A Research-Based Instructional Model for Integrating Meaningful Learning in Elementary Science and Reading Comprehension: Implications for Policy and Practice

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An emerging trend in education is the attempt to dynamically link ongoing research initiatives for advancing the quality of K-12 teaching and learning with the more generally evolving process of systemic school reform (e.g., No Child Left Behind – NCLB; Secretary's Summit on Science, 2004). In advocating an operational strategy that integrates and applies paradigmatically different interdisciplinary research perspectives (e.g., Bransford et al., 2000) to the persistent problems of science education reform, the objective of this paper is to raise the awareness of educational practitioners, researchers, and policy developers regarding the mechanisms associated with advancing and the potential for in-depth meaningful learning in science as a critical element in furthering school reform efforts, in general, and science education at the elementary level, in particular. This broader perspective departs from current elementary education reform efforts that emphasize the improvement of achievement outcomes in literacy (e.g., reading comprehension, writing) as ends in themselves rather than as the means for furthering meaningful learning in content domains (e.g., science). In addition, reformers have seriously neglected addressing issues associated with aligning meaningful learning outcomes with the combination of a conceptually coherent and well-articulated curricular structure in science and advancements in interdisciplinary research having implications for the quality of instruction. Further, building school capacity to sustain any such systemic science education initiative is necessary for producing desired achievement outcomes (Romance & Vitale, 2007).

In addressing these issues, this paper offers a set of interdisciplinary perspectives and evidence about how a researched-based instructional model, Science IDEAS (and several related initiatives) implemented within a multi-year timeframe, can provide a framework for identifying key research and policy issues associated with achieving meaningful, in-depth science learning in K-5 classrooms in a manner that also furthers the literacy development of all students. Such an integration of interdisciplinary views, all relevant in different ways to the three aspects of science education (student learning, teaching, research), have the potential to accelerate advancement of the understanding of meaningful learning in science, even in the face of resistance from other curricular domains competing for instructional time (e.g., reading). With the preceding in mind, this paper consists of the following sections: (a) achievement trends and issues in science education reform, (b) consensus research perspectives about meaningful learning in science, (c) representative research demonstrating the importance of science instruction in elementary (K-5) settings, (d) the Science IDEAS instructional model, (e) evidence in support of the effectiveness of the Science IDEAS model, and (f) directions and implications for systemic education reform.

Achievement Trends and Issues in Science Education Reform

Despite numerous panel reports and studies about the quality of science in the US, student achievement in science (and reading comprehension) has remained a systemic problem (e.g., Lutkus, et al, 2006; NAEP 2003, 2005). When reaching high school, many students representative of all SES strata do not have sufficient prior knowledge in the form of conceptual understanding necessary to perform successfully in secondary science courses. It is not surprising that the lack of instructional time devoted to in-depth science teaching in elementary schools (see Dillon, 2006; Jones et al., 1999; Klentschy & Molina-De La Torre, 2004) has been identified as one of the issues that is key to successful school reform in science (Hirsch, 1996; Vitale, Romance, & Klentschy, 2006) and to reading comprehension (Chall, 1985; Guthrie et al., 2002). Within a framework of school accountability, a predominant reform strategy has been to increase the time allocated to basal reading programs by reducing the instructional time allocated to science, especially for at-risk students most dependent upon school to learn. In fact, recent evidence (2008 USDOE/IES Reading First Report) suggests that the increased instructional time at the primary grades (K-3) allocated for instruction in the five elements of literacy (National Reading Panel, 2000) and the preparation of students for non-content-oriented reading tests has not significantly impacted achievement outcomes in reading comprehension for grade 3 students, as was predicted.

Representing views addressing such science and literacy concerns, Duke and Pearson (2002) noted that there is little involvement in ‘doing’ science and reading informational text at the primary level and that many teachers erroneously believe instruction in science comprehension must wait until students become proficient decoders in reading. In addition, Duke and Pearson also refuted major unsupported beliefs that serve as barriers to both science teaching and use of informational text at the primary grades. In general, it is important to recognize that K-2 instructional interventions which emphasize the development of meaningful knowledge in science are becoming consistent with emerging literacy trends (Palmer & Stewart, 2003) that emphasize the use of informational text for developing background knowledge and comprehension proficiency at the primary levels (see also Holliday, 2004; Klentschy & Molina-De La Torre, 2004; Ogle & Blachowicz, 2002; Gould, Weeks, & Evans, 2003, for related views).

