *American Psychologist*, *51,* 335-365.

Anderson, J. R., & Fincham, J. M. (1994). Acquisition of procedural skills from examples. *Journal of Experimental Psychology, 20,* 1322-1340.

Anderson, J. R., & Lebiere, C. (1998). *The atomic components of thought.* Mahwah, NJ: Erlbaum.

Armga, C., Dillon, S., Jamsek, M., Morgan, E.L., Peyton, D., & Speranza, H. (2002). Tips for helping children do science. *Texas Child Care, 26*, 2-7.

Artzen, E., & Holth, P. (1997). Probability of stimulus equivalence as a function of training decision. *Psychological Record, 47,* 309-320.

Asoko, H. (2002). Developing conceptual understanding in primary science. *Cambridge Journal of Education, 32*, 153-164.

Block, C. C., & Pressley, M. (Eds.). (2002). *Comprehension instruction: Research-based best practices.* New York: Guilford Press.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn.* Washington, DC: National Academy Press.

Bredderman, T. (1983). Effects of activity-based elementary science on student outcomes: A quantitative synthesis. *Review of Educational Research*, *53,* 499-518.

Carnine, D. (1991). Curricular interventions for teaching higher order thinking to all students: Introduction to a special series. *Journal of Learning Disabilities, 24,* 261-269.

Cavanagh, S. (2004). NCLB could alter science teaching. *Education Week*, *24*, 1 & 12-13.

Cervetti, G., Pearson, P. D. (2006). Reading and writing in the service of inquiry-based science. In R. Douglas, M. Klentschy, & K. Worth (Eds.), *Linking science and literacy in the K-8 classroom* (pp. 221-244). Arlington, VA: NSTA Press.

Chall, J. S., & Jacobs, V. A. (2003). The classic study on poor children's fourth grade slump. *American Educator*, *27*, 14-16.

Colker, L. J. (2002). Teaching and learning about science. *Young Children, 57*, 10-11, 47.

Conezio, K. & French, L. (2002). Science in the preschool classroom: Capitalizing on children's fascination with the everyday world to foster language and literacy development. *Young Children, 57*, 12-18.

Dillon, S. (2006). *Schools cut back subjects to push reading and math*. Retrieved March 26, 2006 from http://www.nytimes.com/2006/03/26/education/26child.html?pagewanted=1&_r=1.

Dolan, M. F. (2005). Assessment success today or learning success tomorrow? How a longitudinal perspective helps standards-based accountability systems eliminate the persistent gap between nominal and actual achievement for high school graduates. (Doctoral dissertation, Florida Atlantic University, 2005). *Dissertation Abstracts International*, *66*, 567.

Dougher, M. J., & Markham, M. R. (1994). Stimulus equivalence, functional equivalence and the transfer of function. In S.C. Hays, L.J. Hays, M. Santo, & O. Koichi (Eds.), *Behavior analysis of language and cognition* (pp. 71-90). Reno, NV: Context Press.

Duke, N. K. (2000a). 3.6 minutes per day. The scarcity of informational texts in first grade. *Reading Research Quarterly*, *35*, 202-224.

Duke, N. K. (2000b). For the rich it's richer: Print experiences and environments offered to children in very low- and very high-socioeconomic status first grade classrooms. *American Educational Research Journal*, *37*, 441-478.

Duke, N.K. (2007). Let's look in a book: Using nonfiction reference materials with young children. *Young Children*, *62*, 12-16.

Duke, N. K., Bennett-Armistead, V. S., & Roberts, E. M. (2003). Filling the nonfiction void. *American Educator, 27*, 30-35.

Duke, N., & Pearson, P. D. (2002). Effective practices for developing reading comprehension. In A. E. Farstrup & S. J. Samuels (Eds.), *What research has to say about reading instruction.* (pp.205-242). Newark, DE: International Reading Association.

Farstrup, A. E. & Samuels, S. J. (2002). *What research has to say about reading instruction*. Newark, DE: International Reading Association.

