INT. J. SCI. EDUC., 2001, VOL. 23, NO. 4, 373-404

RESEARCH REPORT

Implementing an in-depth expanded science model in elementary schools: Multi-year findings, research issues, and policy implications

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Summarized are research findings and policy implications obtained over a 5 year period (51 teachers, 1200 students) from the implementation of an in-depth expanded applications of science (IDEAS) model with average, above average, and at-risk students in grades 2-5. The IDEAS model replaced the time allocated for traditional reading/language arts instruction with a daily 2 hour time-block dedicated solely to in-depth science concept instruction which encompassed reading comprehension and language arts skills (e.g. concept-focused teaching, hands-on activities, utilization of science process skills, reading of science print materials, concept map construction, journal writing). The multi-year results revealed a consistent pattern of the model's effectiveness in improving both the science understanding (effects on the Metropolitan Achievement Test-Science ranged from 0.93 to 1.6 grade equivalents) and reading achievement (effects on the Iowa Test of Basic Skills-Reading and the Stanford Achievement Tests-Reading ranged from 0.3 to 0.5 grade equivalents). Participating students also consistently displayed significantly more positive attitudes and self-confidence toward both science and reading. Interpreting the findings, the IDEAS model was considered to provide clear evidence for the importance of focusing the teaching-learning process on the conceptual structure of the curricular knowledge to be learned in a fashion consistent with research and policy issues raised by the recent TIMSS study. Also discussed was the role of the IDEAS model as a means for linking theoretical perspectives from instructional design and cognitive science to science educational reform.

Introduction

A primary concern in the science education literature has been the ongoing discussion of policy and research issues relating to the understanding and improvement of science teaching and science learning (e.g. Linn 1987, Reif 1990, Shymansky and Kyle 1991, Yeany 1991, Wright 1992, 1993, Abd-El-Khalick and Boujauode 1997, Schmidt *et al.* 1997). Of particular importance in this regard has been the findings and interpretations of the recent Third International Mathematics and Science Study (TIMSS) which have emphasized the importance of the in-depth study of core curricular concepts (Schmidt *et al.* 1997). In reflecting and addressing these concerns, this paper consists of three sections. First, the paper presents a developing rationale that has served as a foundation for a multi-year research programme designed to explore the major facets of science teaching and learning within which the series of studies emphasizing In-Depth Expanded Applications of Science (IDEAS) are included. Second, the paper overviews and

International Journal of Science Education ISSN 0950-0693 print/ISSN 1464-5289 online
http://www.tandf.co.uk/journals

discusses the multi-year results of empirical studies conducted in a variety of elementary schools over the multi-year period to investigate the effects of the IDEAS model. And, third, the paper discusses the implications of the multi-year findings for research and policy issues that underlie the future improvement of science education in elementary schools.

Overview of the Research Programme

Rationale of the overall research programme

The overall programme rationale described in Vitale and Romance (1991, 1992a, 1995) and Romance *et al.* (1994b) is based on two interdependent concerns for using research to improve the process of science teaching in elementary schools. The first, conducting research to advance understanding of the science teaching process and the professional training of pre- and inservice teachers, addresses a key element in improving classroom teaching practices. However, despite its importance, such research alone is not sufficient to improve classroom teaching when there is inadequate time during the school day to teach science in the depth needed for students to master the core concepts and related concept applications within the science curriculum. In the same sense, simply increasing the amount of time for science instruction alone is not a sufficient condition for improving science learning without qualitatively modifying the classroom teaching-learning process. Clearly, in order for research to have an impact on classroom science learning, both the question of how to change teaching to make it better and the question of how to allow such changes to be implemented must be addressed concomitantly. Although beyond the scope of this paper, the portion of the overall programme emphasizing science teacher preparation is described in Vitale and Romance (1992a, 1992b, 1992c). Within the preceding context, investigations of the IDEAS model should be considered to address the question of identifying a practical means for expanding the time for science instruction in elementary classrooms which would allow an in-depth focus by students upon the science concepts and concept applications to be learned.

Rationale and description of the IDEAS model

The lack of adequate instructional time for science teaching in the elementary grades is well documented and serves to restrict any qualitative reform efforts (Schoeneberger and Russell 1986, Mullis and Jenkins 1988). Such time-restricted elementary science programmes are characterized by an emphasis on assigned reading activities and vocabulary drill (Staver and Bay 1989) rather than in-depth science instruction (e.g. hands-on science activities, science process skills, cumulative mastery of science concepts). Researchers (Linn 1987, Mullis and Jenkins 1988) have suggested that poor science instruction at the elementary level contributes to the generally negative attitudes of students at the secondary level and beyond. Recognizing that while other causal factors have been identified (e.g. inadequate science knowledge of elementary teachers, poorly designed curriculum and instructional methods) as contributors to poor science teaching at the elementary level, it is reasonable that improvements in science learning and instruction require, at a minimum, an increase in instructional time (Romance and Vitale 1992a).

The implementation of the IDEAS model focused on replacing the time allocated for traditional reading/language arts instruction with a daily 2 hour time-block dedicated solely to in-depth science concept instruction (e.g. concept-focused teaching, hands-on activities, extensive utilization of science process skills, enhanced reading of trade science materials, concept map construction, journal writing). In advocating this model, Romance and Vitale (1992a) have argued that because schools are unlikely to increase the amount of instructional time available for science alone or to completely abandon reading/language arts, the embedding of reading/language arts within a 2 hour block of time for elementary science could be acceptable to schools within a curriculum integration framework.

Within such an integrated approach, specific factors supporting the acceptability of the IDEAS model to schools include: (a) the strong overlap between applied reading skills and science thinking/process skills (Crocker *et al.* 1986); (b) the increased emphasis in schools upon content-area reading (e.g. Lapp *et al.* 1996); and (c) the plausibility that most curriculum goals in applied reading instruction in grades 2–5 are encompassed naturally within the range of activities within a strong in-depth science curriculum (Glynn and Muth 1994, Holliday *et al.* 1994). Thus, as a result of implementing the IDEAS model, not only would teachers gain the time they need for in-depth science instruction but, because science offers a meaningful content domain with conceptually structured knowledge—vs the lack of content in traditional basal reading materials (Beck and McKeown 1989)—teachers also would be able to address the development of applied reading comprehension and language arts skills of students in a far stronger fashion as well.

Figures 1, 2, and 3 provide a schematic representation of the instructional architecture of the IDEAS science teaching model. As figure 1 shows, the model emphasizes the science concepts to be taught as the contextual focus and integrative framework for all student learning activities. In turn, the concept-connected set of related learning activities then serves as the basis for the in-depth pursuit of scientific understanding by students (see Vosniadou 1996). Figure 2 presents an expanded illustration of how the general architecture of the teaching model might be used within a typical IDEAS classroom. More specifically, figure 2 shows a connected set of 11 different student activities, all of which focus on the same concept or concepts being taught. Within the IDEAS model of expanded time for science, a pattern of activities such as those shown in figure 2 would be completed over a number of 2 hour class periods on successive days. As figure 2 also suggests, to maintain continuity, each daily lesson would include a review of prior knowledge gained by students on earlier lessons and, at the option of the teacher, a concept mapping activity to visually represent the concept relationships addressed in the complete unit (i.e. across the complete set of activities). Finally, as figure 3 shows, assessment of student learning is based upon qualitatively different categories of performance across the range of different learning activities assigned. A more detailed example illustrating the introduction and application of the model on a day-to-day basis in the classroom is shown in the Appendix.