It is no surprise, then, that lack of emphasis on science at the elementary level effectively withholds opportunities for meaningful science learning for all students across grades K-8. The negative effect of such curricular decisions is further magnified when struggling (at-risk) learners are enrolled in high school science content courses and likely is a major contributor to the “Black-Hispanic-White” test gap in science (e.g. NAEP 2005). Although the short-term pressures of accountability might be difficult for elementary schools to overcome, of even greater importance are the long-term curricular implications that serve as barriers for preparation of students for high school science courses and general reading comprehension that ultimately become manifest at the high school level (NAEP, 2003, 2005; Snow, 2002).

A second, related issue identified as a result of a review of trends in research by science educators in scholarly journals, handbooks and textbooks revealed a surprising finding (Vitale & Romance, 2007c). In fact, relatively few of the studies in science education were found to involve experimental (or field experimental) research that demonstrated the effects of approaches to or characteristics of science instruction on meaningful conceptual understanding by students in regular school settings. Rather, as Vitale and Romance found, the majority of science education research described teacher experiences in science instructional settings, teacher frustration dealing with student misconceptions, and the use of science as a context to deal with other issues such as inquiry/questioning and diversity. In marked contrast, interdisciplinary research from cognitive science and instructional psychology presently offer rich perspectives and findings that bear directly on the improvement of science teaching and learning. The next section addresses these findings in terms of their implication for improving student meaningful understanding of science.

Consensus Research Perspectives about Meaningful Learning in Science

Current interdisciplinary research related to meaningful learning summarized in the National Academy Press, *How People Learn,* (Bransford et al., 2000) provides a foundation as to why and how early conceptual understanding in content domains such as science establishes the prior knowledge and eventual organizational knowledge-structure necessary to support all future learning while also serving as a core element in literacy development (e.g., reading comprehension as a form of understanding, coherent writing). In their overview, Bransford et al summarized established research studies of experts and expertise as a unifying concept for meaningful learning. Such studies have repeatedly established that in comparison to novices, experts demonstrate a highly-developed organization of knowledge that emphasizes an in-depth understanding of the core concepts and concept relationships in their discipline (i.e., domain-specific knowledge) that, in turn, they are able to access efficiently and apply with automaticity. Although the instructional implications of such a perspective (discussed below) are highly supportive of the importance of building student conceptual understanding in science, these same implications are in direct conflict with present trends in elementary education that advocate emphasis on narrative, non-content reading and an over-emphasis on skills and test preparation (e.g., Hart & Risley, 2003; Hirsch, 1996, 2003; Walsh, 2003).

In the following sections, a combination of theoretical perspectives and empirical findings are presented as a way of emphasizing the factors associated with conceptual understanding within a domain of knowledge, how this framework can, in turn, support the relevancy of in-depth elementary science instruction to the development of desired student achievement outcomes in science and reading comprehension, both of which are critical reform goals under NCLB, and, finally, how the Science IDEAS model presented in this paper can serve as an exemplar of such learning.

In considering disciplinary expertise as a foundation, the notion of knowledge-based instruction provides a methodological perspective for approaching curriculum and instruction in a conceptually-coherent fashion. More specifically, cognitive scientists (e.g., Kearsley, 1987; Luger, 2002) have noted that the distinguishing characteristic of knowledge-based instruction models is that all aspects of instruction including (a) the determination of learning sequences, (b) the selection of teaching methods, (c) the specific activities required of learners, and (d) the evaluative assessment of student learning success are related explicitly to an overall design representing the logical structure of the concepts within the subject-matter discipline to be taught. Such a curricular structure optimally parallels the knowledge-organization of disciplinary experts.