French, L. (2004). Science as the center of a coherent, integrated early childhood curriculum. *Early Childhood Research Quarterly, 19*, 138-149.

Gamse, B. C., Bloom, H. S., Kemple, J. J., & Jacob, R. T. (2008). *Reading First impact study: Interim report* (NCEE 2008-4016). Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U. S. Department of Education.

Gelman, R. & Brenneman, K. (2004). Science learning pathways for young children. *Early Childhood Research Quarterly, 19*, 150-158.

Ginsburg, H. P., & Golbeck, S. L. (2004). Thoughts on the future of research on mathematics and science learning and education. *Early Childhood Research Quarterly, 19*, 190-200.

Glaser, R. (1984). Education and thinking: The role of knowledge. *American Psychologist, 39,* 93-104.

Gonzales, P., Williams, T., Jocelyn, L., Roey, S., Kastberg, D., & Brenwald, S. (2008). *Highlight from TIMSS 2007: Mathematics and science achievement of U.S. fourth- and eighth-grade students in an international context* (NCES 2009-001). Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education.

Gould, S. J., Weeks, V., & Evans, S. (2003). Science starts early. *Gifted Child Today Magazine, 26*, 38-43.

Guthrie, J. T., & Ozgungor, S. (2002). Instructional contexts for reading engagement. In C.C. Block & M. Pressley (Eds.), *Comprehension instruction: Research-based best practices* (pp. 275-288). New York: The Guilford Press.

Guthrie, J. T., Wigfield, A., Barbosa, P., & Others. (2004). Increasing reading comprehension and engagement through concept-oriented reading instruction. *Journal of Educational Psychology, 96*, 403-423.

Guthrie, J. T., Wigfield, A., & Perencevich, K. C. (Eds.). (2004). *Motivating reading comprehension: Concept-oriented reading instruction.* Mahwah, NJ: Earlbaum.

Hand, B., Hohenshell, L., & Prain, V. (2004). Exploring students' responses to conceptual questions when engaged with planned writing experiences. *Journal of Research in Science Teaching, 41*, 186-210.

Hapgood, S., Magnusson, S. J., & Palincsar, A. S. (2004). Teacher, text, and experience: A case of young children's scientific inquiry. *The Journal of the Learning Sciences*, *13*, 455-505.

Hapgood, S., & Palincsar, A. S. (2007). Where literacy and science intersect. *Educational Leadership*, *64*, 56-60.

Hirsch, E. D. (1996). The s*chools we need. And why we don't have them.* New York: Doubleday.

Hirsch, E. D. (2001). Seeking breadth and depth in the curriculum. *Educational Leadership, 59*, 21-25.

Hirsch, E. D. (2003). Reading comprehension requires knowledge of words and the world: Scientific insights into the fourth-grade slump and stagnant reading comprehension. *American Educator*, *27*, 10-29.

Hirsch, E. D. (2006). *The knowledge deficit*. New York: Houghton Mifflin.

Holliday, W. G. (2004). Choosing science textbooks: Connecting science research to common sense. In W. Saul (Ed.), *Crossing borders in literacy and science instruction* (pp. 383-394). Newark, DE: International Reading Association and NSTA Press.

Jones, J., & Courtney, R. (2002). Documenting early science learning. *Young Children, 57*, 34-38, 40.

Jones, M. G., Jones, B. D., Hardin, B., Chapman, L., Yarbrough, T., & Davis, M. (1999). The impact of high-stakes testing on teachers and students in North Carolina. *Phi Delta Kappan, 81*, 199-203.

Jorgenson, O., & Vanosdall, R. (2002). The death of science? What are we risking in our rush toward standardized testing and the three r's. *Phi Delta Kappan*, *83*, 601- 605.

Kearsley, G. P. (Ed.). (1987). *Artificial intelligence and instruction: Applications and methods.* New York: Addison-Wesley.

Kintsch, W. (1994). Text comprehension, memory, and learning. *American Psychologist*, *49*, 294-303.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. Cambridge, UK.: Cambridge University Press.