As a consequence of integrating science and reading instruction within a 2 hour daily time block, the research expectation (e.g. Romance and Vitale 1992a) was that student science and reading achievement would improve, along with

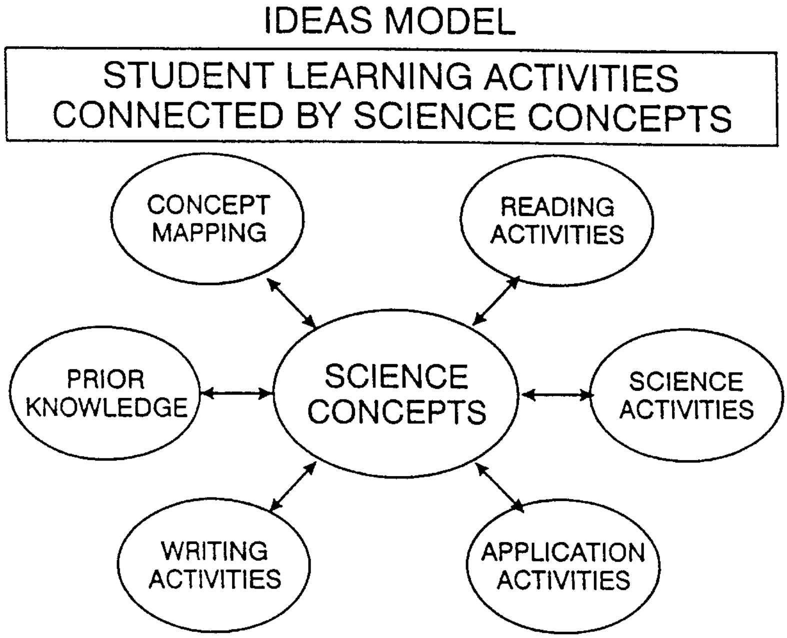

Figure 1. **Conceptual interdependence of classroom learning activities in IDEAS model. Conceptual structure of science concepts taught provides a natural link for varieties of classroom activities in science, reading, and writing within the IDEAS model.**

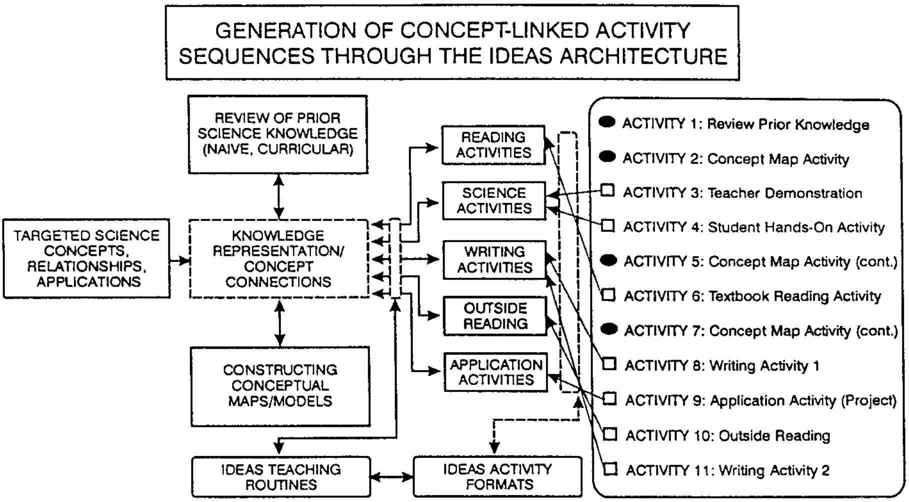

Figure 2. **General architecture of the IDEAS Model. The 2 hour daily time block for science instruction in the IDEAS model allows teachers and students sufficient time to engage in different activities focusing on one or more related science concepts. The specific set of activities across a multi-day unit would be planned by the individual classroom teacher.**

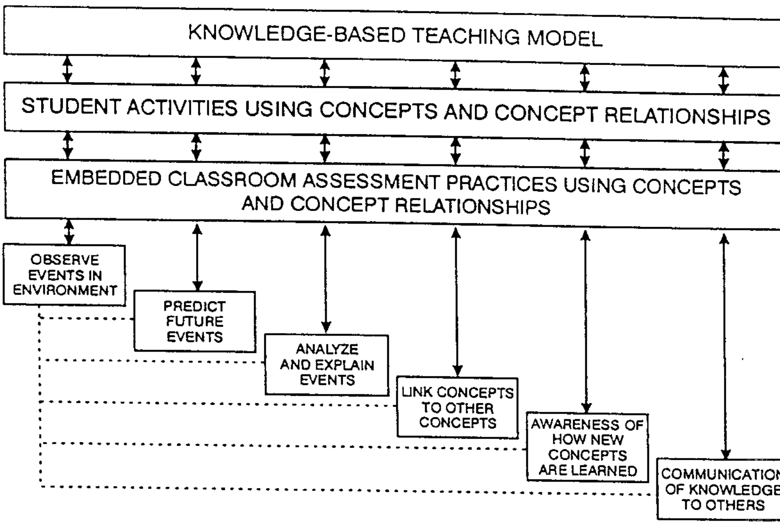

Figure 3. Embedded forms of assessment used in the IDEAS model for evaluation of student classroom performance. Specific assessment categories used in a lesson would be determined by the individual classroom teacher and reflect the different learning activities used.

positive student affective perceptions (e.g. attitude, self-confidence) and teaching efficiency (i.e. preparing for and teaching in-depth science is much easier than preparing for science in addition to reading and language arts). In context of the above, more detailed descriptions of the implementation of the model and its underlying rationale can be found in Romance and Vitale (1992a, 1994).

Multi-year research design and findings

This section overviews a series of studies exploring the effects of the IDEAS model over a 5 year period. In doing so, the emphasis is upon the pattern of empirical results involving student performance in years 1-4 and implementation issues studied in year 5 rather than on the concomitant evolution of perspectives and research issues from the studies themselves. These perspectives and research issues, however, are addressed later in a following section.

For convenience and as appropriate for an overview, the technical details are not included for work previously published. However, in understanding the subsequent sections, it is important to note the methodological commonalities among all of the studies. First, all studies reported here were conducted in a multicultural urban school system 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 the comparison groups matched those of the experimental groups as did the general demographics of their schools (ability levels, ethnicity, parental income). (Specific demographics are noted in the section for each study, as appropriate). Third, the method of data analysis was a general linear models approach in which the previous year's reading achievement was used as a covariate for all analyses of science and reading achievement and associated affective outcomes (attitude and self-confidence).

All of the studies involving student achievement (conducted in years 1-4) used nationally-normed standardized achievement tests to measure student academic performance. In all of the studies, science achievement was measured by the Metropolitan Achievement Tests (MAT)-Science. Due to changes in the school district's testing programme, reading achievement was measured in years 1, 2 and 3 using the Iowa Tests of Basic Skills (ITBS)-Reading and, in year 4, using the Stanford Achievement Tests (SAT)-Reading. The ITBS and the SAT Reading subtests are recognized by educators as valid measures of reading comprehension. Similarly, the MAT-Science subtest is accepted nationally as a measure of student general science understanding. All three tests are used widely in US elementary schools.

