Perspectives for Improving School Instruction and Learning:
An Interdisciplinary Model for Integrating
Science and Reading in Grades K-5 [1,2]

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This paper describes implications for school reform based on findings associated with an interdisciplinary model which integrates reading comprehension and writing within meaningful science instruction. As implemented in grades 3-4-5, the model, Science IDEAS, replaces the daily 1.5-2 hour time-block typically allocated to traditional reading/language arts with in-depth science instruction. In turn, literature (now considered as a content-area subject) is allocated to the time traditionally dedicated to science instruction (e.g., 30 minutes 2-3 times per week). Across multi-day lessons focusing on science concepts, students initially learn and then expand their understanding by engaging in a variety of instructional activities that comprise the basic elements of the Science IDEAS model. These activities involve hands-on experiments, reading comprehension, propositional concept mapping, journaling/writing, and application activities. From an inquiry standpoint, a major emphasis in the implementation of the model is for students to learn more about what they are learning across the concept-focused activities in which they are engaged.

Although details of the model itself are overviewed in subsequent sections, the primary focus here is on addressing paradigmatic issues associated with school reform that follow from the interdisciplinary perspectives on which the Science IDEAS model is based. In this regard, the present paper "wraps" prior research involving the Science IDEAS model within two meta-analytic perspectives: (a) evaluative aspects of the school reform process and (b) issues in the scale up of research-based interventions by schools. Both perspectives are of primary importance because without being addressed in a methodologically sound fashion, any research findings and possible paradigmatic implications following from the Science IDEAS and related research are unlikely to be adopted and sustained by schools or school systems.

In support of the present paper, we have made accessible several supplementary sources of more detailed information relating to different aspects of the model. However, the paper certainly may be read without reference to these additional materials. Specifically, these additional materials are as follows:

1. Romance and Vitale (2001). *Implementing an In-depth Expanded Science Model in Elementary Schools: Multi-Year Findings, Research Issues, and Policy Implications*. This is a summary and findings of earlier work with the Science IDEAS model. Included are details of the lesson design process.

2. Romance and Vitale (2008). *Science IDEAS: A Knowledge-Based Model for Accelerating Reading/Literacy through In-Depth Science Learning*. This PowerPoint presented at AERA overviews the scope of the present multi-year IERI/NSF project investigating aspects of scale up of the Science IDEAS model. Includes details of the Science IDEAS model and the associated set of implementation/support tools being developed.

3. Vitale, Romance, and Dolan (2006). *A Knowledge-Based Framework for the Classroom Assessment of Student Science Understanding.* This chapter presents a criterion-referenced form of assessment model designed for teacher use in the assessment of facets of student understanding of science as addressed within the Science IDEAS model.

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[1] *Paper presented to the University of Chicago - Committee on Education Workshop on Education Lecture Series, November 12, 2008.*
[2] *The research reported here was supported by the National Science Foundation through Grant REC 0228353.*

4. Vitale and Romance (2007). *A Knowledge-Based Framework for Unifying Content-Area Reading Comprehension and Reading Comprehension Strategies*. This chapter presents interdisciplinary foundations for addressing reading comprehension solely as a logical subset of more general comprehension learning processes (i.e., vs. reading "skills"). In turn, the argument advanced is that such comprehension processes can be approached through knowledge-based curriculum emphasizing cumulative, in-depth, content area learning.

5. Romance and Vitale (2007). *Elements for Bringing a Research-Validated Intervention to Scale: Implications for Leadership in School Reform*. This paper presented at AERA discusses issues and presents a scale up model developed as part of a multi-year IERI/NSF funded project that expanded the application of the Science IDEAS model.

6. Vitale, Romance, and Klentschy (2006). *Improving School Reform by Changing Curricular Policy toward Content-Area Instruction in Elementary Schools: A Research-Based Model.* This paper presented at AERA discusses policy implications that would make content-area instruction (e.g., science, social studies, literature, mathematics) the focus of systemic school reform in grades K-5.

7. Vitale and Romance (2006). *Concept Mapping as a Means for Binding Knowledge to Effective Content-Area Instruction: An Interdisciplinary Perspective*. This paper presented at the Second International Conference on Concept Mapping outlines a modular strategy for enhancing the quality of meaningful content-area instruction at the secondary level as an extension of the original grade 3-4-5 Science IDEAS model.

With the preceding in mind, this paper consists of five sections: (a) an informal overview of issues in school reform and scale up, (b) a rationale for curriculum-based reform following from the issues identified, (c) an overview of the interdisciplinary research foundations on which the Science IDEAS model is based, (d) a description of the Science IDEAS model along with present research findings and other related approaches, and (e) the resulting implications for school reform policy. In the interest of providing a useful framework for the Seminar Presentation, extensive references included in the supplementary papers for the most part are not included. Readers interested in a more complete list of associated references are referred to these materials.

COMPLEMENTARY ISSUES IN SCHOOL REFORM AND SCALE UP

It is a fair statement that systemic school reform initiatives in the U.S. over the past 25+ years have been less than successful, particularly in the area of reading. For example, focusing on the extremes of the K-12 continuum, recent NAEP (2005) findings showed a decrease in reading achievement at the high school level while the preliminary year-2 Reading First component of NCLB has been evaluated as non-effective. Of interest here, however, is the contrasting fact that accountability reports from low-achieving states (e.g., Florida, North Carolina) continue to report a high-degree of success on statewide reading reform initiatives emphasizing student performance on state-developed tests in grades 3-8. But, such state initiatives continue to ignore the substantial declines in the achievement of school-dependent (e.g., low SES) students at the high school level and the related evidence that the state-established proficiency levels set at the upper elementary grades are set far too low to be predictive of subsequent student academic success in high school (see Dolan, 2005). Complementing these circumstances is the fact that the majority of instructional initiatives and other reform strategies that schools select for reading improvement consist of "more of the same" approaches in the form of instructional alternatives, coaching initiatives, and leadership strategies.

Methodological Enhancements to School Accountability

From a logical standpoint, academic expectations representing desired outcomes are the key dynamic for driving school reform. However, from a systemic perspective, such academic expectations to the present are primarily expressed as the proportions of students at particular grade levels whose performance meets or exceeds proficiency standards set for “basic-skills” tests. The view advanced in this paper is that expectations established in such a fashion artificially limit the academic expectations that determine the criteria for the success of any systemic school improvement initiative. This is discussed more broadly in a following section. However, here, the primary question addressed is one of test validity. If reading tests at the upper elementary and/or middle school levels do not measure the forms of student proficiency that are required for academic success in high school content-area courses, then the interpretation of student “success” based on such tests is misleading.

Although most reform states maintain their tests in a “secure” fashion so the content cannot be analyzed, some aspects of the North Carolina (NC) school reform system illustrate the overall concern. First, NC curricular reading standards in grades 3-5 have little to do with student content-area comprehension in a particular discipline. Although the reading comprehension skills and strategies specified in the State curriculum are intended to be generalizable, in fact, they all require some form of prior knowledge in order to be applied. As an example, the reading skill “main idea” requires full comprehension of a reading passage before it can be identified. Therefore, logically, student understanding of the main idea is a result of reading comprehension, not a cause. The point here is not that understanding main idea in a passage is an inappropriate instructional goal, but rather that attempting to teach it as a transferrable, content-free skill has little potential for transfer to content-area reading.

Second, the NC state-established, equal-interval, developmental scale scores on state reading tests require approximately 13.6 scale units of growth for students in grade 3 that begin the year as “proficient”. However, for students in grade 8 who begin the year as “proficient” (based on their prior years’ state testing at the end of grade 7), only approximately 1.8 units of growth are required to maintain their proficiency on the state reading test. Clearly, whatever the state reading test is measuring, it has little to do with the development of the forms of content-area understanding that, as a prerequisite for high school success, are the academic focus of middle school curricula. And, third, it then is no surprise that the success of low-SES students dependent on school for learning who meet proficiency levels on State grade 8 reading comprehension tests is substantially lower on State high-school content-area tests.

While aspects of the NC accountability system are state-specific, the general pattern of reading assessment problems is common to many reform states (e.g., Florida). Such a pattern of problems has the combined effect of allowing incremental success in school improvement to be based upon student achievement -- a kind of grade-focused TQM sub-optimization-- while, at the same time, avoiding focus on the forms of achievement that are the most important goals of K-12 school success-- projections of academic performance in grades 9-12. Adopting school reform goals that reflect the present approaches to school accountability serves to diminish the level of academic expectations that could be targeted for school children.