Kintsch, W. (2004). The construction-integration model of text comprehension and its implications for instruction. In R. B. Ruddell, & N. J. Unrau (Eds.), *Theoretical models and processes of reading* (5th Ed.) (pp. 1270-1328). Newark, DE: International Reading Association.

Klentschy, M. P. (2003). The science literacy connection. *California Curriculum News Report, 28*, 1-2.

Klentschy, M. P. (2006). Connecting science and literacy through student science notebooks. *California Journal of Science Education*, *6*, 51-79.

Klentschy, M. P., & Molina-De La Torre, E. (2004). Students' science notebooks and the inquiry process. In E.W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 340-354). Newark, DE: International Reading Association.

Klentschy, M. P., & Thompson, L. (2008). *Scaffolding science inquiry through lesson design*. Portsmouth, NH: Heinemann.

Kolodner, J. L. (1993*). Case-based reasoning.* San Mateo, CA: Morgan Kaufmann.

Kolodner, J. L. (1997). Educational implications of analogy: A view from case-based reasoning. *American Psychologist, 82*, 57-66.

Lee, J., Grigg, W. S., & Donahue, P. L. (2007). *The Nation's Report Card: Reading 2007* (NCES 2007496). Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education.

Lee, M., Lostoski, M., & Williams, K. (2000). Diving into a school wide science theme. *Science and Children, 38*), 31-35.

Luger, G. F. (2008). *Artificial intelligence: Structures and strategies for complex problem-solving*. Reading, MA: Addison Wesley.

Lutkus, A. D., Lauko, M. A., & Brockway, D. M. (2006). *The Nation's Report Card: Science 2005 trial urban school district assessment* (NCES 2007453). Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education.

McNamara, D.S., de Vega, M., & O'Reilly, T. (2007). Comprehension skill, inference making, and the role of knowledge. In F. Schmalhofer & C.A. Perfetti (Eds.), *Higher level language processes in the brain: Inference and comprehension processes* (pp. 233-253). Mahwah, NJ: Erlbaum.

McNamara, D.S., & Kintsch, W. (1996). Learning from text: Effects of prior knowledge and text coherence. *Discourse Processes, 22*, 247-288.

Magnusson, S. J., & Palincsar, A. S. (2003). Learning from text designed to model scientific thinking in inquiry-based instruction. In E. W. Saul (Ed.), *Crossing borders in literacy and scientific instruction* (pp. 316-339). Newark, DE: International Reading Association.

Maniates, H., & Pearson, P. D. (2008). The curricularization of comprehension strategies instruction: A conspiracy of good intentions. In Y. Kim, V. J. Risco, & others (Eds.), *The fifty-seventh yearbook of the national reading conference* (pp. 271-284). Oak Creek, WI: National Reading Conference.

National Academy of Sciences. (1997). *Science for all children: A guide for improving elementary science education in your school district.* Washington, DC: National Sciences Resources Center, Smithsonian Institution.

National Reading Panel. (2000). *Teaching children to read: An evidence-based assessment of scientific research literature on reading and its implications for reading instruction*. Jessup, MD: National Institute for Literacy.

National Research Council. (1996). *National science education standards*. National Committee on Science Education Standards and Assessment. Washington, DC: National Academy Press.

Newton, L. D. (2001). Teaching for understanding in primary science. *Evaluation and Research in Education, 15,* 143-153.

Niedelman, M. (1992). Problem solving and transfer. In D. Carnine & E. J. Kameenui (Eds.), *Higher order thinking.* (pp. 137-156). Austin, TX: Pro-Ed.

Norton-Meier, L., Hand, B., Hockenberry, L., & Wise, K. (2008). *Questions, claims, and evidence: The important place of argument in children's science writing.* Portsmouth, NH: Heinemann

Ogle, D., & Blachowicz, C. L. Z. (2002). Beyond literature circles: Helping students comprehend informational texts. In C. C. Block & M. Pressley (Eds.), *Comprehension instruction* (pp. 247-258). New York: Guilford Press.