As an illustrative example, Vosniadou (1996) suggested that concepts have a relational-nature which influence their order of acquisition. Yet, in her analysis of astronomy units in elementary texts in both Greece and the US, she noted major gaps in the presentation of concepts that, in turn, confound both the learning of the concepts being presented and those that follow. Not surprisingly, such situations are exacerbated by elementary teachers' lack of content knowledge in science. Similarly, the emphasis by Bransford et al (2000) on expertise is consistent with an explicit curricular focus on core concepts and concept relationships and the enhancement of prior knowledge as being of paramount importance for meaningful learning (see also Schmidt et al., 2001). Further, the emphasis by Bransford et al on disciplinary expertise in learning and performance amplified the importance of a curricular emphasis that develops both conceptual understanding and use of knowledge in application tasks (e.g., analyzing and solving problems).

As characteristics of meaningful learning processes, the preceding emphasizes the extensive role of varied experiences (i.e., practice) that focus on curricular knowledge in the form of the concept relationships to be learned as critical to the development of the different aspects of automaticity associated with expert mastery in any discipline (see Anderson, 1992, 1993**)**. In related research, Sidman (1994) and others (e.g., Artzen & Holth, 1997; Dougher & Markham, 1994) have explored the conditions under which extensive practice to automaticity focusing on one subset of concept relationships can result in additional subsets of relationships being learned without explicit instruction. In these studies, the additional relationships were not taught, but rather were implied by the original set of relationships that was taught (i.e., formed equivalence relationships). In other work, Niedelman (1992) and Anderson (1996) have offered interpretations of research issues relating to transfer of learning that are consistent with a knowledge-based approach to learning. Considered together, these findings represent a set of perspectives on what constitutes meaningful learning (in science) that must be strategically linked to the use of age-appropriate instructional interventions in order to engender meaningful learning in science.

Because the disciplinary structure of science knowledge is highly coherent, cumulative in-depth instruction in science provides a learning environment that is well-suited for the development of understanding. As such, a coherent curricular structure naturally incorporates critical elements associated with the development of curricular expertise by students (e.g., acquisition and organization of conceptual knowledge, experiencing a potentially wide range of application experiences that provide varied practice in learning). And, in turn, with the active development of such in-depth conceptual understanding serving as a foundation (e.g., Carnine, 1991; Glaser, 1984, Kintsch, 1998; Vitale & Romance, 2000), the use of existing knowledge in the acquisition and communication of new knowledge provides the basis for engendering meaningful learning outcomes in science as well as scientific literacy and general comprehension.

Representative Research Demonstrating the Importance of Science Instruction in Elementary (K-5) Settings

Building on the research in the preceding sections, a major emphasis in support of any sound K-5 science curriculum intervention is that science knowledge offers a meaningful context through which students are able to experience learning more about what is being learned in a fashion that enhances their capacity for understanding and in-depth learning (i.e., cumulative comprehension). As such, science conceptual knowledge deals with everyday events that students experience on an ongoing basis enabling students to (a) link together different events they observe, (b) anticipate the occurrence of events (or manipulate conditions to produce outcomes), and (c) make meaningful interpretations of events that occur, all of which are key elements of meaningful understanding in science (Vitale & Romance, 2000; Vitale, Romance, & Dolan, 2006).

Representative research in K-3. At the K-3 level, researchers (Conezio & French, 2002; French, 2004; Smith , 2001) reported the feasibility of curricular approaches in which science experiences provide rich learning contexts for an early childhood curriculum that results in science learning and early literacy development. Gelman & Brenneman (2004) have shown from the standpoint of feasibility how a preschool science program which incorporates guided hands-on activities can be used as a framework for instruction that engenders the development of subject knowledge in young children. In working with 3 to 6 year olds, Smith (2001) described how active involvement of young children in gaining science knowledge is naturally motivating (see also) if topics are approached with sufficient depth and time, a position consistent with the 1995 "National Science Education Standards" (see Rakow & Bell, 1998). Further Schmidt et al. (2001) characterized high-achieving nations as those having a conceptually coherent, meaningfully sequenced and well-articulated science curriculum across all grade levels for all students. Finally, within the context of children's learning in developmental psychology, Ginsberg and Golbeck (2004) suggested that those researching science learning as well as practitioners should be critically open to the possibilities of unexpected competence in young children (e.g., Revelle et al., 2002) perspectives related to those of Newton (2001) and Asoko (2002) and highly consistent with the importance of in-depth science instruction at the primary level (see also Sandall, 2003).