Steps for raising reform expectations through assessment. Although extended treatment of these issues is beyond the scope of this present paper, some specific methodological enhancements to present accountability and evaluative practices related to assessment that could raise achievement expectations can be noted:

1. *Re-structuring the focus of reading comprehension tests in grades 3-8 from general reading comprehension skills to meaningful content-area understanding.* Since prior-knowledge of academic content is the primary determinant of future disciplinary learning and, by implication, also of learning from text, focusing accountability assessment on student meaningful understanding of content area concepts would increase the validity of the accountability testing process.

2. *Explicitly linking, for purposes of interpretation, student performance levels at lower grades with their projected levels of success in high school content-area courses.* Such a linkage would imply that successful student performance in lower grades reflects a meaningful expectation of academic success in subsequent grades, a feature missing from the majority of present accountability assessment systems. Note, however, that such across-grade linkage should be predictive of and reported in terms of absolute levels of success (e.g., as expectancy tables) rather than simply as correlations among student performance across different grades.

3. *Broadening and otherwise adjusting the levels of students tested.* The view in this paper is that two levels of student performance should be used to represent the scope of student achievement in reform: (a) the achievement progress of students in grades K-2 and (b) the performance of students on required high school courses in grades 9-10. In general, present accountability systems de-emphasize student performance at both extremes. Although costly, funding for such initiatives could be obtained by eliminating (or reducing) testing in other grade levels or through a variety of controlled sampling approaches. For example, one possible approach to accountability could test at the following grade levels: (a) grades K-2 in reading, (b) grades 3, 5, and 8 in content-area learning, and (c) grades 9-10 in core courses required for graduation. With the appropriate use of developmental scale scores, student progress could be reported in terms of metrics indicating both the cumulative levels of student achievement progress and their degree of preparation for success in subsequent grades.

Considered together, the preceding could strengthen the assessment foundations for raising student expectations in school reform.

Disaggregating and aggregating student performance as measures of school success. In terms of data management, the majority of school reform initiatives compare student performance in the present year by grade level with that of different students at the same grade level the preceding year. Within the accountability process for school reform, improvement is defined as an increase in the proportion of students over the one-year time span who meet or exceed the proficiency level established for a particular test. (Note- although important, AYP and other NCLB issues are not considered here). From the standpoint of evaluating academic improvement at the school level, the present approach is misleading insofar as the effectiveness of an elementary, middle school, or a school system comprised of elementary and middle schools is concerned.

As an alternative, the view advanced here is that student achievement should be disaggregated across school grade spans according to the following process:

1. *Identification of all students who have been enrolled continuously across the grade range of the school (e.g., K-5 for elementary schools, K-8 for elementary-middle school feeder patterns), then report the achievement of these students by grade level.* For purposes of accountability for systemic school improvement, the performance of students continuously enrolled is the most direct measure of the overall effectiveness of a school's instructional program. Such performance could then be interpreted in terms of levels of achievement by grade level or in terms of improved achievement trajectories across grade levels in comparison to those of preceding years. If a school is not effective with students continuously enrolled, then such a school is in need of serious curricular, instructional, and/or operational refinement.

2. *Identification of all students not enrolled continuously, but enrolled for a complete school year.* For purposes of accountability in school reform, the performance of these students is important to report because serving these students effectively is a measure of school success as well. Such performance could then be interpreted in terms of levels of achievement by grade level or in terms of improved achievement trajectories across grade levels in comparison to those of preceding years. If a school is not effective with students attending that school for a full year, then such a school is in need of serious curricular, instructional, and/or operational refinement. At the same time, in reporting the performance of these students, some measure of entering level(s) of achievement should be used (e.g., preceding years' end-of-year tests) to allow more precise evaluation of their achievement progress.

3. *Identification of all remaining students enrolled for only a portion of a school year.* For purposes of school level accountability, the achievement of such students should not be used since they were only enrolled for a portion of the school year at any particular school. However, the performance of these students should be analyzed and reported from the district level (see following).

Just as the achievement of the preceding categories of students can be reported at the school level, the aggregated performance of each of the three categories of students across schools can be reported at the district level as well. Together, the patterns of cumulative achievement of these three categories of students provides a powerful measure of systemic school effectiveness.

Establishing explicit linkage between the grade-articulated structure of curricular content taught and student achievement across grade levels. Although this form of initiative would require some degree of development on the part of schools (or school districts), it would provide a powerful framework for interpreting student outcomes in a manner that has significant implications for raising student achievement expectations. This rationale is straightforward. In schools, it is the cumulatively taught curricular content that is the basis for student achievement since curricular content is what students are to learn in schools. Once such a cumulative curricular content structure is explicated across grade levels, then student position(s) within the curricular sequence can be identified at time of testing.

When both types of data are available, then student performance outcomes can be represented graphically as a function of their position on the established curricular sequence on the base (X) axis and the associated distribution of performance scores on the outcome (Y) axis. Although details are beyond the scope of this paper, the display of achievement progress as a function of a curricular sequence makes an important point regarding the degree to which achievement increases across (and within) grades can be expressed as resulting from conceptually-sequenced classroom instruction. In this regard, accelerating student achievement progress as a desired outcome can be expressed in terms of their progress through a core curricular sequence that is accomplished through the manipulation of such factors as more effective teaching and/or greater allocation of instructional time. Such a perspective has major implications for raising achievement expectations for all students since this outcome is expressed as the result of actions directly under school control. In turn, if achievement levels cannot be related to the cumulative curricular structure, then serious analysis of the curriculum should be undertaken.

Summary of major points. Ideally, academic expectations of student performance are the core dynamic that underlies school reform initiatives. Among the approaches for raising such expectations within a systemic framework are: (a) expressing the interpretation of all achievement outcomes in terms of their projected levels of success at subsequent grade levels, (b) increasing the focus of assessment at the elementary and middle school levels upon student content-area understanding rather than on general reading skills, (c) using the cumulative achievement of students continuously enrolled in a school or district as the major indicator of systemic school success, and (d) building linkages between cumulative curricular structures across (and within) grades and student performance outcomes as a means for reporting, interpreting, and addressing improved cumulative student achievement.

Scale Up Methodology as an Approach for Facilitating School Reform and School Reform Expectations

The issues relating to scale up are closely related to those associated with both paradigmatic and non-paradigmatic (i.e., more of the same as enhancements to present approaches) school reform. However, the scale up issues associated with paradigmatic school reform are more critical. This is because a school or school system considering the adoption of any form of intervention that is paradigmatically different from its regular operations is unlikely to have either the internal expertise or organizational infrastructure necessary to support the intervention. Such concerns involving scale up necessarily focus on the development of the organizational infrastructure and specialized expertise needed to insure the initiation, sustainability, and eventual expansion of a research-validated instructional intervention adopted by a school system. So defined, scale up is recognized as a major issue in research-utilization by schools. If schools or school districts making an initial commitment to use an evidence-based intervention do not have the capacity to sustain (or eventually expand) its use in school settings, then such interventions, no matter how promising, cannot contribute toward systemic school improvement. Gaining an understanding of the scale up processes involved in school utilization of research-validated interventions was the primary objective of the multi-year IERI-funded initiative at the Federal level (see Schneider & McDonald, 2006a, 2006b).

Science IDEAS scale up project. A major goal of the Science IDEAS scale up project funded by IERI/NSF was to involve an increasing number of schools in the implementation of the Science IDEAS model and then study the resulting collaborative processes for supporting schools involved the project scale up initiative. In doing so, a major project objective was to identify strategies and tools that would support the different elements of the overall scale up process (e.g., initiation, sustainability, expansion to new sites) while implementing the Science IDEAS model in a fashion that resulted in meeting student performance outcomes established in prior research. Because the Science IDEAS model involves replacing traditional (basal) reading language arts with in-depth science instruction, Science IDEAS does represent a paradigmatically different approach for teaching reading comprehension and writing in grades 3-4-5. As a result, the scale up model being developed by the project (which is ongoing) consists of a number of complementary facets.

The first facet frames the idea of scale up as a process in which school system personnel assume implementation responsibility from project researchers on a phase-in basis. The second targets the development of the different areas of expertise that ultimately would provide the internal capacity necessary to sustain and expand the implementation of the model (e.g., teacher leadership cadres, principal implementation strategies). The third provides implementation support (e.g., professional development modules, web-based support tools for teachers, principals, and administrators) that would form the organizational infrastructure for implementation. And, the fourth addresses the question of how to establish the value added by the intervention to the systemic goals of the school district.

Operational facets of the scale up model. In applying the scale up model, the first three facets are consistent with a reverse-engineered instructional systems development approach. As applied to Science IDEAS, key project components include: (a) a schoolwide implementation model for grades 3-4-5, (b) multi-year teacher professional development/support modules, (c) a teacher leadership cadre, and (d) an instructional management system. As the project evolved, project staff conducted professional development and provided school support with regard to planning multi-day lessons that used Science IDEAS elements. Subsequently, a majority of such professional development and support are now provided by teacher leadership cadre members. Similarly, in the initial years of the project, staff assessed classroom teaching fidelity. However, at this point, principals are now capable of determining classroom fidelity. In a related fashion, a number of the expertise-based perspectives used by project staff in working collaboratively with school personnel are now in the process of being transformed into web-based tools.