As a measure of affective outcomes, all studies used the same six-scale School Science Appraisal Inventory (SSAI), to measure student: (a) attitude toward learning science; (b) self-confidence in learning science; (c) attitude toward reading; (d) self-confidence in reading; (e) attitude toward learning science *out of school*; and (f) attitude toward reading *out of school*. The SSAI is a criterion-referenced set of item formats developed by Vitale (1980) to measure attitude in science and reading (e.g. science is interesting, you like to study different topics in science, you look forward to reading each day, you enjoy reading aloud in class) and academic self-confidence in science and reading (e.g. you are good in learning science, you understand most of what you read). The technical characteristics of the SSAI (e.g., a two-factor structure representing attitude and self-confidence formats, intra-scale Cronbach's alphas between 0.80-0.90) have been explored extensively (Vitale 1975, 1980) and the validity of the system has been demonstrated in a variety of school settings (e.g., Romance and Vitale 1992a, Woodul *et al.*, 2000.)

All participating teachers in the multi-year study received IDEAS training that consisted of three complementary parts. The first developed teachers' understanding of core physical science concepts (e.g. properties of matter, heat energy and transfer, force and motion) applied to earth science (e.g. forces that shape the earth, weather applications). A major tool in this part of teacher training was the use of a videodisk instructional programme, Core Concepts in Earth Science (Hofmeister *et al.*, 1989). The second developed teachers' repertoire of hands-on activities for use in classroom settings reflecting the core physical science concepts learned. And, the third, building upon teachers' science understanding and hands-on activities repertoire, prepared teachers to plan and implement classroom instruction using the IDEAS model architecture (see figures 1 and 2). As a result of the emphasis on physical and earth science in the training, all teachers in grades 2–5 were able use the IDEAS model initially to amplify units of study in their required curriculum that emphasized those concepts (e.g. weather, changing earth, understanding heat and energy) during their daily 2 hour time-block and then subsequently apply the IDEAS model to enhance science instruction on other topics. (Detailed guidelines for the IDEAS training developed during the project are shown in the Appendix).

Year 1 design and findings

The initial study investigating the IDEAS model was conducted in all grade 4 classrooms ($N = 3$) over a full year in a single school with predominantly white average and above average ability students. As described in Romance and Vitale

(1992a), teachers eliminated the basal reading/language arts programme in favour of a 2 hour daily time block during which they implemented the IDEAS model in which reading and language arts objectives were encompassed within in-depth science learning activities. Results of the study (Romance and Vitale 1992a) revealed both significant achievement and affective effects, with the IDEAS students outperforming comparable controls by approximately one year's grade equivalent (GE) in standardized science achievement (+.95) and a third of a year's GE in standardized reading achievement (+.32). In addition, the IDEAS students displayed significantly more positive attitudes and self-confidence toward science and reading as measured by the SSAI scales.

In keeping with the student performance results, teachers found the IDEAS model very easy to implement and informally reported that both classroom learning processes and feedback from parents volunteered to teachers throughout the school year were very positive (e.g. 'My child really loves science', 'My child spends lots of time at home reading about science'). The conclusion from the year 1 study was that the IDEAS model was potentially a very powerful instructional model that teachers found relatively easy to implement. In addition, while the fact that students did better in science and were more affectively positive was to be expected, the fact that students did better (as opposed to doing just as well as) in reading provided evidence justifying the IDEAS model as a practical implementation alternative for learning in science and for developing reading comprehension.

Year 2 design and findings

The results from year 1 of the initial study provided sound empirical evidence in the form of proof-of-concept of the potential effectiveness of the IDEAS model. With this in mind, a second year-long study was conducted with the same three teachers in the original school to determine the replicability of the results with a new group of grade 4 students. This study (see Vitale and Romance 1995) found results similar to the initial study, with the IDEAS students (in comparison to demographically similar average to above average students) again significantly obtaining greater levels of achievement in both MAT-Science (effect of +1.5 GE) and ITBS-Reading (effect of +0.41 GE), while again displaying a more positive attitude and self-confidence toward science and reading and a more positive attitude toward learning science out-of-school (e.g. interest in science learning activities at home) on the SSAI scales. Again, as in year 1, the teachers reported that they found the IDEAS model which naturally encompassed reading and language arts within science instruction easy to implement in comparison to teaching their regular basal programmes in reading, language arts, and science separately. The conclusion from year 2 was that it provided evidence that the IDEAS model was replicable and additional justification for it to be considered as a viable alternative for instruction in grades 4–5, a consideration having important curriculum policy implications for elementary science and reading.

Year 3 design and findings

Although the IDEAS model was replicated in the original classrooms for a third year with new students, the major research emphasis in year 3 was to test the robustness of the IDEAS model by expanding the implementation to a small number of new teachers (and schools) and to a wider range of students, with particular emphasis on low-achieving at-risk students in grades 4 and 5. The extension of the model to at-risk students was of particular interest - not only because previous research with the IDEAS model had focused on average/above average students - but also because of issues in the literature (e.g. Pogrow 1990, Means and Knapp 1991, Carnine 1992) regarding the appropriateness of in-depth conceptual (vs remedial) curriculum for at-risk students. Additionally, because of the new teachers and classrooms associated with the expansion of the project, the year 3 study implemented a prototype inservice training programme for teachers in the fall of the school year prior to their initiating the IDEAS model in their classrooms. As a result, the initial inservice programme for new teachers shortened the length of their subsequent classroom implementation to approximately one-half of the school year (i.e. 5 months).

Since the emphasis in year 3 was upon the expansion of the IDEAS model to 'difficult to teach' at-risk students in grades 4 and 5 and given limited research resources, only this aspect of the implementation was explored experimentally. These results (Romance and Vitale 1992b) found that the low SES predominantly African-American IDEAS at-risk students in grade 5 significantly outperformed comparable controls in science (by 2.3 GE on MAT-Science) and reading (by 0.51 GE on ITBS-Reading) achievement. At the same time, in contrast to the large achievement effects found for grade 5 students, no achievement differences were found for the younger at-risk grade 4 students during the 5 month implementation. However, results of the affective performance measures showed the IDEAS model had the same consistent and positive effect on both grade 4 and 5 at-risk students that had been found in previous years with average and above-average students. More specifically, the IDEAS at-risk students not only displayed more positive SSAI attitudes and self-confidence toward both science learning and reading in school but, also more positive attitudes toward learning science and reading out-of-school.

Again, with the expansion of the implementation to at-risk students in grades 4 and 5 (and a new group of teachers), the weight of the evidence in terms of student performance complemented by informal teacher feedback and ongoing classroom observations as extensions of the training model was that the IDEAS model was a highly replicable model that benefitted students and teachers alike. In interpreting the lack of significant achievement effects with at-risk students in grade 4, teachers agreed with the researchers that the 'floors' of the on-level standardized tests administered to students performing far below grade level were not sensitive to their actual achievement progress within the 5 month instructional period in a way that off-level testing (or a year-long treatment) might allow. To verify this interpretation, implementation of the IDEAS model with at-risk students during the subsequent whole school year was designated as a major project priority.

To complete the year 3 findings, an assessment of the end-of-year performance of the original 3 classrooms (with average to above average students) using the IDEAS model showed their achievement levels to be comparable to previous years' findings, although no comparison data were collected from an average/above average comparison group. Thus, even with the increase and variability in the teachers and students participating in the project, the overall finding for year 3 was that the evidence again supported the conclusion from previous years that the IDEAS model was powerful and replicable. Importantly, the effect of the IDEAS model was shown to be generalizable from average and above-average ability students to below average/at-risk students and its implementation context to a new group of teachers in different grade levels at different schools.