Palincsar, A. S., & Magnusson, S. J. (2001). The interplay of first-hand and second-hand investigations to model and support the development of scientific knowledge and reasoning. In S. M. Carver & D. Klahr (Eds.), *Cognition and instruction: Twenty-five years of progress* (pp. 151-195). Mahwah, NJ: Erlbaum.

Palmer, R.G., & Stewart, R. (2003). Nonfiction trade book use in primary grades. *The Reading Teacher, 57,* 38-48.

Pearson, P. D., & Duke, N. (2002). Comprehension instruction in the primary grades. In C. C. Block & M. Pressley (Eds.), *Comprehension instruction* (pp. 247-258). New York: Guilford Press.

Pearson, P. D., & Fielding, L. (1995). Comprehension instruction. In R. Barr, M. L. Kamil, P. B. Mosenthal, P. B., & P. D. Pearson. (Eds.), *Handbook of reading research, Volume II* (pp. 815-860). Mahwah, NJ: Lawrence Erlbaum Associates.

Pressley, M., Rankin, J., & Yokoi, L. (1996). A survey of instructional practices of primary teachers nominated as effective in promoting literacy. *Elementary School Journal, 96,* 363-384.

Revelle, G., Druin, A., Platner, M., Bederson, B., Hourcade, J. P., & Sherman, L. (2002). A visual search tool for early elementary science students. *Journal of Science Education and Technology, 11*, 49-57.

Rivet, A. E., & Krajcik, J. S. (2008). Contextualizing instruction: Leveraging students' prior knowledge and experiences to foster understanding of middle school science. *Journal of Research in Science Teaching, 45,* 79-100.

Romance, N. R., & Vitale, M. R. (1992). A curriculum strategy that expands time for in-depth elementary science instruction by using science-based reading strategies: Effects of a year-long study in grade 4. *Journal of Research in Science Teaching, 29,* 545-554.

Romance, N. R., & Vitale, M. R. (2001). Implementing an in-depth expanded science model in elementary schools: Multi-year findings, research issues, and policy implications. *International Journal of Science Education, 23,* 373-404.

Romance, N. R., & Vitale, M. R. (2006). Making the case for elementary science as a key element in school reform: Implications for changing curricular policy. In R. Douglas, M. Klentschy, & K. Worth (Eds.), *Linking science and literacy in the K-8cClassroom* (pp. 391-405). Washington, DC: National Science Teachers Association.

Romance, N. R., & Vitale, M. R. (2007, April). *Elements for bringing a research-validated intervention to scale: Implications for leadership in educational reform.* Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL.

Romance, N. R., & Vitale, M. R. (2008, April). *Science IDEAS: A knowledge-based model for accelerating reading/literacy through in-depth science learning.* Paper presented at the annual meeting of the American Educational Research Association, New York.

Sandall, B. R. (2003). Elementary science: Where are we now? *Journal of Elementary Science Education, 15*, 13-30.

Saul, W. (Ed.). (2004). *Crossing borders in literacy and science instruction*. Newark, DE: International Reading Association and NSTA Press.

Schmidt, W. H., McKnight, C., Cogan, L. S., Jakwerth, P. M., & Houang, R. T. (1999). *Facing the consequences: Using TIMSS for a closer look at U.S. mathematics and science education*. Dordrecht/Boston/London: Kluwer.

Schmidt, W. H., McKnight, C., Houang, R. T., Wang, H. C., Wiley, D. E., Cogan, L. S., et al. (2001). *Why schools matter: A cross-national comparison of curriculum and learning*. San Francisco: Jossey-Bass.

Schmidt, W. H., McKnight, C., & Raizen, S. (1997). *A splintered vision: An investigation of U.S. science and mathematics education*. Dordrecht/Boston/London: Kluwer.