Included among these are: (a) a web-based administrative tool supporting the initial and follow-up planning processes for implementing Science IDEAS, (b) a web-based resource for teachers including curriculum resources and modeled teaching skills, and (c) a web-based tool using school-reported data to communicate implementation status of the model to administrators (e.g., Science IDEAS teaching schedules, amount of daily instructional time, numbers of pull-outs, teaching fidelity). Although there are other aspects, the preceding provides a representative view of key parts of the the Science IDEAS scale up model.

Value-oriented facet of the scale up model. In the project scale up model, the first three facets focus on factors that are operational in nature-- that is on the development of the capability of the school system to implement Science IDEAS. As important as these are, operational factors alone are not sufficient to insure sustainability of an intervention. For sustainability to occur, an intervention, in this case Science IDEAS, must be recognized as “adding value” to the established goals of the institution. While it is important in the initial start-up process to obtain advocacy for an intervention from educational professionals (e.g., teachers, principals, administrators), the concept of added value used here is broader because it must transcend the presence of specific individuals in the institution. This is a necessary requirement simply because the roles of individuals within schools systems tend to change with regularity. As a related illustration, state accountability systems have caused schools to assign a high degree of institutional value to student test scores. And, institutional value associated with state testing and the sustainability of state testing initiatives is consistent in the face of personnel changes in administrators, principals, or teachers.

While the preceding statewide testing example is artificial because the value added was forced externally on school districts by the state, the point of congruence from the state perspective that links institutional value and sustainability is important. In the case of Science IDEAS, although there are many aspects of the model that have potential systemic value, the strategies for establishing such added value to the institution are only in the preliminary stages. Certainly included among these are district-recognized factors such as scores on state reading tests and the use of school reading and science achievement outcomes to assign grades to schools. But, as important as these criteria are, they only reflect a very minor aspect of the overall benefits resulting from implementation of the Science IDEAS model.

For example, as part of the implementation of the Science IDEAS model, there are a variety of processes or outcomes that potentially map directly the value structure of participating school systems. At the classroom level, visitors could observe that students are (a) actively engaged in learning science (vs. comparable classrooms), (b) highly motivated to learn and provide evidence of their accomplishments that indicate accelerated learning (e.g., journals, concept maps, projects), and (c) able to summarize what they have learned in a highly coherent fashion. At the teacher level, visitors could observe that teachers are (a) able to implement Science IDEAS lessons they have planned in an effective manner, (b) provide mutual collaborative support by sharing instructional resources and ideas, and, (c) as leadership cadre members, are able to provide effective professional development and in-school support to new Science IDEAS teachers. At the principal level, visitors could observe that principals are able (a) to work collaboratively with teachers to develop grade-articulated curricular plans in science and (b) to monitor fidelity of implementation in a professionally positive manner that emphasizes recognition for effective Science IDEAS teaching. At the administrative level, a variety of different central school administrators are able to recognize the importance (a) of the positive effects upon student classroom learning reported by teachers and principals as resulting from students having a firm foundation in prior knowledge when they enter the next grade and (b) of the empirical evidence showing the magnification of test achievement at the middle school level as a transfer effect resulting from students being in Science IDEAS in grades 3-4-5 at the elementary level.

Because of the collaborative project-school system relationship, each of the preceding examples have been observed and recognized repeatedly as being of “high value” by samples of teachers, principals, administrators, and, even in some cases, parents. In this regard, the continuation (i.e., presence) of the project over a 7-year period and the continuing addition of new Science IDEAS schools provide a positive context for recognizing such value-oriented factors. And, as will be noted in the following section, it is important to recognize that each of the preceding examples has either direct or indirect implications for raising student achievement expectations. At the present time, determining what strategies are best to apply in order to engender institutional value is an important project objective.

Summary of major points. Issues involving scale up and school reform are closely linked. The dual purpose of scale up methodology is (a) to develop the capacity of school systems to implement research-validated interventions that have been adopted so that sustainability and expansion can be accomplished and (b) to establish the value added by an intervention to the institution in support of working to accomplish sustainability (and expansion). Across the scope of an intervention, the elements associated with such a value added process also contribute toward raising student achievement expectations.

Toward Linking School Reform Expectations and Scale Up Methodology

As noted previously, improvements in student achievement expectations are a major dynamic for school reform. And, as appropriate, any form of intervention that results in such positive improvements should become positioned in a positive fashion within a school system. At the same time, however, this perspective leaves open the question of what the scope of possible improvements could be. The view taken here is that insofar as school reform addressing improvement in reading comprehension is concerned, student achievement expectations have been limited substantially by present school reform evaluative methodology on one hand and the lack of school capacity to consider and adopt paradigmatic alternatives to present instructional approaches to reading on the other.

As a paradigmatic alternative to traditional approaches to reading comprehension and writing, limitations in reform methodology in combination with school implementation capability provide substantial barriers to be overcome. First is the issue of reading comprehension test validity. In order for Science IDEAS to produce improved achievement, such tests must provide a structure in which prior achievement gained within reading passages must be used to answer comprehension questions. In this regard, the project has used the nationally-normed ITBS Reading subtests as outcome measures because state-administered reading test specifications do not meet this requirement. Second is the issue of assessment of the depth and acceleration of student conceptual learning in science. In this regard, the project has used the ITBS Science subtest as a measure of science achievement. However, despite its strengths in some aspects of science, there is presently no adequate developmental measure of in-depth science understanding that would address the scope of student learning in Science IDEAS. At present, the project is working toward the development of a web-based student assessment tool that would address this important methodological need.

In fact, all of the preceding suggestions for improvements in the evaluative methodology of school reform in the area of testing and data analysis apply directly to the present to Science IDEAS scale up scenario. Included among these are (a) increased emphasis on assessment of content-area understanding (vs. generic reading skills), (b) interpreting and reporting student achievement levels in terms of their projected achievement levels at higher grades, (c) linking student increases in achievement levels to an inter- and intra-grade curricular sequence, and (d) disaggregating the achievement trends of students continuously enrolled across an elementary or elementary-middle school grade range from those of students enrolled for shorter time periods. Each of the above methodological initiatives would contribute toward raising student achievement expectations while providing a more powerful evaluative framework for assessing the effectiveness of the Science IDEAS model as it is implemented across a time-phased implementation series in an increasing number of schools. In fact, as a framework for expressing increased student expectations, the above range of achievement outcomes would map directly into established institutional values.

Just as methodological enhancements to school reform evaluative methodology would complement a scale up initiative, the key facets of the Science IDEAS scale up model described above could be abstracted in a form that they are applicable to any school reform instructional intervention. No matter what specifics of an intervention are, the operational facets for capacity development and organizational infrastructure in support of the intervention are essential for insuring effectiveness. Moreover, different aspects of an intervention that potentially offer added value to an institution beyond test scores are important to explicate for purposes of sustainability.

Considered together, the suggested enhancements to school reform evaluative methodology and the facets of the Science IDEAS scale up model offer significant benefits to school systems engaged in reform initiatives. And, to the degree to which a school system lacks the capacity (specialized expertise) and infrastructure to support an intervention, the more important these methodological perspectives are for enhancing expected student achievement outcomes.

TOWARD A RATIONALE FOR CURRICULUM-BASED REFORM

The relevance of curriculum to school reform is straightforward. Curriculum considered as the academic content to be taught in schools provides the context for instruction and cumulative student learning. In effect, curricular content and student learning outcomes are a relationship within which "teaching" as a means to engender learning outcomes is implied. In applying the preceding to school reform, the more school-dependent (e.g., low SES) students are for meaningful academic learning, the more critical the quality of curricular content is in providing a foundation for instruction.

Although the characteristics of academically sound curricular content are well understood (see Duschl et al. (2007) for the content-area of K-8 science), such characteristics are only minimally present in the curricular content of schools, particularly at the elementary level. In fact, most school systems define their curricular content and structure in terms of state-specified standards in which academic content is listed. While such state standards may provide schools with a potential focus for state-administered accountability tests, they do not provide a sound curricular structure. For example, the characteristics of exemplary curricular structure identified in the literature include: (a) a clear focus on core concepts within a content discipline, (b) a high degree of coherence of the conceptual relationships comprising curricular content, and (c) meaningful articulation (i.e., sequencing) of the degree of conceptual understanding to be gained across grade levels. In comparison, state standards (e.g., Florida) tend to be fragmented with serious omissions, not organized around core concepts, and not meaningfully sequenced.