Representative research in grades 3-5. The building of student background knowledge for cumulative learning within a discipline (i.e., science) has been evidenced repeatedly by the extensive work of Guthrie and his colleagues (e.g., Guthrie et al., 2004; Guthrie & Ozgundor,

2002) with upper elementary students as having the additional benefit of enhancing student reading comprehension and motivation. In this regard, Armbruster and Osborn (2001) summarized research findings demonstrating positive student achievement in reading comprehension resulting from integrating science content with reading/language arts. Numerous other researchers (Beane, 1995; Ellis, 2001; Hirsch, 1996, 2001; Schug & Cross, 1998; Yore, 2000) also have also presented findings that support interventions in which core curriculum content serves as a powerful framework for building background knowledge and greater proficiency in the use of reading comprehension strategies. The research findings associated with the *Science IDEAS* model (presented below) also have demonstrated that replacing traditional reading/language arts with in-depth science instruction within which reading comprehension and writing are embedded consistently results in higher achievement outcomes in both reading comprehension and science on norm-referenced tests (Romance & Vitale, 1992, 2001, 2008).

The Science IDEAS Instructional Model

As a cognitive-science-oriented model, Science IDEAS in grades 3-5 exemplifies an in-depth, instructional approach (e.g., Mintzes et al., 1998) to science teaching and learning that emphasizes students learning more about what is being learned in a meaningful fashion. In doing so, the model is designed to prepare teachers for classroom instruction that engenders an in-depth understanding of both science concepts and the nature of science by students that is consistent with national science standards (e.g., AAAS, NRC) and articulated across grade levels. The architecture of the model involves sequencing different types of classroom activities (e.g., hands-on, reading, concept-mapping, journaling/writing) based upon a conceptually coherent framework of concepts (see Figure 1) consistent with recommendations in the literature (e.g., Donovan et al 2003; Romance & Vitale, 2006; Vitale & Romance, 2006b) that also provide the means for an embedded approach to assessment (e.g., Pellegrino et al., 2001; Vitale, Romance,

& Dolan, 2006). Implementation of the Science IDEAS model (see Figure 1) involves teacher construction of propositional concept maps representing the conceptual structure of the science concepts to be taught which, in turn, serve as the framework for identifying, organizing, and sequencing all instructional activities and assessments. Because of this requirement, Science IDEAS requires comprehensive professional development that focuses on increasing teacher science understanding and providing continuing teacher support in the form of apprenticeship and coaching (e.g., King & Newmann, 2001).