Year 4 design and findings

The fourth year of the research programme marked a shift in emphasis from proof-of-concept (and the associated question of replicability) of the IDEAS model to that of developing (and validating) the capability to implement the model on a larger scale. In year 4, the research effort encompassed more school sites (15), a widened grade-range (from an original emphasis in grades 4-5 to additional grade 2 and 3 classrooms to broaden the IDEAS model), and an increased number of teachers-per-grade in schools that had adopted the model in the preceding year or in new schools. As a result, the year 4 study included students whose ability ranged from at-risk/below-average to average/above-average. Additionally, given the opportunity to refine the teacher training prototype during the summer months, all teachers (with the exception of the original 3 who served as informal mentors) participated in an initial 1 week (30 hours) staff training programme prior to the start of the school year. Then, in follow-up training, during the first 3 months of the school year, teachers completed an additional 30 hours of training (after school and on weekends) followed by monthly ‘sharing success’ seminars for the remainder of the school year. Finally, complementing the training, teachers received 1 or 2 informal classroom-support visits by mentors or project researchers. As a consequence, in year 4, all participating teachers were able to initiate the IDEAS model at the beginning of the school year (see Appendix for IDEAS training guidelines).

The year 4 results for grade 4-5 students are presented here in greater technical detail than those in preceding sections because they have not been published elsewhere. A linear models approach (see Romance and Vitale 1992a) was used to analyse student performance ($N = 540$) on each of three dependent variables (MAT–Science, SAT–Reading, SSAI Attitude/Self-Confidence) in which the effects of treatment condition (IDEAS, Comparison), group-type (At-risk, Regular, i.e. non at-risk average and above), and grade (4 and 5) were investigated, using the previous years’ ITBS–Reading achievement as a covariate. As previous research findings had shown different attitude and self-confidence subscales to be highly correlated in their response to the IDEAS treatment, student affective performance in year 4 was analysed as a composite SSAI Attitude/Self-Confidence measure.

Table 1 shows the means and standard deviations for the IDEAS model and the comparison groups on the three performance measures and the covariate. Specifically, the results of the analysis for all students found the effects of the IDEAS model to be significant on each of the three dependent variables (MAT-Science, SAT-Reading, SSAI Attitude/Self-Confidence). Thus, students receiving the 2 hour IDEAS model not only displayed greater dependent in science ($F_{1,438} = 52.79, p < 0.01$), but, accomplished greater learning in reading as well ($F_{1,497} = 18.18, p < 0.01$). In addition, the IDEAS students also displayed more positive SSAI attitudes toward and greater confidence in learning ($F_{1,500} = 3.05, p < 0.01$) than the comparison students who received their regular basal reading/language arts and science programmes separately. The differences obtained in adjusted grade equivalent scores (in favour of the experimental group)

Table 1. Means and standard deviations for the experimental (IDEAS), comparison, and total groups.

variable		experimental	comparison	total
covariate:				
ITBS-R (1991)	N	227	166	393
	M	3.8	3.6	3.7
	SD	1.7	1.0	1.1
performance measures:				
MAT-S	N	261	183	444
	M	5.2	4.0	4.8
	SD	2.0	1.4	1.9
SAT-R (1992)	N	250	245	503
	M	4.6	4.2	4.4
	SD	1.4	1.3	1.3
SSAI attitude/S-C	N	255	251	506
	M	3.9	3.7	3.8
	SD	0.6	0.7	0.6

note: overall $N = 540$, differences in total N's caused by missing data. MAT-S: Metropolitan Achievement Tests - Science; SAT-R: Stanford Achievement Tests - Reading; and ITBS-R: Iowa Tests of Basic Skills - Reading are reported in grade-equivalent (GE) scores. Higher values of SSAI Attitude/Self-Confidence(S-C) scale indicate positive responses.

were +1.11 GE on MAT-Science and +0.37 GE on SAT-Reading, effects that should be considered highly educationally significant and consistent with previous years' findings. (Differences in adjusted means of the SSAI combined scale are not reported because the scale units as summed scores were arbitrary).

In other findings, grade 5 students outperformed grade 4 students in both MAT-Science ($F_{1,438} = 12.60, p < 0.01$) and SAT-Reading ($F_{1,497} = 20.70$, $p < 0.01$), regular (i.e. non at-risk) students displayed significantly higher achievement in SAT-Reading ($F_{1,497} = 90.25, p < 0.01$) than at-risk students, and no difference (on adjusted means) was found between regular and at-risk students on MAT-Science achievement. Finally, no interaction effects were found significant. Considered together, these findings support the conclusion that the IDEAS model was equally effective in science for both at-risk and regular students after statistically adjusting (via the covariate) for achievement differences attributable to initial levels of prior reading and that the year-long treatment was effective for younger grade 4 as well as older grade 5 at-risk (and regular) students.

The conclusions for year 4 again reconfirmed the strength of the IDEAS model in terms of treatment effects in achievement (science, reading) and affective outcomes (attitude/self-confidence) that were highly meaningful educationally and offered a practical instructional alternative for science, reading, and language arts that had significant implications for school curriculum policy. As in previous years, the student performance data were supported by informal teacher feedback and classroom observations regarding the workability of the model and general qualitative aspects of the classroom learning process (e.g. active involvement of students in a variety of learning activities linked together by the core science concepts taught, conceptual understanding as a context for use of basic skills in reading and language arts, an affectively positive classroom environment in which students are motivated to learn about science). In addition, in year 4, written comments from all participating teachers were obtained at the end of the school year with respect to direct observations about their students and classrooms as a result of using the IDEAS model. Table 2 presents a summary of the major categories of teachers' individual responses as reported by Romance *et al.* (1994a). As table 2 shows, teacher responses were supportive of the IDEAS model as an approach that resulted in qualitative changes that enhanced both their students' achievement and the classroom learning environment.

Additionally, year 4 also provided encouraging results on a number of other important research and development concerns. First, informal qualitative observations suggested that the IDEAS model could work in lower grades as well with no teacher training modifications. More specifically, the model was readily implemented by the grade 2 and grade 3 teachers who simply were included in the

Table 2. Compilation of written comments from participating teachers regarding the perceived effects of implementing the IDEAS model in their classrooms.

Question 1: as a result of using the IDEAS model, what are the most noteworthy changes you have observed in your students?

- increased vocabulary acquisition
- increased science reading by using trade books in science
- improved cooperative learning skills
- increased eagerness to learn science
- increased willingness to participate and answer science questions
- increase in number of questions posed by the students
- increase in responses and participation of at-risk students
- increased confidence and motivation of all students in science learning
- increase in science knowledge learned
- decrease in amount of time spent on drill and practice in reading skills (students used reading skills daily)
- increased opportunities for meaningful thinking in science
- increased requests by students to do more science activities
- increased reading proficiency
- increased performance on the Florida Writing Assessment

Question 2: what characteristics of your IDEAS classroom most differentiate it from your previous classrooms?

student classroom characteristics

- fewer in discipline problems
- more critical thinking and problem solving
- more questions posed by at-risk students
- more learning by exceptional students (e.g., ESOL, LD)
- more willingness to learn challenging concepts
- fewer bored or disinterested students
- more connections and applications of concepts by students

increased teacher classroom expectations

- how well all students performed in science (including exceptional and at-risk)
- quality of ideas by students
- how much science knowledge was retained throughout the year
- how much more they enjoyed teaching science
- that they could never return to the previous way of teaching each subject (reading, language arts, science) separately
- how much of the instructional day could revolve around teaching science while covering basic skills in language arts

study with the grade 4 and grade 5 teachers from the standpoint of training and classroom support. Secondly, year 4 provided an opportunity to successfully implement and then refine the prototype teacher training programme initially developed in year 3. Such a model was considered a critical element in the eventual transportability of the IDEAS model to other sites. And, thirdly, year 4 provided an opportunity to explore and develop plans for adding a mentor component to the implementation design in which teachers experienced in the IDEAS model provide guidance to those who are initially implementing it. Overall, the year 4 results provided strong evidence that the IDEAS model had the potential to be implemented successfully on a large-scale basis.