In practice, these fragmented state standards and benchmarks are placed into the hands of K-5 teachers who lack the adequate content knowledge to fill in curricular gaps. As a result, the implementation of weakly structured curricular content diminishes the potential for in-depth learning of all students, and in particular for low SES students who are more dependent on school experiences for academic learning. Overall, a poorly specified curricular structure has an adverse effect on classroom instruction and learning because it fails to explicate the prior knowledge students need and/or have previously gained that provide an efficient starting points for teaching.

In summary, curricular content and organizational structure are key elements in school reform because they provide students with the highest need with a school-based opportunity for meaningful, cumulative learning and teachers with a foundation for planning classroom instruction that is efficient and effective. Together, this set of dynamics is important for systemically raising the achievement expectations of both high-need and non-high-need students. A major goal of the Science IDEAS has been to build curricular frameworks in science that provide teachers with a coherent, articulated, and conceptual guide for planning classroom instruction.

APPLYING INTERDISCIPLINARY RESEARCH PERSPECTIVES TO REFORM: KNOWLEDGE-BASED INSTRUCTION MODELS

The interdisciplinary foundations of Science IDEAS reflect research and development initiatives relevant to meaningful school learning that have been conducted in the areas of cognitive science, cognitive psychology, applied learning, instructional design/development, and educational research. Although a wide variety of work is certainly relevant, several key research-based perspectives represent the primary tenets of the model. The first has to do with the architecture of knowledge-based instruction systems (Luger, 2008) originally developed to implement computer-based instructional tutoring systems. The second (Kintsch, 1994, 1998, 2004) has to do with the importance of having a well-structured curricular environment for learning. 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). The fourth has to do with cognitive research dealing with the linkage of declarative knowledge to procedural knowledge and automaticity (Anderson, 1982, 1987, 1992, 1993, 1996). And, finally, the fifth has to do with principles for the design and development of validated instructional systems (Dick et al., 2007; Engelmann & Carnine, 1991). These perspectives are overviewed here in order to provide interdisciplinary foundations for the Science IDEAS model described in the following section.

Interdisciplinary Perspectives on Meaningful Learning

Knowledge-based instruction as a foundation for meaningful learning. The distinguishing characteristic of knowledge-based instruction models is that all aspects of instruction are related explicitly to an overall design framework that represents the logical structure of the concepts in the subject-matter discipline to be taught. Because of this architectural framework for curriculum and instruction, knowledge-based instruction serves as an interdisciplinary perspective that has important implications for meaningful learning in school settings. The idea of a knowledge-based approach to instruction dates back to the mid-1980's when the original intelligent tutoring systems were developed in the field of artificial intelligence (e.g., Luger, 2008). In knowledge-based instruction systems, explicit representation of the concepts and concept relationships to be learned allows conceptual knowledge to serve as a coherent (curricular) framework for the sequencing of instructional activities, teaching strategies, student learning activities, and assessment. Within such a knowledge-based framework, as Bransford et al. (2000) have noted, experts, in comparison to novices, are able to organize and access knowledge in a fashion that allows knowledge to be applied to novel problems through automaticity (i.e., automatically without thinking). In this regard, building prior knowledge is recognized as a major determinant of meaningful comprehension, in general, and reading comprehension, in particular.

An example of learning dynamics associated with a knowledge-based model of meaningful learning is the construction-integration model developed by Kintsch and his colleagues (e.g., Kintsch, 1994, 1998, 2004). Although developed and applied extensively to reading comprehension in the analysis of learning from text, the construction-integration model is generalizable to other learning settings as well. More specifically, Kintsch's model explains the process of reading comprehension by distinguishing between the propositional structure (i.e., semantic meaning) of a text that is being read and the prior knowledge the reader brings to the process of reading. Within this context, meaningful comprehension results when the prior knowledge of the learner is able to join 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., 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 model is readily generalizable to any form of meaningful learning in school settings that involves the interaction of student prior knowledge with a (cohesive) curricular structure that, together, provide the context for instruction.

Dynamics for proficiency development and transfer: A knowledge-based perspective. Related to the preceding is general work in cognitive science by Anderson and others (e.g. Anderson, 1982, 1987, 1992, 1993, 1996). This work distinguishes the "strong" problem solving processes of experts that are highly knowledge-based and automatic from the "weak" strategies novices with minimal knowledge exhibit that may range from heuristics to trial-and-error search. Within the context of either meaningful school learning or reading comprehension, the prior knowledge that students bring to learning or reading tasks can be considered to provide a basis for strong knowledge-based problem solving. In comparison, reading (and other) comprehension strategies can be considered as weak strategies (i.e., as heuristic tools) that, when well-developed, eventually may become automatic. Both these processes, presumably, operate in a complementary fashion at a level of automaticity for expert learners in both general comprehension and reading comprehension learning tasks.

As Anderson and others (Anderson, 1982, 1987, 1992, 1993, 1996; Anderson & Fincham, 1994) have shown, developing strategies as cognitive skills requires extensive amounts of varied practice across a range of representative conditions to reach the degree of automaticity that is characteristic of expert performance in any setting. Also directly relevant are research-based elements introduced in Anderson's (1992, 1996) earlier versions of the ACT cognitive theory that, in considering cognitive skills as forms of proficiency that are knowledge-based, (a) distinguish between declarative and procedural knowledge (i.e., knowing about vs. applying knowledge), and (b) identify the conditions in learning environments that determine the transformation of declarative to procedural knowledge.

In complementary work, both Niedelman (1992) and Anderson et al. (e.g., Anderson, 1996) have offered interpretations of research issues relating to transfer of learning that are consistent with a knowledge-based approach to learning and understanding, including reading comprehension. Such work on transfer of learning is of major importance in understanding the potentially differential practical effects of student learning of meta-cognitive strategies whose use is embedded within a content-oriented domain (e.g., science) as opposed to their learning such strategies in non-content-oriented domains that are different from the content-oriented application contexts in which they are intended to be used.

Considering instructional systems development methodology as a general design heuristic. The purpose of instructional systems development models (e.g., Dick et al., 2007; Engelmann & Carnine, 1991) is to design, develop, and empirically validate instructional programs as effective through iterative field-test/revision cycles. In turn, once validated, such instruction is packaged for use by schools along with the specific professional training and instructional support/management components that are necessary for fidelity of implementation. In effect, the field-test/validation process insures that the program will be effective as long as the associated support procedures are able to be implemented to insure fidelity.

The typical instructional systems development initiative (see Dick et al., 2007) consists of a sequence of phases prior to field-testing that include specification of the initial curricular goals and objectives, the development of assessment tools, the sequencing of curricular content, the identification of instructional strategies, and the development of instructional media. Although generic instructional systems approaches to development draw heavily on the experience and expertise of a development team, other instructional design models (Engelmann & Carnine, 1991) are more detailed in terms of the identification of core concepts (vs. just specifying desired outcomes), sequencing strategies that insure students gain prerequisite knowledge before attempting more complex tasks, and specific instructional algorithms incorporating multiple examples as a basis for teaching concepts, concept relationships, and concept applications.

Considered together, these two complementary approaches to instructional design and development are suggestive of standards for effective instruction that have important implications for the adoption of effective instructional materials by school practitioners.

Summary of major points. The interdisciplinary perspectives overviewed in this section are suggestive of a view of effective school learning that is paradigmatically different from the present practices in a majority of schools. Focusing on research implications, these findings are supportive of a strong curriculum-based approach to school reform that focuses on structural properties of a grade-level articulated and core- concept-oriented curricular framework as the foundation for accelerating the rate and depth of student academic expectations through effective instruction. In particular, the idea of knowledge-based instruction provides an operational mechanism for achieving such student achievement outcomes. Within such a knowledge-based framework, a variety of instructional dynamics (e.g., focus on core concepts and concept relationships, effective use of examples to gain conceptual understanding, representation of the organizational structure of concepts and concept relationships learned, and the explicit interplay in a cumulative learning environment between review and accessing of prior knowledge required for learning) can be used to make classroom instruction more optimal in terms of engendering student learning mastery.

Implications of Interdisciplinary, Reform, and Scale Up Perspectives for the Science IDEAS Model

This section briefly outlines how the preceding perspectives serves as a methodological foundation for the Science IDEAS model.

Major interdisciplinary implications for Science IDEAS implementation. As noted in a preceding section, the Science IDEAS scale up model is primarily a reverse-engineered instructional systems development model. In this regard, the scale up model has been designed to include the major implementation support tools required by schools or a school system to implement the model (Note-development of these components is ongoing). At the same time, it is important that such an implementation by schools is necessarily an evolutionary process that requires specialized expertise for initiation. Such expertise could be obtained from resources from within or out of a school district. However, if intra-district expertise is used for start-up, such expertise would have to be developed prior to implementation. In general, the components of operational support that are necessary for implementation of Science IDEAS model parallel those of an instructional systems development initiative.