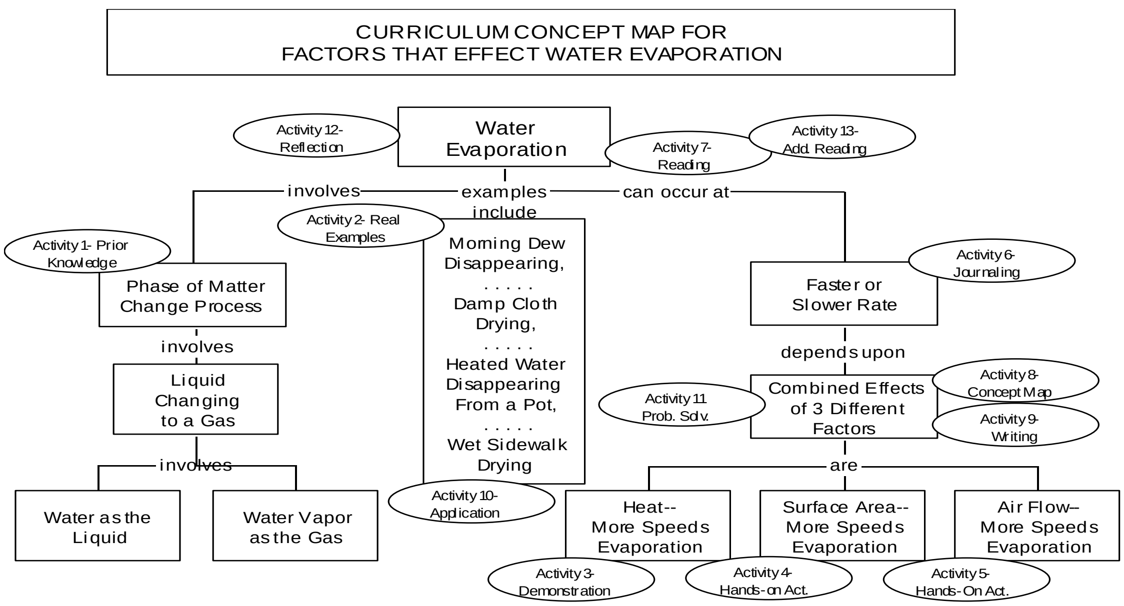

Figure 1. Simplified illustration of a propositional curriculum concept map used as a guide by grade 4 *Science IDEAS* teachers to plan a sequence of instructional activities.

Science IDEAS amplifies the importance of focusing all aspects of instruction on the cumulative development of student mastery of core concepts and concept relationships within a domain of knowledge (e.g., physical science, earth science, life science). Implementation of Science IDEAS involves a daily 2-hour block of time which replaces regular reading/language arts instruction across grades 3-5 and consists of multi-day science lessons which emphasize cumulative learning experiences. For example, referencing Figure 1, in teaching core concept relationships, teachers may use of variety of instructional approaches (e.g., hands-on science experiments, reading text/trade/internet science materials, writing about science, science projects, maintaining science journals, propositional concept mapping), all of which focus on enhancing science conceptual understanding (Romance & Vitale, 1992; 2001). Because Science IDEAS is an integrated instructional model, teachers are able to strategically embed science-based reading and language arts activities appropriately, thus linking in-depth science learning and reading comprehension (and writing) in an authentic fashion (see also Hapgood et al., 2004).

As an explicit support for in-depth learning, the Science IDEAS model emphasizes the use of student-constructed science journals for archiving all lessons and activities, posing questions, and communicating in varied formats (e.g., charts, graphs, summaries and conclusions, questions, illustrations) what has been learned. Additionally, student journals provide a chronology that serves as cumulative evidence of the growth and sophistication of student thinking, and, in doing so, adds a dimension of stability and permanence to children's work, something that is rather rare in education and particularly at the elementary school level. In support of this approach, Rivard (1994) has suggested that this form of "knowledge-focused" writing also supports student linkage of new information with prior knowledge while supporting student recording of science experiences as a natural part of science learning (Hapgood et al., 2004; Harlen, 1988). Thus, in Science IDEAS schools, all students participate in experiences that require them to collect and interpret data and observations, a strategy that helps them deepen their understanding of the science phenomena being observed (Harlen, 2001).

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. Such an approach is consistent with more recent complementary research (e.g., Klentschy et al., 2004; Magnusson & Palincsar, in press; Palincsar & Magnusson, 2001; Swan & Guthrie, 1999) that has emphasized that the integration of hands-on science activities (first-hand investigations) with reading and writing (second-hand investigations), rather than hands-on science alone, can result in increased student achievement outcomes in science and literacy.

Several other key aspects of the Science IDEAS model are important to note in terms of their contribution to meaningful student learning in science. Science IDEAS is a year-long intervention that is implemented schoolwide across grades 3-5 and, therefore, involves the articulation of multiple topics in science (e.g., matter, energy, force and motion, processes that shape the earth) across grade levels. In doing so, the architecture of the model enables learners to focus in a cumulative fashion on the core concepts and relationships which, in turn, provides the prior knowledge necessary for further in-depth learning to occur. As an example, key concepts related to matter and heat energy can be applied coherently across other topics in science (e.g., atmospheric and crustal movement), thus providing learners with extensive amounts of varied experiences (i.e., practice) focusing on the elaboration of concept relationships to be learned associated with age-appropriate mastery (e.g., Duschl et al., 2006). By way of contrast, current practices in elementary science typically repeat topics from one year to the next or teach lists of benchmarks with little, if any, elaboration.

An important aspect of Science IDEAS that impacts schoolwide science learning outcomes results from the fact that students who remain at the participating schools experience three years of in-depth science instruction. 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. This factor has been found to serve as a motivator for both teachers and students, each of whom have become more interested in addressing topics in science at a much deeper level.