Shymansky, J .A., Hedges, L. V., & Woodworth, G. (1990). A Reassessment of the effects of inquiry-based science curricula of the 60's on student performance. *Journal of Research on Science Teaching*, 27, 127-144.

Sidman, M. (1994). *Stimulus equivalence.* Boston, MA: Author's Cooperative.

Siegler, R. S. (2000). The rebirth of children's learning. *Child Development, 71*, 26-35.

Smith, A. (2001). Early childhood – A wonderful time for science learning. *Investigating: Australian Primary & Junior Science Journal, 17*, 18-21.

Snow, C. E. (2002). *Reading for understanding: Toward a research and development program in reading comprehension.* Santa Monica, CA: RAND Reading Study Group.

Sowa, J. F. (2000). *Knowledge representation: Logical, philosophical, and computational foundations.* New York: Brooks Cole.

Swan, E., & Guthrie, J. T. (1999, April). *Influences of science observation and science trade books on reading comprehension and motivation*. Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada.

Tytler, R., & Peterson, S. (2001). Deconstructing learning in science – young children's responses to a classroom sequence on evaporation. *Research in Science Education, 30*, 339-355.

Vitale, M. R., & Romance, N. R. (2000). Portfolios in science assessment: A knowledge-based model for classroom practice. In J. J. Mintzes, J.H. Wandersee, & J.D. Novak (Eds.), *Assessing science understanding: A human constructivist view* (pp. 168-197). San Diego, CA: Academic Press.

Vitale, M. R., & Romance, N. R. (2005, April). *A model for scaling up a research-validated instructional intervention: Implications for leadership in educational reform.* Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada.

Vitale, M. R., & Romance, N. R. (2006a). A knowledge-based framework for the classroom assessment of student science understanding. In M. McMahon, P. Simmons, R. Sommers, D., DeBaets, & F. Crawley (Eds.), *Assessment in science: Practical experiences and education research* (pp. 1-14). Arlington, VA: NSTA.

Vitale, M. R., & Romance, N. R. (2006b, April). *Effects of embedding knowledge-focused reading comprehension strategies in content-area vs. narrative instruction in grade 5: Findings and research implications.* Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.

Vitale, M. R, & Romance, N. R. (2007a, April). *Adaptation of a knowledge-based instructional intervention to accelerate student learning in science and early literacy in grades 1-2.* Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL.

Vitale, M. R., & Romance, N. R. (2007b). A knowledge-based framework for unifying content-area reading comprehension and reading comprehension strategies. In D. McNamara (Ed.), *Reading comprehension strategies* (pp. 73-104). Mahwah, NJ: Erlbaum.

Vitale, M. R., Romance, N. R., & Klentschy, M. (2006, April). *Improving school reform by changing curriculum policy toward content-area instruction in elementary schools: A research-based model.* Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA

Walsh, K. (2003). Lost opportunity. *American Educator, 27*(1), 24-27.

Weaver, C. A., & Kintsch, W. (1995). Expository text. In R. Barr, M. L. Kamil, P. B. Mosenthal, & P. D. Pearson (Eds.), *Handbook of reading research, Volume II* (pp. 230-245). Mahwah, NJ: Lawrence Erlbaum Associates

Biographical Sketches

Dr. Nancy Romance is a Professor of Science Education at Florida Atlantic University. Her research interests focus on the integration of science and literacy in grades K-8 as a means of accelerating student meaningful learning in science and reading comprehension.

Dr. Michael Vitale is a Professor of Educational Research at East Carolina University. His research interests focus on the application of interdisciplinary research perspectives to meaningful learning in K-12 school settings.