In terms of the Science IDEAS model itself, it is important to recognize that the classroom instructional elements of the model are designed to be used in conjunction with a sound science curricular framework. Certainly, the instructional elements of the model could be implemented by focusing on any set of credible science concepts that, if implemented with fidelity, would result in meaningful student learning. However, from a more systemic perspective relevant to school reform, a well-structured and grade-articulated science curricular framework is the key element for guiding teacher planning of multi-day lessons in a manner that results in efficient and meaningful cumulative learning by students. In doing so, as described in the following section, the knowledge-based architecture of the Science IDEAS model implemented using concept-focused activities (e.g., hands-on experiments, reading comprehension, propositional concept mapping, journaling/writing, and applications) provides a multifaceted instructional setting in which student learning is continuously broadened.

The fact that the Science IDEAS model is paradigmatically different from traditional approaches for teaching reading/language arts does result in a several initial barriers. However, these barriers are overcome as the intervention is implemented across time. The first initial barrier is that any Science IDEAS intervention in an accountability-oriented state must insure that state testing objectives are met. As a practical requirement this is addressable by a variety of strategies. But the best strategy is to support schools' reasonable use of test preparation modules while concurrently working toward accelerating student learning progress so that test requirements are addressed within a coherent, articulated science curriculum in advance of the state-specified grade-levels at which they are to be taught. From the standpoint of cumulative learning, the allocation of 1.5 - 2 hours of instructional time to in-depth science makes this strategy feasible insofar as state science testing is concerned. With regard to reading comprehension, the replicated research findings reported in the following section show that developing student reading and science proficiency for performing successfully on accountability tests is not a problem. Once such processes are initiated, then the Science IDEAS implementation should work toward encouraging the district to apply the methodological enhancements for the evaluation of school reform described in earlier sections in order to document the effectiveness of the intervention.

The initial second barrier is that when beginning the implementation of the model, teachers need substantial initial professional development and follow-up support that continues in a diminished fashion over a three-year period. In general, teacher implementation of the Science IDEAS elements at the classroom level has not been a major problem. This is because the elements themselves have been refined so that they are natural for teachers to use within classroom settings. In this sense, the Science IDEAS model is easy for teachers to implement. The problem from a paradigmatic perspective, however, is that the majority of elementary teachers have only a minimal background knowledge of science at best. This is a major implementation barrier to overcome because Science IDEAS is a knowledge-based model in which the conceptual structure of the discipline provides the framework for classroom instruction. In addressing this barrier, we have been successful in focusing a major part of professional development and follow-up support on teachers gaining a firm understanding of the science to be taught so that they are able to plan concept-focused multi-day lessons and, eventually, work collaboratively to develop grade-articulated science curriculum frameworks at their schools. Additionally, the project also has developed and is presently refining curriculum resource "binders" in support of teacher curricular planning. As teachers gain greater understanding of science, this initial issue is resolved and teachers typically report that the Science IDEAS model is a natural approach to teaching. Further, the project development of the teacher leadership cadre provides the means to insure that all schools, even those initiating use of the model, have teachers on-site who can demonstrate effective classroom instruction using the Science IDEAS model. In fact, the combination of continuing professional development and support and the teacher leadership cadre are the basic project scale up mechanisms for the capacity development necessary to sustain and expand use of the model.

The third and final barrier to be mentioned has to do with the question of "value". As discussed previously, instantiating the range of benefits to students, teachers, principals, and central administrators so that they fit within or enhance the district-adopted value structure is an essential component for sustainability. Also as noted, the project is presently working on replicable strategies through which this critical outcome can be accomplished.

Major interdisciplinary implications for the Science IDEAS model. The interdisciplinary perspectives presented in earlier sections have significant implications for the pursuit of school reform by educational practitioners. Overall, the idea of knowledge-based instruction in conjunction with a grade-articulated, core-concept oriented curriculum provides a framework that would establish any systemic reform initiative as "curriculum-based". Moreover, in operation, such a curricular framework would provide the degree of structure that is necessary (a) to insure that the forms of instruction used result in cumulative, meaningful learning and (b) to insure that the methodological innovations for reform evaluation could be applied.

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 Science IDEAS model. As applied to the area of science, 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 to maximize comprehension of "new" content to be taught.

3. Focus instruction on core disciplinary concepts (and relationships) 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).

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, use IF/THEN principles to predict outcomes, apply 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 developing proficiency in reading comprehension and written communication.

Through iterative development, Science IDEAS has evolved to a stage at which each of the preceding eight principles are addressed in the model. Doing so has primarily been an engineering process through which each of the basic elements has been refined so that teachers are able to use them successfully in classroom instruction. At the same time, however, as noted previously, in order to optimize the effectiveness of classroom teaching, instructional planning must follow from a well-designed, grade-articulated, curriculum framework. In this sense, the Science IDEAS elements for classroom instruction are curricular in the sense of being consistent with the operation of a knowledge-based model. The impact of the Science IDEAS model upon student reading comprehension alone depends only upon focusing the basic Science IDEAS elements on the science concepts about which students are to gain in-depth understanding. However, the efficient cumulative development of student science knowledge across grade-levels necessarily requires an associated grade-articulated, conceptually-oriented curriculum.

DETAILED OVERVIEW OF THE SCIENCE IDEAS MODEL

The Science IDEAS model was initially validated within a grade 4 upper elementary setting (Romance & Vitale, 1992) and subsequently broadened across ethnically and academically diverse classroom settings (Romance & Vitale, 2001, 2008; Vitale & Romance, 2006). Because the Science Ideas model is implemented schoolwide for the entire year across grades 3-5, students who remain at the participating schools experience three years of in-depth science instruction which impacts science learning outcomes. The net effect is that by 5th grade, teachers are able to offer a far richer science curriculum because students enter their classrooms with more prior knowledge than ever before. Additionally, in many Science IDEAS schools (see following section), K-2 teachers are implementing an adaptation of the model. In these schools, the cumulative growth of in-depth science learning (and the associated growth of literacy proficiency) would be further accelerated. The K-5 implementation of Science IDEAS has the effect of making in-depth science instruction a schoolwide focus and serves as a motivator for all aspects of school operations and events (e.g., family science night, field-trips, special assembly programs, and for resources purchased for instruction) for students, teachers, and parents.

As an integrated instructional model, the Science IDEAS architecture combines science, reading comprehension, and writing through multi-day science lessons that integrate the six Science IDEAS instructional elements within a conceptually-organized science curriculum framework that serves as the basis for identifying, organizing, and sequencing all instructional activities (e.g., Donovan et al 2003; Romance & Vitale, 2006; Vitale & Romance, 2006b) in an authentic fashion necessary for promoting deep and meaningful student understanding of core science concepts.

Requirements of the Science IDEAS Model

As a validated instructional intervention, the Science IDEAS model is based upon an explicit set of requirements designed to insure quality implementation across multiple sites. The key project requirements focus on (a) scheduling of instruction within the school, (b) monitoring fidelity of implementation, (c) development and subsequent leadership by school administrators and a teacher leadership cadre, and (d) school participation in project evaluative activities.

Scheduling instruction: A key component in capacity building for sustainability is the ability of schools to implement the model as designed in order to replicate the original research findings (see Romance & Vitale, 2001) by involving learners in in-depth science. In meeting this requirement, schools establish a schedule that earmarks 1 ½ hours daily for science (with integrated reading/writing) across grades 3-5. Further, the project emphasizes the importance of maintaining instructional coherence by reducing the number of students (e.g., ELL, ESE, Title I) pulled-out of class during the Science IDEAS instructional block.

Monitoring fidelity of implementation: In order to insure consistency across classrooms in implementation of the Science IDEAS model, all participating schools are required to enroll their teachers in a comprehensive professional development program consisting of an initial two-week Summer Science Institute designed to accelerate teacher science knowledge and skill in using/integrating the elements of the model within the context of teaching science. Following the initial institute, teachers participate during the first and second years of the project and subsequent summers in on-going professional development opportunities as a support for and enhancement to their implementation of the Science IDEAS model within their classrooms. In monitoring teacher fidelity of implementation, the project utilizes several approaches, including school/classroom visitations by project staff, teacher reflective surveys of fidelity, principal clinical judgment, and informal input from teacher leadership members. Summary reports of clinical findings were shared twice annually with principals and annually with area administrators.