Evidence in Support of the Effectiveness of the Science IDEAS Model

Overall Research Design

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 is upon the pattern of findings, the 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, for each study, both the student demographics (ability, ethnicity) of comparison groups matched those of the experimental groups, as did general school demographics. 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 studies 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, no significant effect was found for younger grade 4 at-risk students, indicating that the Science IDEAS intervention had a consistent effect across at-risk (vs. non-at-risk) student groups.

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, overall, grade 5 students outperformed grade 4 students while, in a similar fashion, regular students outperformed at-risk students. But, as in year 3, no interactions were found, indicating that Science IDEAS was effective consistently across 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, 2006a).

This section overviews 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.

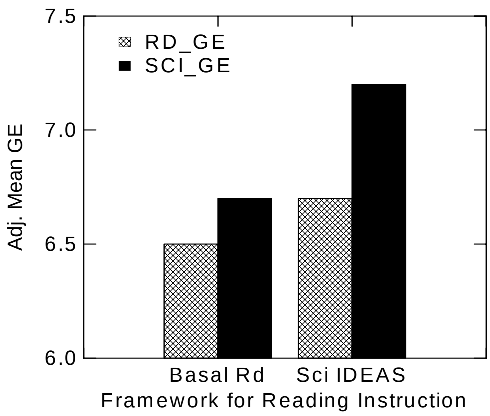

Figure 2. Adjusted grade-equivalent means on ITBS Reading and Science for Science IDEAS and Comparison (Basal) students.

Figure 3 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

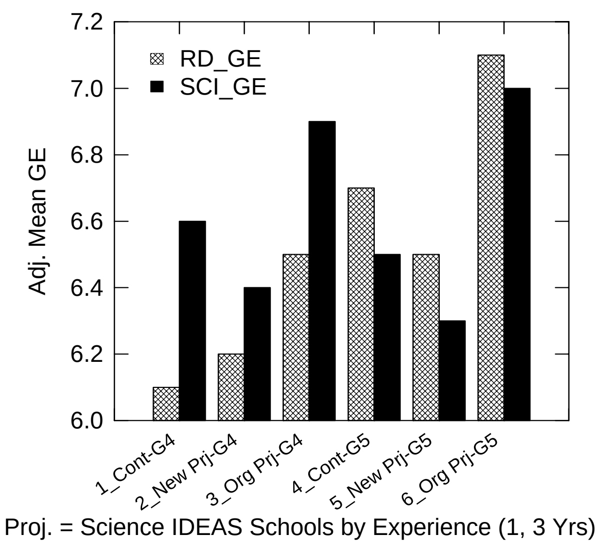

Figure 3. Adjusted grade-equivalent means on ITBS Reading and Science for Continuing and New Science IDEAS and Comparison (Basal) students.

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.

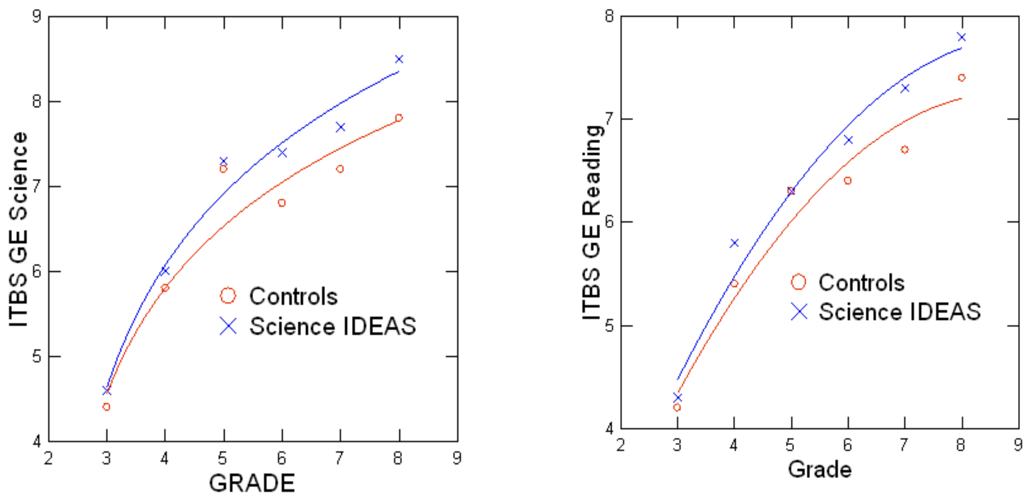

Figure 4. 2006-2007 Achievement Trajectories for Science IDEAS and Control Schools for ITBS Science and Reading.