Year 5 design and findings

Unlike the initial four years focusing on the effect of the IDEAS model on student performance, the primary emphasis in year 5 was upon developing and verifying the capability to support the large-scale implementation of the model. Thus, during year 5, the number of teachers (and schools) implementing the IDEAS model was expanded and the IDEAS model and teacher training support programme studied qualitatively for subsequent documentation. Within this context, the specific objectives during year 5 included: (a) a greater emphasis upon schoolwide adoptions of the model within the 2-5 grade range; (b) the addition of a formal student journal-writing component to the IDEAS model; (c) the continued refinement of the teacher training and supervision/support programme; (d) the formalization of a prototype teacher mentor model within which teachers shared techniques, problems, insights, and solutions, and (e) the development of the technical capability to establish the transportability of the IDEAS model to other non-local schools.

In general, the year 5 project evaluation focusing on the overall implementation of the IDEAS model by teachers and the teacher training programme found both to be highly effective. For example, in an evaluation of a representative 2 week summer IDEAS training session for 25 teachers, Vitale (1995) determined that over 90% of the participants rated the workshop as successful in enhancing teacher understanding of science concepts, use of hands-on/demonstration activities, in-depth teaching and the IDEAS model, planning skills to implement the IDEAS model, and developing their leadership capabilities (see table 3). As supportive data, Vitale's (1995) evaluation also showed that participants pre-post mastery knowledge of core concepts in physical and earth science as measured by mastery tests increased from 54% correct to 90% correct as a result of workshop participation. This was an important workshop goal to document because without a firm understanding of the science concepts to be taught, teachers would have been unable to implement the in-depth IDEAS model for 2 hours each day.

In addition, complementing the teacher training evaluation, qualitative observations of IDEAS (comparison) classrooms by mentors and project researchers during the school year confirmed meaningful instructional and student performance characteristics that distinguished IDEAS from non-IDEAS classrooms. As table 4 shows, teachers implementing the IDEAS model were found to offer students a variety of activities emphasizing an in-depth understanding of core science concepts that involved students in learning in an interactive and highly motivating fashion. As reported in table 4, the activities were also consistent with

Table 3. Participant ratings of the effectiveness of the major areas addressed by a representative IDEAS 2-week summer workshop.

scaled percent agreement*	mean rating (4-3-2-1)	effectiveness of training workshop in improving science IDEAS teaching and leadership skills
		teacher understanding of science concepts
99	3.96	helped me gain new understanding of science concepts
98	3.92	increased my understanding of the role of 'big ideas' or 'core concepts' in science
95	3.80	increased my understanding of the role of conceptual understanding in thinking - and problem solving applications
92	3.68	increased my ability to use science concepts as a basis for organizing science instruction
		teacher use of hands-on/demonstration science activities
97	3.88	helped me learn new science activities to use in classroom teaching
96	3.84	increased my ability to demonstrate and/or involve students in hands-on science activities
96	3.84	increased my ability to link classroom hands-on activities with student conceptual learning
91	3.64	increased my ability to link classroom learning activities with real life applications
		in-depth science teaching and the IDEAS model
91	3.64	helped me gain a good understanding of in-depth science teaching using the IDEAS model
92	3.68	learned IDEAS strategies to teach for in-depth student conceptual understanding emphasizing big ideas in science
94	3.76	learned IDEAS strategies to use science concepts as a means for coordinating different student classroom learning activities in science (e.g. hands-on experiments, reading, concept mapping, writing, problem applications)
91	3.64	learned IDEAS strategies to integrate the development of reading/ language arts/writing skills within in-depth science instruction
91	3.64	learned IDEAS strategies to use student prior knowledge in conjunction with teacher modeling and questioning to facilitate student understanding of science concepts
		planning to implement the IDEAS model
92	3.68	learned how to develop a classroom plan to implement the IDEAS model in my classroom
90	3.52	learned to plan the daily 2 - $2\frac{1}{2}$ hour block of time for teaching integrated science/reading/language arts/writing objectives within multi-week instructional units
91	3.64	learned to plan a wide variety of classroom activities that emphasize the development of student conceptual understanding and the integration of reading/language arts/ writing within science instruction
91	3.64	learned to identify the resource requirements (e.g. for hands-on experiments, demonstrations, student reading) needed to implement the planned IDEAS activities
		developing leadership capabilities of elementary science teachers
97	3.88	enhanced my own perspectives of why it is important to teach science in elementary grades
98	3.93	enhanced my own perspectives of why science instruction should include hands-on activities
92	3.68	enhanced my own perspectives of characteristics of exemplary science programmes
90	3.60	enhanced my own perspectives of roadblocks to effective science instruction in elementary schools
93	3.72	enhanced my own perspectives of how to improve science instruction in my school and district

N = 25

* scaled percent agreement based on mean 4-category ratings (4 = strongly agree, 3 = agree, 2 = disagree, 1 = strongly disagree) expressed on a 100-0 scale using the formula: (mean rating/4)* 100

Table 4. Qualitative characteristics observed in IDEAS classrooms (vs comparison classrooms).

instructional process observations

- science concepts taught are explored in-depth across multiple class sessions (rather than content coverage being rushed) allowing for extensive elaboration/application of concepts
- during a typical class period (e.g. 2 hours), teachers involve students in a variety of individual and/or group learning activities
- structure of science concepts taught provides links that connect all hands-on, reading, writing, concept application, and other learning activities
- core science concept relationships are illustrated dynamically through the extensive use of visual representations (e.g. graphics organizers, classifications using blackboard) as an integral part of teaching
- substantial amounts of class time (at least 30 min. per day) are used to involve students in individual or group hands-on activities or in teacher demonstrations of experiments
- focused multiple hands-on activities are used to illustrate specific concepts and to provide a foundation for subsequent reading comprehension activities
- a variety of assessment methods are used to evaluate student performance (e.g. journals, group discussions, individual performance/paper-pencil tests)

student performance observations

- active classroom participation by students indicates a high interest in and motivation to learn science concepts
- quality of the frequent questions asked by students reflects an in-depth understanding of science concepts taught
- explanations of real-life applications by students in terms of science concepts are indicative of (and serve as tests for) in-depth understanding and scientific curiosity
- all students participate actively and enthusiastically in hands-on and other science classroom activities
- students are able to explain science concepts in their reading materials in terms of classroom science experiments and real-life applications
- students are observed to engage in informal discussions of science concepts, experiments, and applications out-of-science class
- students view themselves as highly successful learners in science and participate productively in all science classroom activities

note: instructional and student characteristics noted by qualitative observers as distinguishing IDEAS classrooms from traditional time-constrained science instruction across a variety of demographic settings (e.g. grades 3-5, average, above-average, at-risk).

earlier preliminary findings reflecting differences in the frequency of ‘in-depth’ classroom activities (e.g., hands-on activities, teacher demonstrations) reported by IDEAS students in comparison to non-IDEAS students receiving traditional instruction (Romance and Vitale 1990).