Leadership support for project implementation. In building school capacity, the project has emphasized developing the role of school based leaders in supporting and monitoring the program. For example, periodic principal seminars addressed issues of schedule maintenance, reduction of pull-outs, monitoring teacher fidelity, assuring adequate resources including non-fiction trade book libraries, establishment of a schoolwide K-5 science curriculum articulation committee, involvement of media specialist and other support personnel, and incorporation of Science IDEAS goals into the school's improvement plan.

Participation in project evaluation activities. All participating schools are required to cooperate with the project's research plan for assessment of student learning outcomes in science and reading comprehension through use of the Iowa Test of Basic Skills (ITBS) and a project survey of student science attitude/self confidence. District collaboration also is obtained to arrange for evaluative testing in control schools. The clearly delineated set of requirements provides the guidelines necessary to insure quality implementation of the project and has helped to avoid school adoption of competing instructional initiatives.

Six Elements of the Science IDEAS Model

The Science IDEAS model includes a set of six complementary instructional elements (e.g., hands-on experiments, reading comprehension, propositional concept mapping, journaling/writing, application activities) that teachers sequence across concept-focused, multi-day lessons to support student conceptual understanding of the science concepts being taught. In determining how to sequence instruction using the six elements, teachers consider three important facets that directly impact learning: (a) the conceptually-organized and sequenced set of concepts and relationships to be taught, (b) where students are positioned within the curricular sequence, and (c) student levels of pre-requisite knowledge needed to support learning of the science concepts.

In general, all instruction is preceded by teacher assessment of relevant student prior knowledge and/or cumulative review. In explicating how the Science IDEAS architecture actually functions in an instructional sequence, the evaporation concept map in Figure 1 illustrates how the elements might be ordered to engender deep and meaningful understanding of science and student reading comprehension proficiency. In considering the sequence of activities shown in Figure 1, it is important to recognize that this is one of many possible instructional sequences and multiple sets of elements (e.g., teachers could include more reading comprehension activities and or more hands-on activities).

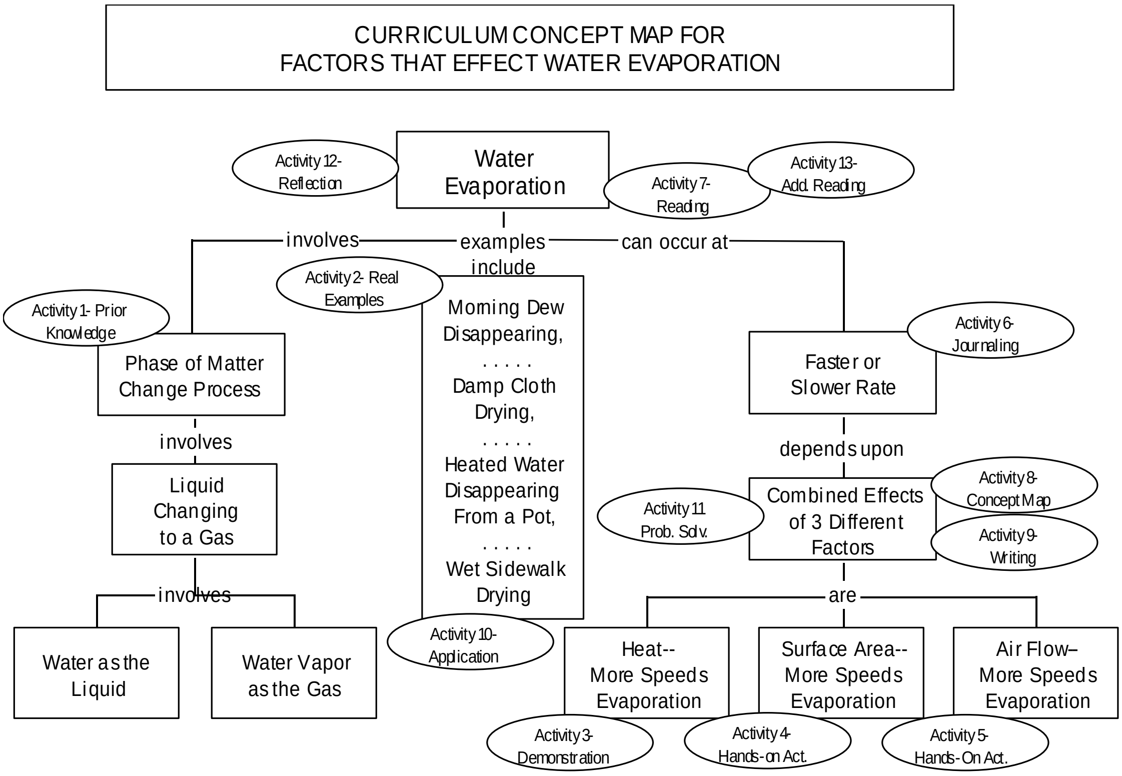

Figure 1. Simplified illustration of a propositional curriculum concept map used as a guide by grade 4 *Science IDEAS* teachers to plan a multi-lesson sequence of instructional activities.

The following offers a description of how the different elements in Figure 1 have been ordered for instructional purposes. Note that in the example in Figure 1, ovals indicate the order in which the different elements for instruction will be used while boxes represent the conceptual content of the activities. As noted previously, some elements appear several times in the lesson.

Prior knowledge and Cumulative Review. Once the conceptual framework for instruction has been established (i.e., organization of concepts associated with learning about evaporation), instruction begins by querying students to determine their prior knowledge about their understanding of phase change in matter and how water is transformed into a gas, water vapor (Activity 1). Next, given sufficient background knowledge, teachers highlight/discuss/review and/or direct student attention to everyday scenarios in which they directly observe evaporation (Activity 2). Such engagement promotes classroom discussion about evaporation and invites students to reflect on how and why evaporation occurs in the examples.

Hands-on Activities/Inquiry/Investigations. After having established the conceptual context for learners, the teacher guides student understanding of the factors associated with the rate of evaporation by engaging them in hands-on activities that encourage student generation of plausible explanations as to how the rate of evaporation can be changed or an explanation of the impact of the factors on the rate itself (Activities 3-4-5). As students gather data and evidence, they are guided in terms of how to use the evidence to support a claim or offer an argument. As with all activities, teachers model for students how to link experiences to the concept (s) being learned and/or relevant everyday encounters. As an important strategy to engender in-depth learning of the science concepts, teachers engage students in multiple related experiences on the same topic (e.g., three sets of activities depicting the effect of heat, surface area and air flow on evaporation). Multiple experiences encourage in-depth classroom discussion, reading more about the topic, and generating journal entries, all of which serve to insure student mastery of the concept relationships being taught.

Journaling Writing. Following the hands-on experiences in this example, students engage in a variety of writing formats (e.g., experimental report, qualitative descriptions of what they observed, construct labeled diagrams) in order to record their initial ideas, observations, questions, and the evidence gathered (Activity 6). Student journals become a source of great pride as they archive and organize what they have learned across multiple lessons and units. Student journals provide a longitudinal record of the topics being learned that, in turn, serves as cumulative evidence of the growth and sophistication of their thinking. Such journal records add a dimension of stability and permanence to children's work, something that is rare in education, particularly at the elementary school level. In related work, other researchers have suggested that science journals provide an instructional focus in which language, observations, and general experience operate jointly to form meaning for students while providing teachers with a window into student thinking processes across time (see Klentschy & Molina-De La Torre, 2004; Palincsar & Magnusson, 2001).

Reading Comprehension. Following the numbered sequence of ovals depicted on the evaporation concept map (Figure 1), teachers would implement the Science IDEAS reading comprehension strategy (Activity 7). In using this strategy, students are guided to access relevant prior knowledge as a means for understanding what they are reading. In turn, students summarize and link each paragraph to the previously read paragraphs in a manner that cumulatively builds conceptual understanding. As with all other Science IDEAS elements, the reading comprehension strategy is first modeled by the teacher and then followed by guided and independent practice by students. In preparation for using the strategy, teachers pre-read the selection in its entirety, reflectively determine what they know about the topic that makes key components of the passage understandable to them, and then transform the prior knowledge they have identified for the key components into questions ("knowledge notes") that can be used to guide student reading. As students read the passage, the teacher guides student comprehension using the knowledge-note questions as a basis for discussing the passage with the students, while modeling and guiding summarization within and across paragraphs, pages and/or sections within a text. In doing so, the emphasis of the strategy is to illustrate how prior knowledge (and understanding) supports new learning and how it combines with new knowledge to deepen learning through reading. As a result of such comprehension, students are able to identify the main idea of a selection. In effect, selecting the main idea is the result of comprehension.