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 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 schoolwide implementation of the model more comprehensive. Unlike the grade 3-5 model however, in grades K-2, teachers only incorporated a 45 minute science instruction block into their daily schedules but continued with 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. A 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, 2006a) 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 following 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 (i.e., use of the reading comprehension strategy by Science IDEAS student 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 based on the pattern of multi-year findings is that Science IDEAS has been shown to be 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 (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 are that (a) the effect of Science IDEAS is consistent for both regular and at-risk students, (b) the adaptation of the model for use in grades K-2 is feasible and (c) Science IDEAS, in emphasizing in-depth, conceptual learning, provides a more effective context for reading comprehension enhancement strategies than narrative-oriented basal reading materials. Overall, the multi-year research initiative involving Science IDEAS provides a strong pattern of evidence of the effectiveness of the Science IDEAS model in particular and the natural linkage of science and literacy in general (Romance & Vitale, 2006).

Future Directions and Implications for Systemic Educational Reform

The prevailing dominant curricular policy involving science and other content area instruction used by elementary schools for over 20 years of school reform has been to enhance student achievement on state-mandated reading assessments by replacing content area instruction with supplementary reading instruction for reading test preparation. At present, the combined instructional time allocated to traditional reading instruction and to reading test preparation is a stable curricular commitment to reform while the substantive content (e.g., science, social studies) of classroom instruction has received minimal policy attention (see Hirsch, 1996).

Within the context of standards-based school reform (e.g., AFT, 1997; Feldman, 2000), an apparent logical contradiction is that states demonstrating cumulative improvement in reading achievement in grades 3-8 as measured by state reading tests have experienced no corresponding student performance improvement at the high school levels (e.g., Florida, North Carolina). A number of complementary perspectives suggest that the substantial lack of success of reform at high schools can be readily understood. First, in content-oriented high school courses, student prior knowledge is a major determinant of successful learning (see Bransford et al., 2000;

Hirsch, 1996). In this sense, when students do not have the prior levels of understanding required for success, teachers are faced with the problem of replacing portions of high school courses with remedial instruction on the prerequisite knowledge students have not acquired in the preceding grades (K-8).

Second, the reason as to why students have not developed adequate prior knowledge in the elementary and middle school levels is that instruction at those levels emphasizes teaching practices as ends in themselves rather than meaningful student understanding of academic content (e.g., use of teaching strategies vs. core curriculum content mastery). In fact, "teaching reading comprehension" per se is a major curricular emphasis in grades 3-8, despite the fact that reading itself cannot logically function as a curriculum because, given the poor quality of school instructional materials (see Schmidt et al., 2001), content comprehension is highly dependent upon prior disciplinary knowledge (see Kintsch, 1998). In this regard, the problem is not with the concept of literature per se. Rather the problem is that the materials labeled as literature that schools use have minimal opportunities for developing meaningful understanding beyond the referencing of common student life experiences because they have no meaningful academic content by design (see Walsh, 2003).

To the detriment of long-term educational reform, the "opportunity cost" of allocating student instructional time to reading programs that emphasize non-academic, non-content materials is that such time replaces the opportunities for students to interact with the very forms of content-oriented instruction and reading materials that are necessary to provide them with the knowledgeable foundation necessary for future success in high school courses and to develop a potentially transferable proficiency in content-area reading comprehension. With this in mind, it is easy to understand why low-SES students who depend on schools to learn would be expected to perform poorly at the high school level unless they receive content-rich learning opportunities (e.g., Coleman, 1966). This illustrates the importance of Hirsch's (1996) views on why the lack of emphasis in the curriculum policy of elementary schools on the development of the prior knowledge of low-SES students has the effect of systemically withholding the exact form of intellectual capital they need for future academic success.