Summary of the multi-year findings

Considered together, the major findings of the multi-year project can be summarized as follows:

- The IDEAS model (which replaced the regular 2 hour daily time block separately allocated to Reading, Language Arts, and Science programmes) consistently resulted in greater student achievement in both science and reading (see figures 4 and 5) and in more positive affective student outcomes (attitude, self-confidence).

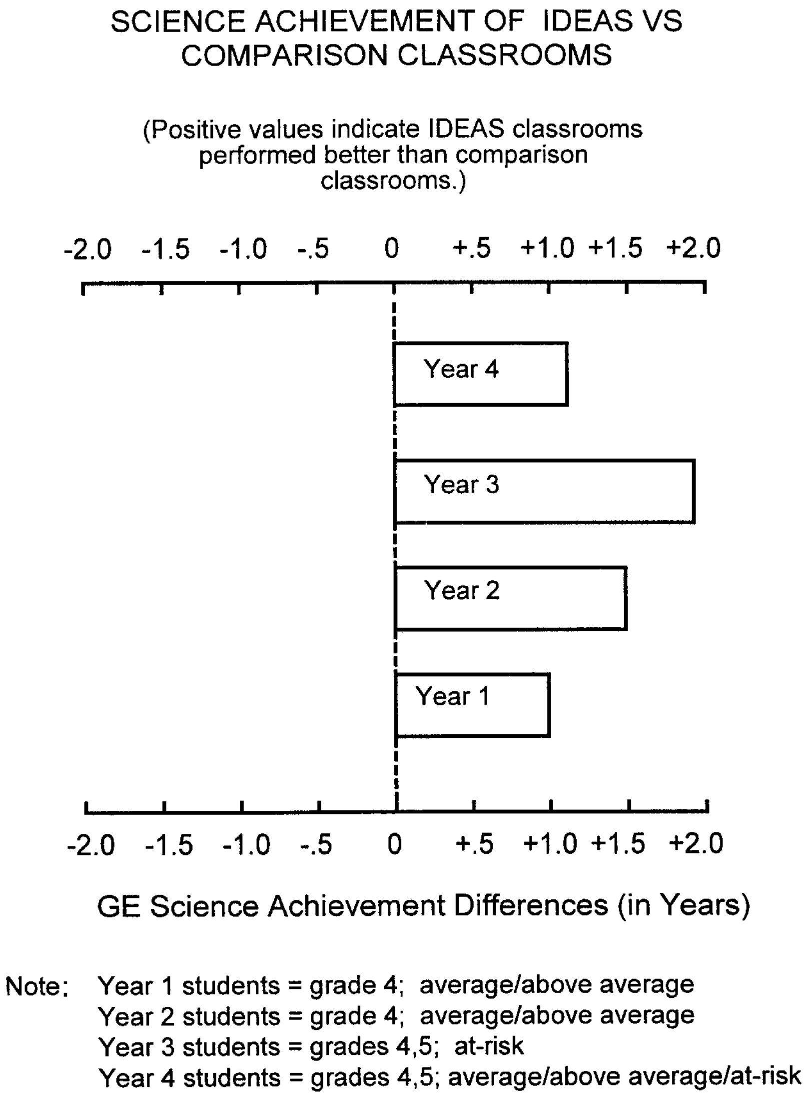

Figure 4. Summary of adjusted mean difference scores in grade-equivalent years showing higher science achievement of IDEAS vs. comparison classrooms on MAT-Science.

- The architecture of the IDEAS model as documented in the multi-year project was demonstrated to be replicable and transportable.
- Teacher implementation of the IDEAS model was shown to be supportable effectively on a relatively large-scale through the teacher training and supervision programmes developed in the multi-year project. (See the Appendix for detailed guidelines).
- The use of the IDEAS model was shown to be a practical curriculum strategy through which in-depth science could be taught in elementary schools.

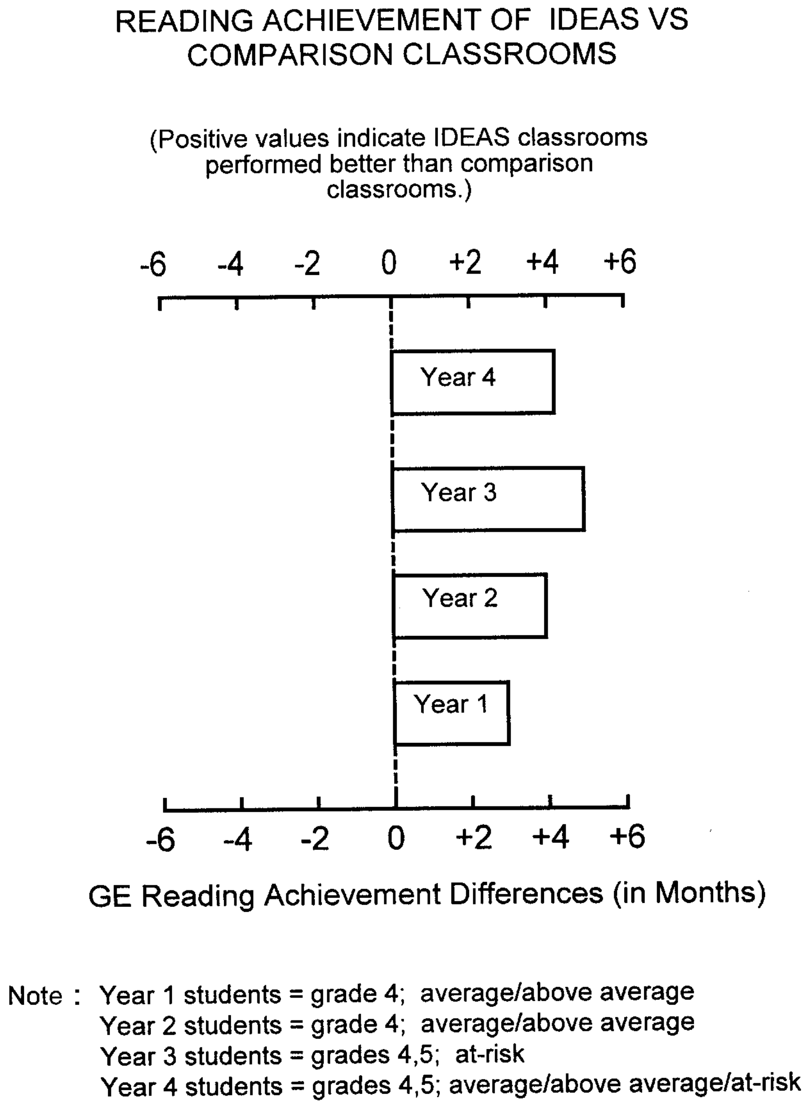

Figure 5. Summary of adjusted mean difference scores in grade-equivalent years showing higher reading achievement of IDEAS vs. comparison classrooms on ITBS-Reading (years 1, 2, 3) and SAT-Reading (year 4).

Research and policy implications emerging from the multi-year project

Complementing the pattern of empirical findings summarized above, this section overviews broad research implications that have emerged from the multi-year studies that have explored the IDEAS model over the past 5 years. In particular, these findings are considered in light of the Third International Mathematics and Science Study (TIMSS) whose results (Schmidt *et al.* 1997) emphasized the importance of in-depth science instruction in a fashion that is generally supportive of the IDEAS model and rationale. Further, while exploring these implications it is important to keep in mind that a major long-term goal of the IDEAS research effort is to provide a school-classroom environment within which the cumulative effects of in-depth science teaching and learning can be investigated (see Wright 1993).