Unlike general reading instruction where students are told to find the main idea, the Science IDEAS model provides students with guidance in their use of prior knowledge (and other learning experiences) as they cumulatively deepen their understanding of the topic. As a result of using the strategy, students are able to build in-depth comprehension of the conceptual content that enables them to identify causal relationships, compare and contrast characteristics of objects or events, sequence steps in a process, and problem solve in order to generate explanations. The next step in applying the strategy involves students re-reading the passage in order to identify the key concepts and concept relationships. In turn, the key concepts and relationships are recorded on postit notes for later use. Throughout the reading/language arts component of each lesson, students select and read multiple sources on the same topic (e.g., other non-fiction trade books, related literature, web pages, reference materials) as a means to deepen their knowledge and build a sense of expertise through advanced meaningful learning. Within the Science IDEAS model, science learning is enhanced by embedding multiple sources (Activity 13) of content-area reading materials in science teaching in a manner that builds upon the synergistic relationship between and supports student learning in both science and reading comprehension.

Propositional Concept Mapping. In Science IDEAS, propositional concept maps (Activity 8) provide a means for students to organize the concepts being learned, serve as a blueprint for writing and as a tool for review. As Figure 1 shows, unlike other graphic organizers, propositional concept maps are organized hierarchically and represent science concepts that are linked together using verbs and verb phrases in order to construct concept relationships in the form of complete sentences. In general, the process for constructing concept maps involves writing the conceptual content on postit notes (typically generated in the reading strategy), arranging the notes in a hierarchically meaningful fashion, and then adding the links. An important aspect of this process is the discussion among students regarding the concept relationships and how they are organized coherently.

In addition to providing an instructional guide for teachers, the concept map on evaporation in Figure 1 serves as an example of the type of map students would first be guided to create and then later encouraged to construct themselves. To do this, teachers would model and/or guide the process multiple times (e.g., at least three to five times) before students are encouraged to work in collaborative groups of two and create their own concept maps. Student generated concept maps are usually focused on a topic that has been recently taught in-depth and serve as an organizational review. As a final step in the process, teachers model how to use the propositional concept map as a blueprint for expository writing with specific emphasis on how it supports the development of coherently linked paragraphs, thus greatly improving student writing proficiency (Activity 9).

Application Tasks. As the lesson progresses, teachers provide students with opportunities to expand and deepen their understanding by engaging in different types of expansion tasks (e.g., applying the concepts learned to new situations; conducting new open-ended investigations) that are designed to apply what has been learned to novel contexts (Activity 10-11-12). Within Science IDEAS, application tasks are an important way of encouraging students to learn more about what they have been learning.

In summary, the details of the instructional sequence presented in Figure 1 illustrate how a coherent curricular framework provides an instructional guide to effective student in-depth learning in science and reading comprehension and how Science IDEAS operates as a knowledge-based model. As such curricular structures are articulated across grade levels, student cumulative mastery of science concepts can be considered as a form of knowledge-based expertise in which the development of organized prior knowledge serves as the most critical determinant of future success in meaningful learning across all varieties of instructional tasks, including reading comprehension.

Some Characteristics of Mature Science IDEAS Implementations

As the implementation of the Science IDEAS model evolves, teachers are able to engage in a variety of mutually supportive initiatives. Included among these are continuing efforts to refine and enhance their grade-level planning and the schools K-5 curriculum articulation process. Both of these insure that students experience a conceptually coherent curriculum in which in-depth science instruction using the Science IDEAS elements are embedded. Paralleling this is the capability of experienced Science IDEAS teachers to orient and provide ongoing mentor support to teachers new to the school. In addition to sharing approaches for improving Science IDEAS instruction in their own schools, teachers also engage in collaborative activities between schools and in presentations at the state and national level. In general, Science IDEAS has been an effective vehicle for supporting the professional growth of participating teachers.

Another important characteristic of Science IDEAS schools is the display of student work (e.g., writings, graphs/pictures, concept maps, journals, scientific models, experiments, projects) in classrooms and throughout the school. Such displays are highly motivating to students and of great interest to parents and other visitors to schools. Finally, at the classroom level, both Science IDEAS students and teachers are highly motivated and engaged in the learning of science.

Research Evidence in Support of the Effectiveness of the Science IDEAS Model

The proposition that replicability of research findings in diverse settings is the goal of all scientific enterprises (e.g., Sidman, 1960) provides a framework for interpreting the multi-year findings associated with the Science IDEAS model presented in this section. In a parallel sense, the multi-year findings are consistent with the concept of “patch” experiments and the associated implications for external validity outlined by Campbell and Stanley (1963). In this sense, the cumulative findings reported in this section provide an aggregate form of evidence of the effectiveness of the Science IDEAS model.

Although the cumulative research findings associated with Science IDEAS encompass a variety of student performance outcomes (e.g., affective judgments of students, qualitative observations of Science IDEAS classrooms, student-constructed products), this section is limited to student achievement outcomes as measured by nationally-normed standardized tests in science and reading.

With this in mind, the following sections overview student achievement outcomes associated with implementation of the Science IDEAS model reported in the literature and other professional outlets (e.g., papers) from 1992 through the 2006-2007 school year. Because the emphasis here is upon the pattern of findings, methodological details in the original sources are not presented here. However, it is important to note the methodological commonalities in all of the following overviews. First, all studies reported here were conducted in multicultural urban school systems in southeastern Florida having a wide range of student demographics (e.g., ability levels, ethnicity, parental income). Second, in each study, both student and school demographics (ability, ethnicity) of comparison groups were similar to those of the experimental groups. Third, the method of data analysis was a general linear models approach in which prior reading and/or science achievement were used as a covariate in a majority of studies. And, fourth, all student achievement outcomes reported here consisted of nationally-normed science (ITBS, MAT) and reading (ITBS, SAT) achievement measures.

Reported pattern of research evidence: 1992-2001. 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 (Romance & Vitale, 1992), three grade 4 classrooms in an average performing school implemented the Science IDEAS model over the school year. The achievement measures were ITBS Reading and MAT

Science subtests. 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 & Vitale, 2001).

In the third and fourth studies that followed (Romance & 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 & 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/classroom 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.

Reported pattern of research evidence: 2004-2007. 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 was composed of two different initiatives. The primary initiative (Romance & 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 13 over the 5-year project). The increasing number of such schoolwide interventions provided a framework for the study of issues relating to scale-up of Science IDEAS model through a project supported by the National Science Foundation. The second initiative consisted of two small-scale studies embedded within the overall scale-up project that explored extrapolations of the Science IDEAS model to grades K-2 (Vitale & Romance, 2007b) and as a setting for reading comprehension strategy effectiveness (Vitale & Romance, 2006).

This section overviews three perspectives on the effect of Science IDEAS on student achievement in science and reading (Romance & Vitale, 2008). Figure 2 shows the adjusted GE means for grade 4-5 Science IDEAS and basal reading classrooms during the 2003-2004 school year. After statistically equating students for differences on the preceding years state-administered FCAT Reading achievement, Science IDEAS students displayed significantly higher ITBS achievement on Reading and Science.

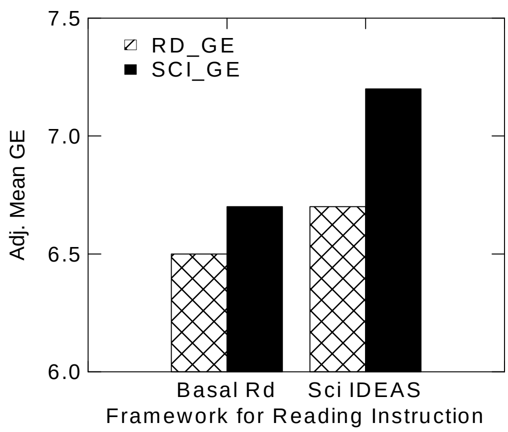

Figure 2. Adjusted grade-equivalent means on ITBS Reading and Science for Science IDEAS and Comparison (Basal) students.

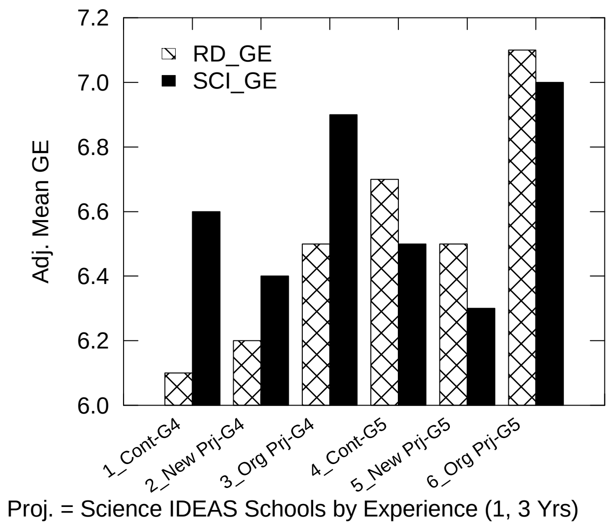

Figure 3. Adjusted grade-equivalent means on ITBS Reading and Science for Continuing and New Science IDEAS and Comparison (Basal) students.