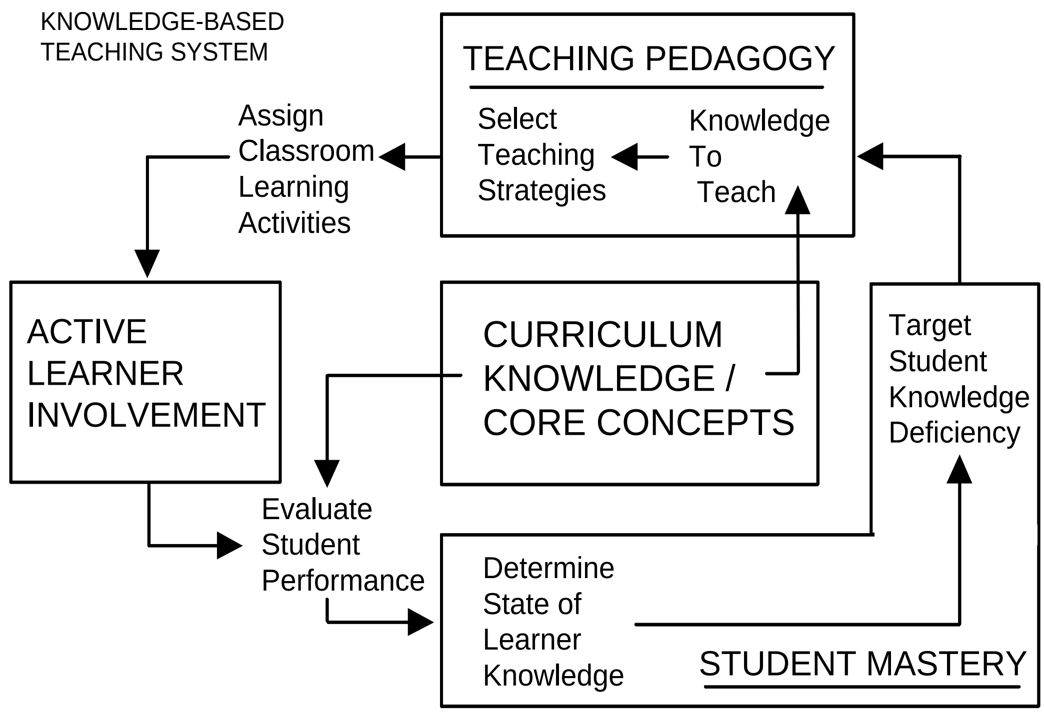
Figure Captions

Figure 1. Architecture for a knowledge-based intelligent tutoring system.

Figure 2. Simplified illustration of a propositional curriculum concept map used as a guide by grade 4 *Science IDEAS* teachers to plan a sequence of knowledge-based instruction activities.

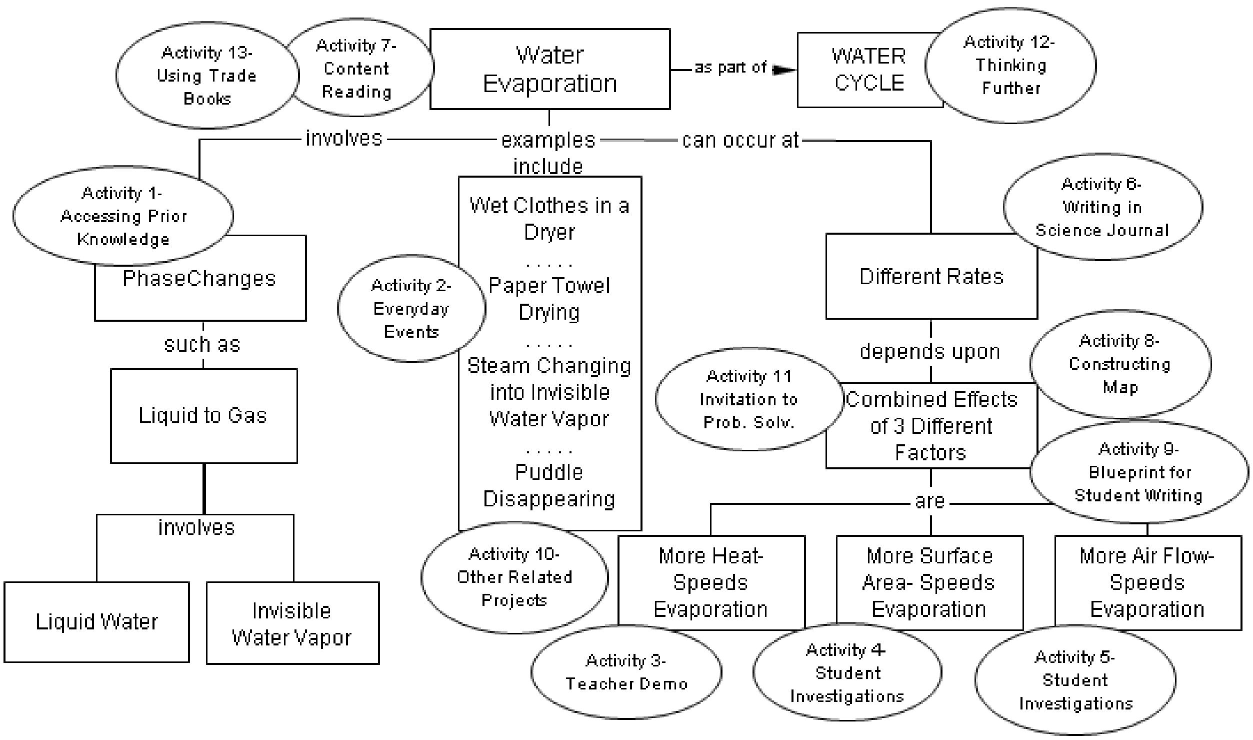
Figure 3. 2006-2007 ITBS Achievement Trajectories for *Science IDEAS* and Control Schools in Science and Reading across grades 3-8.