TIMSS as an international perspective emphasizing the importance of curriculum content and in-depth teaching

The goal of the TIMSS was to conduct a comprehensive international comparison of student performance and instructional practices in a fashion that would serve as a resource for subsequent school improvement efforts (Schmidt *et al.* 1997). Among the characteristics differentiating top performing nations in science from those such as the US which were less successful was the nature of the curriculum itself. Specifically, in the top performing nations the curriculum focused on fewer core topics which were conceptually organized and sequenced, a structure that enabled teachers to focus instruction on core concepts in a more in-depth fashion. The importance of this interpretation was illustrated by the fact that Minnesota eighth graders whose curriculum focused on earth science topics displayed the highest achievement of all nations reported by TIMSS. Clearly this in-depth curricular focus, in contrast to the more prevalent approach of covering a multitude of topics reported by US teachers, resulted in greater and more meaningful achievement for Minnesota students.

In general, TIMSS found top performing nations had much greater gains in those topic areas in which teaching emphasized in-depth instruction. In comparison, the US curriculum approach emphasizing coverage of many topics resulted in fewer gains and never produced cumulative large gains in any topic in contrast with many of the top performing nations who were first in at least one science content area (e.g. physical science, force and motion). A parallel TIMSS finding used to explain the difference between top and low performing nations in science was the comparative analysis and extent of topic coverage in US textbooks and curriculum materials conducted by TIMSS. While American texts frequently contained up to 600 pages and addressed many more topics superficially, the text materials in many of the top performing nations were usually 100 pages in length and stressed the far fewer core topics in a much more in-depth fashion.

Primary importance of curricular conceptual content and structure in the IDEAS model

The initial focus of the IDEAS model was to provide the instructional time during the school day to teach science at the depth needed for students to master the core concepts and related concept applications to be learned within the science curriculum. As noted above, the intent was to establish a research (or research-application) environment in school settings within which improvements in the science teaching-learning process could be implemented. Except for the logical requirement that there be a ‘reasonably credible’ science curriculum, the original effort focused primarily upon the processes of instruction rather than curricular conceptual content, *per se*. Within this perspective, the IDEAS model itself was considered as a 'curriculum generalizable' process that, when implemented within a credible science curriculum, would result in meaningful in-depth science instruction. Certainly, the emphasis of the empirical research findings presented in this paper are consistent with this perspective. Yet, although our original interests are unchanged after 5 years of research within IDEAS classrooms, the emphasis of our future research efforts (e.g. Vitale and Romance 1999, 2000) now focuses primarily upon the conceptual structure of the science curriculum that is being taught and learned as the critical factor in understanding effective teaching and learning rather than upon the teaching process itself. This change in perspective (e.g. Romance *et al.* 1994b) has been engendered by repeatedly observing student learning (and teacher instruction) in a cumulative fashion across time while comparing the conceptually rich IDEAS classroom learning environment with traditional (control) classes who, in comparison, are taught reading, language arts, and science separately.

In effect, our qualitative observations found that what seemed to make the IDEAS model effective with students was the fact that it provided them with an opportunity to pursue an in-depth understanding of the conceptually meaningful structured knowledge of which science is composed. In doing so, students had an ongoing opportunity first to 'construct meaningful knowledge' and then to benefit subsequently by using such knowledge to support their understanding of applications or future learning, a view consistent with that outlined by Mintzes *et al.* (1998). In comparison, students in control classrooms had only a very limited opportunity for such experiences. In complementary research endeavors, others (Novak and Gowin 1984, Glaser and Bassok 1989, Resnick 1989, Harlen 1992, Galili *et al.* 1993, Lee *et al.* 1993, Mestre 1993, Vosniadou 1996) have emphasized the role of structured knowledge of fundamental science concepts in science learning/teaching and skilled problem-solving.

Interpreting the IDEAS model as a knowledge-based process

Once attention is focused upon the conceptual structure of what is to be taught and learned, it becomes possible to understand some key aspects (Novak and Gowin 1984, Glaser and Bassok 1989, Glaser 1990, Romance *et al.* 1994b Romance and Vitale 1994, Vitale and Romance 1995, 1999, 2000) of the IDEAS model. First, the IDEAS model encourages teachers to incorporate a variety of science-learning activities associated with in-depth science (e.g. concrete demonstrations, hands-on activities, open-ended questioning, extensive utilization of science process skills, direct concept teaching, enhanced reading of text and trade science materials, concept map construction, journal writing). However, as figures 1 and 2 illustrate, rather than utilizing these activities in a fragmented fashion, the expanded 2 hour daily time block allowed teachers to use the conceptual structure of the science knowledge to be taught to organize and link all of these different activities in an instructionally meaningful manner (e.g. Kuhn 1993, Gaskins and Guthrie 1994). In doing so, teachers using the IDEAS model in our research used the conceptual structure in their science textbook, *Journeys in Science* (Shymansky *et al.* 1988) to organize instruction and to provide a common set of reading materials and strategies (Yore and Shymansky 1991) for their classrooms. However, in principle, the conceptual structure of any curriculum organization would work as well as long as it maintained integrity with the underlying scientific concepts and principles. In this regard, Vitale and Romance (1999) have developed an extension of the IDEAS model as a more general knowledge-based approach to instruction that has recently been applied to post-secondary instruction in chemistry (Haky *et al.* 2000).

Second, in keeping with our prior research (Vitale and Romance 1992a, 1992b, 1992c, Romance and Vitale 1993) in preservice and inservice training, the teacher training programme used to support the classroom implementation of the IDEAS model placed heavy emphasis upon developing teachers' understanding of core concepts in physical and earth science (see Vitale 1995). This provided the elementary teachers (who had poor, prior science backgrounds) with a fundamental understanding of a major portion of the science content they were to teach and a knowledge-based context for conceptual learning within which they were to apply science teaching methods such as concrete demonstrations, open-ended questioning, and hands-on activities. In addition to gaining confidence in using such techniques, IDEAS teachers commonly indicated that without a prior, intuitive understanding of the science concepts they were to teach, they would not have been able to utilize the 2 hour time block with the success they demonstrated in their classrooms.

Although beyond the scope of this paper, the general orientation presented here is consistent generally with newer research developments in the fields of cognitive science (e.g. Anderson 1993, 1996) and instructional design (e.g. Glaser and Bassok 1989, Glaser 1990, Vitale and Romance 1998) and, specifically, with the architecture of knowledge-based instructional programmes within the field of artificial intelligence (see Romance *et al.* 1994b). These latter approaches, referring to efforts to develop computer software that can provide students with intelligent tutoring assistance, always attempt to formally represent three key elements of the teaching process: (a) the knowledge domain to be learned; (b) the status of the student mastery of the knowledge domain; and, given the former, (c) a repertoire of pedagogical strategies that can be chosen in order to be appropriate for the knowledge to be taught and the state of a student's prior knowledge. Building upon the preceding concepts, figure 6 shows an informal outline of a general process of science teaching viewed as a knowledge-based model as described by Romance *et al.* (1994b).