Figure 3 shows the effect of Science IDEAS on student achievement in new and continuing project schools during the 2004-2005 school year. After statistically equating students for differences on the preceding year's state-administered FCAT Reading achievement, *Science IDEAS* students in schools with 3 years experience (N=4) displayed significantly higher ITBS achievement than basal reading schools on both reading and science. However, at the same time, results for *Science IDEAS* schools in their initial year (N=4) were varied, suggesting that more than 1 year for implementation experience is required before the *Science IDEAS* model is implemented with effectiveness.

Figure 4 shows the cross-sectional effect of Science IDEAS across grades 3-8 on ITBS science and reading achievement across 13 participating and 12 comparison schools in 2006-2007. 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 expressed as extensions of the Science IDEAS or comparison school they attended in grade 5.

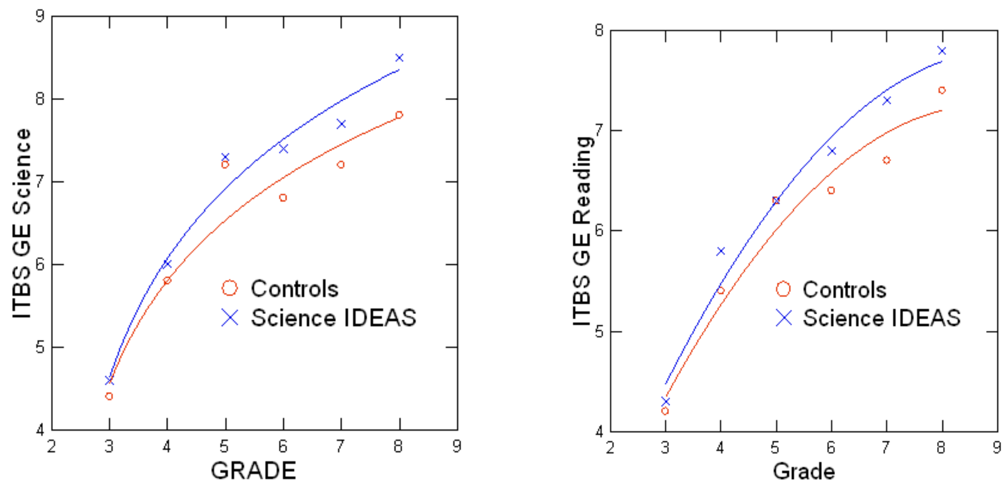

Figure 4 . 2006-2007 ITBS Achievement Trajectories for Science IDEAS and Control Schools in Science and Reading

In interpreting the science achievement trajectories in Figure 4, 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 reading achievement trajectories shown in Figure 4, 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).

Elaborative Science IDEAS mini-studies in K-2 and grade 5. The second 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 as a setting for reading comprehension strategy effectiveness. This section overviews the pattern of findings for these two scale-up initiatives.

The objective of the K-2 mini-study (Vitale & Romance, 2007b) 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 make the implementation of the grade 3-5 model more comprehensive on a schoolwide basis. 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 daily basal reading instruction. Results of a year-long study found an overall main effect in favor of Science IDEAS students on both ITBS science (+.28 GE) and reading (+.42 GE). However, for ITBS reading, 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 & Romance, 2006) was to explore whether research-validated reading comprehension strategies (see Vitale & Romance, 2007a) would be differentially effective in the cumulative meaningful learning setting established by Science IDEAS in comparison to a basal reading instruction emphasizing narrative reading. After a 7-week intervention in which reading comprehension strategies were implemented in Science IDEAS and basal reading instruction in accordance with a 2 x 2 factorial design (with prior state-administered FCAT reading as a covariate), 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.

Summary of the pattern of Science IDEAS research findings. The major conclusion from the multi-year pattern of findings is that Science IDEAS 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, Romance, & Klentschy, 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. All of these findings, though promising, require subsequent replication. Overall, however, 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 & Vitale, 2006).

Other Research Initiatives Linking Science and Literacy

Although an exhaustive list is beyond the scope of this paper, some ongoing research initiatives relevant to the present literature and to the Science IDEAS model are important to mention. These are grouped separately in the reference section to facilitate access. Cervetti and Pearson (2006) have reported the results of studies addressing the role of reading in the service of learning science through their "Roots and Seeds" curriculum. Within their model, students first participate in hands-on hands-on experiments to illustrate science concepts which are then followed by science reading assignments. Duke and her colleagues (Duke, 2000b, 2007; Duke et al., 2002) conducted a series of studies using informational texts in primary grades. These studies addressed an important instructional deficiency identified in earlier work in which Duke (2000a) 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 Maniates & Pearson, 2008; Pearson & Fielding, 1995).

In research closely related to the Science IDEAS model, Guthrie and his colleagues (Guthrie & Oztgungor, 2002; Guthrie, Wigfield, Barbosa, & Others, 2004; Guthrie, Wigfield, & Perencevich, 2004) have conducted a series of studies showing consistent improvement in student reading comprehension and motivation-to-learn resulting from embedding science-focused instructional modules into traditional reading programs using their CORI model. In a broader instructional intervention working with ELL students across grades K-6 for whom science instruction replaced traditional reading/language arts, Klentschy (2003) showed that grade 6 students who participated in the initiative for 4 or more years averaged a percentile rank of 64 on a state-administered nationally-normed reading test. Complementary essays by Hirsch (1996, 2006) addressed the cumulative learning of academic content as a major systemic deficiency in U.S. elementary schools.

In other supportive research, Palincsar and her colleagues (Hapgood, Magnusson, & Palincsar, 2004; Hapgood & Palincsar, 2007; Magnusson & Palincsar, 2003; Palincsar & Magnusson, 2001) have conducted studies investigating the interdependency of hands-on activities and reading about the science concepts related to their hands-on activities on student science and literacy performance. McNamara & Kintsch (1996) studied the role of text cohesiveness as a primary factor influencing comprehension. And Weaver & Kintsch (1995) reported investigations of the role of prior knowledge in comprehension.

As a representative sample of related work, all of these studies are consistent with the general interdisciplinary foundations of the Science IDEAS model.

OVERALL IMPLICATIONS FOR SCHOOL REFORM

The perspectives presented in this paper are suggestive of a variety of implications for school reform because, together, they are suggestive of the means through which school and school systems could pursue the raising of their achievement expectations of student academic performance.

First, from interdisciplinary research, the idea of knowledge-based instruction as a means for providing a framework for sound instruction and the idea of the importance of in-depth, content area learning as a necessary basis for reading comprehension development are implications that are paradigmatically different from present school practices.

Second, from research on scale up, the idea of engineering the development of the organizational infrastructure and internal expertise (as capacity) necessary to initiate, sustain, and expand the implementation of research-validated instructional interventions are implications that are paradigmatically different from present school practices.

Third, from the analysis of evaluative reform methodology, the ideas of enhancing test design to focus on content-area understanding (vs. generic reading skills), disaggregating student data based upon longitudinal enrollment status, and linking achievement progress to a cumulative curricular sequence are implications that are paradigmatically different from present school practices.

Although the paper presents additional supporting details, if a school system were to pursue these major implications, then, as a measure of progress, the direction of school reform would be paradigmatically different. If the supporting research is any indicator, such re-directed school reform initiatives could yield a greater degree of systemic improvement in the academic performance of all students. Although working toward the implementation of such research-based implications is necessarily a significant challenge, given the present state of progress in education reform, accepting such challenges is a better alternative than simply pursuing "more of the same" (see Walsh, 2003).

Within the preceding context, the Science IDEAS model, along with other related research initiatives noted in the preceding section, has the potential to contribute positively toward school reform. Specifically, as a research and development initiative, Science IDEAS addresses the first two sets of implications reflecting interdisciplinary and scale up perspectives. Although the Science IDEAS model itself would always implemented within the operational structure of a school system, the components that comprise the model are sufficiently well-formed to engender the application of the evaluative methodological enhancements in the third set of implications. In this sense, as a paradigmatically different approach for embedding reading comprehension and writing within in-depth science instruction, Science IDEAS offers school practitioners a research-validated alternative to increase student achievement expectations that, potentially, would positively impact different aspects of student learning across the K-12 grade range.

REFERENCES

References in this section are grouped into three parts. The first shows the complete references for the supplementary materials listed in the paper. The second consists of the specific references for related research that parallels the goals of the Science IDEAS model. The third includes all other references cited in the paper.

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1. 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.

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