(Figure 1)

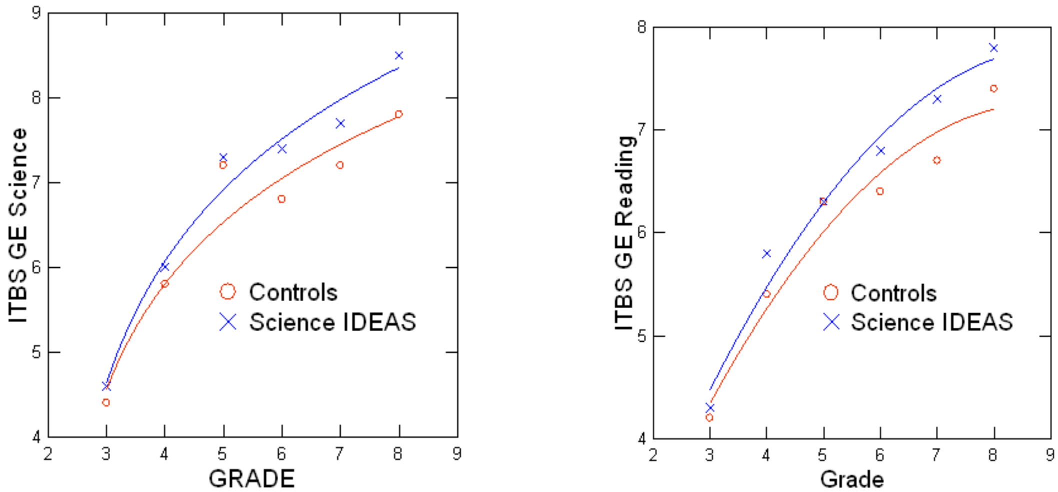

KNOWLEDGE-BASED
TEACHING SYSTEM
TEACHING PEDAGOGY
Select Teaching Strategies
Knowledge To Teach
Assign Classroom Learning Activities
ACTIVE LEARNER INVOLVEMENT
CURRICULUM KNOWLEDGE / CORE CONCEPTS
Target Student Knowledge Deficiency
Evaluate Student Performance
Determine State of Learner Knowledge
STUDENT MASTERY

(Figure 2)

WATER EVAPORATION AS A DYNAMIC PROCESS IN THE WATER CYCLE



(Figure 3)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ITBS GE Reading
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