Overall, the implications of the preceding perspectives for school reform are as follows: (a) the preparation of students for successful meaningful learning in high school should be considered a major reform goal on which minimal progress has yet to be met, (b) the systemic problem explaining the lack of success achieving this goal is the popular misconception that reading is a curriculum in grades 3-8 (i.e., beyond the development of decoding and fluency in grades K-2), and (c) the replacement of academically-oriented instruction (such as science, social studies) that emphasize the meaningful development and subsequent utilization of conceptual prior knowledge with the non-academic "literature" materials common to "reading curricula" is a major barrier to successful educational reform. Given the research presented in this paper, if increasing time for in-depth instruction in science and other content areas is a remedy for addressing the above problem, then changing curriculum policy to increase the instructional time for in-depth science and other content area instruction at the elementary level has the potential to result in significant improvement in systemic educational reform.

In contrast to the common scenario in which reading displaces science and other content area instruction, the research presented here is supportive of why increasing the time allocated for teaching science (and, by inference other content areas) could help solve recognized school reform problems associated with reading comprehension and science while better preparing students for future high school success. In doing so, the fundamental theoretical perspective comes from knowledge-based instruction models from cognitive science and artificial intelligence whose structure is, in fact, highly curricular (see Vitale & Romance, 2000, 2006b).

As discussed here, these models require the specification of the conceptual content to be learned as a logical basis for providing a sound curricular context for both the instructional strategies and assessment methodologies used. In curriculum planning, the logical structure of the discipline (i.e., core concepts and core concept relationships) should be used to provide an organizational framework for specifying the sequence of the content to be taught and, therefore, for instructional strategies and assessment as well. Additionally, in knowledge-based instruction, all teaching activities should require students to relate what they are learning to previously learned core concepts or core concept relationships. As a result, knowledge-based instruction emphasizes the cumulative development of the forms of prior knowledge that enhance student success in new learning tasks.

In adaptations of knowledge-based instruction to science education, the *Science IDEAS* and related models for teaching in-depth science within which literacy goals are integrated concomitantly improved the reading comprehension, writing, and science achievement of highly diverse student populations by replacing traditional, basal-oriented reading/language arts instruction with in-depth science instruction. Considered in a schematic form, the preceding provides educators with a rationale for how expanding the time for in-depth science (and content area) teaching can improve high priority student achievement goals within a school reform/accountability framework through a dual focus: (a) the improvement of student general reading comprehension (and writing) and (b) the development of the prior knowledge students need to be successful in high school science and other content courses.

At the present time, this rationale has been applied successfully as a foundation for initiating *Science IDEAS* in an increasingly larger number of elementary schools (Romance & Vitale, 1992, 2001, 2008). In a complementary fashion, as part of an NSF-funded multiyear project to scale up *Science IDEAS*, the middle schools linked to elementary project feeder schools have further accelerated student achievement preparation for high school science courses. Considered together as successful applications of the rationale presented here, these initiatives should offer educators encouragement for advocating that increasing the time for in-depth science and other content area instruction would have significant implications for improving the success of educational reform in reading comprehension and high school achievement that are not likely to occur without a strong emphasis on content-oriented instruction at the elementary level.

A final matter considered here has to do with the tactics for gathering evaluative evidence in support of pursuing a change in curricular policy in advance of initiating such advocacy. In this regard, the most direct form of supporting data are cross-sectional student achievement trends (including reading comprehension) by grade level, from grade 3 (or earlier) through high school (at least grade 10). In this sense, curricular policy should consider high school achievement outcomes in grades 9-12 as reflecting the cumulative curricular effect of student learning throughout K-12, not just high-school specific instruction at grades 9-12. Complimenting such student achievement trends, additional evaluative information in the form of surveys (or testimonials) should be obtained from high school teachers of key academic courses offered in grade 9 regarding the extent to which their students begin high school with substantial deficiencies in prior knowledge that should have been addressed in earlier grades. Together, these two forms of information provide explicit support for the rationale for improving school reform by increasing the instructional time allocated for in-depth science and other content area instruction. Although the short-term effect of educational reform initiatives may have temporarily diminished the role of content area instruction at the K-5 elementary level, reflections on the present curricular policy that underlie persistent problems in educational reform may well provide educators with the opportunity to expand the role of science (and other) content area instruction at the elementary levels on a long-term basis.

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