Given the preceding perspectives, the initial rationale of the original IDEAS research programme in which the expanded time for science was to provide a means to implement and investigate established methods of science teaching necessarily must be broadened. In its place, our present research perspective is that the IDEAS model provides an environment within which meaningful research can be conducted on cumulative acquisition of conceptual science knowledge by students. In turn, given accessibility to such an environment, IDEAS classrooms clearly provide a context within which research efforts designed to further understanding of the preservice and inservice teacher education process can be validated. This is not to say that a 'curriculum-free' IDEAS model as described here is not of value in its own right - certainly the data reported here argues that it is. Rather, viewing the IDEAS model as a knowledge-based system potentially allows it to be understood in terms of advancements in cognitive science and instructional design whose relevance to the science learning and science teacher education processes otherwise might not be recognized (see Vitale and Romance 1999).

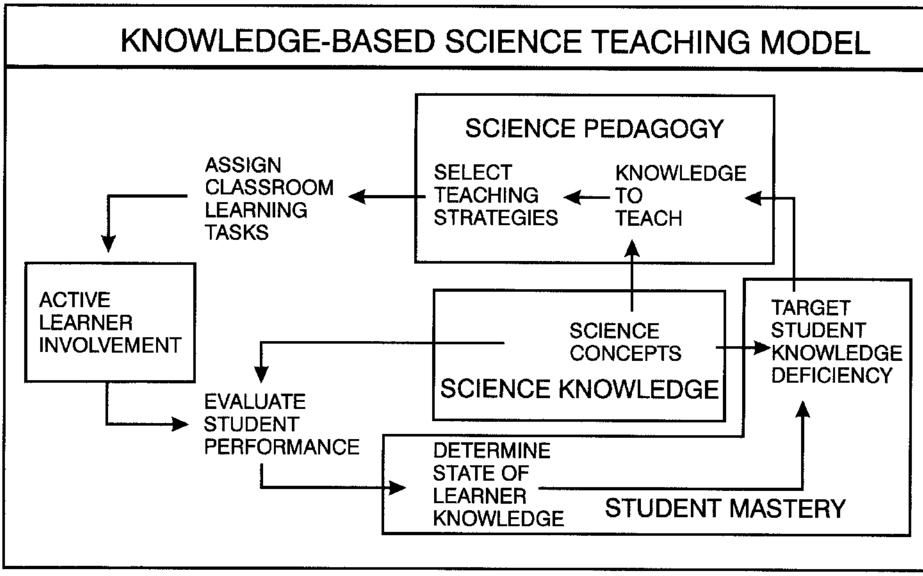

Figure 6. Schematic outline of a knowledge-based science teaching model. As an application of computer-based intelligent tutoring systems, emphasis in the model is upon the role of science conceptual knowledge as the central integrating component of the science teaching process (see Romance *et al.* 1994b).

Selected research and policy issues for improving science teaching and learning

In concluding this paper, it is appropriate to advance some key implications for research and practice that - although implied - are far too important to be left unsaid. As presented here, these purposely combine specific research interests on one hand with positions of professional advocacy on the other.

Specifically, in terms of major research issues, we offer the following:

- Our research findings, consistent with major findings of TIMSS, have led us to the belief that the role of conceptual knowledge (considered from a curricular perspective) has been substantially undervalued in importance in both science education research and associated science education theory. By focusing upon science teaching and learning as knowledge-based processes, it is necessary to represent such conceptual knowledge and, having done so, to link science education to the newly developing areas of cognitive science and instructional design (see Romance *et al.* 1994b, Vitale and Romance 1995). In turn, we believe that the explication of such links as evidenced by the development of the IDEAS model could yield significant advancements in understanding the science teaching-learning process in a form that is directly applicable to classroom practices and to science teacher preparation. In doing so, we anticipate that present conceptions of learners (students, teachers, and scientists alike) as active constructors of knowledge will provide a guiding force for such work. In particular, we anticipate that linking theoretical and research perspectives from cognitive science and instructional design into the field of science education will allow the design of educational environments in school classrooms that accomplish this end (see Collins 1996, Vitale and Romance 1998, 1999).

- Our research findings, in context of recent developments in the cognitive science and instructional design literatures, also have caused us to believe that the time has come to pursue student acquisition of meaningful science (conceptual) knowledge directly as a research goal in a fashion that recognizes both the informal extra-school and the formal curricular in-school conceptual science knowledge that combine to comprise student prior knowledge at the time of instruction. In this regard, we feel that science education in elementary grades (K-5) has emphasized the role of extra-school knowledge at the expense of prior curricular knowledge taught in school. In turn, this has drawn attention from the process of directly teaching science concepts and concept applications to students (e.g. Wittrock 1963, Muthukrishna *et al.* 1993). By focusing on the acquisition of structured conceptual knowledge (Ruiz-Primo and Shavelson 1996), it becomes possible to focus research efforts upon a qualitative understanding of the problem of science teaching in a form that implies the undertaking of the kind of analytic and theory-based experimental research necessary to improve it (e.g. Johnson and Pennypacker 1982).
- Our research findings have encouraged a continued pursuit of our original two-pronged research programme (Vitale and Romance 1992a) which focused upon research questions that led to further understanding of the science teaching-learning process on one hand and the development of implementation schemes within which such theoretical understanding could be applied in classrooms on the other. However, as discussed above, our research findings have led us to reformulate our research perspective in order to be able to link science education theory (and problems) to the emerging disciplines of cognitive science and instructional design (Romance *et al.* 1994b). From this perspective, our belief is that it is now possible to pursue the integration of three central research areas in science education by viewing them as knowledge-based processes: (a) the science learning process itself; (b) the pedagogy of teaching science; and (c) the preparation of science teachers. Presently, in a fashion consistent with other efforts in the field (e.g. Anderson 1992, Linn 1992, Trumbull and Kerr 1993), we are working to establish programmes of research addressing these topics whose emphasis is upon the development of structured conceptual understanding of science concepts by students and teachers (e.g., Romance and Vitale 1999; Vitale and Romance 1999).

Additionally, in terms of major policy issues, we advocate the following:

- Our multi-year research findings provide strong evidence that the IDEAS model in which instructional time allocated to reading and language arts is re-allocated to science should be considered as a potential curricular framework by all elementary schools in grades 2-5. In this regard, we are encouraged by researchers in the field of reading comprehension (e.g. Goodman 1988, Beck and McKeown 1989) who have been critical of the use of basal reading series in grades 2–5 and beyond. These researchers have raised concerns regarding the appropriateness of basal reading materials simply because of the *absence* of structured conceptual knowledge in them. We agree with others (e.g. Guzzetti *et al*. 1997) that the conceptual content of many (but not all) science textbooks (or alternative reading materials) directly addresses this concern and, in conjunction with our findings supporting the effectiveness of the IDEAS model, provides further reason for considering its adoption. This justification is in addition to the positive impact of the IDEAS model upon science instruction by providing a means for implementing high-quality, in-depth science instruction that realistically cannot occur without adequate classroom instructional time. With this in mind, we are continuing work on developing the support structure (e.g. teacher training, mentor collaboration, implementation standards) necessary to insure the transportability of the IDEAS model.

- Extrapolating from our research, the IDEAS model potentially positions science instruction as the centrepiece of more general educational reform movements focusing upon curricular restructuring in grades 2-5. Within this perspective, in-depth science instruction (perhaps complemented by a parallel effort in social science) could provide a context within which the curricular areas of reading, language arts, and mathematics could be integrated meaningfully (see Vitale and Romance 1999). From the standpoint of policy, we would hope that this perspective would evolve into a national commitment that would justify a mandate for the teaching of in-depth science in elementary schools. And, in doing so, our hope also is that such a mandate would result in an increased emphasis on the development of the role of science knowledge as an explicit (rather than assumed) context for science methods courses, in a form that would have implications for a more general approach to knowledge-based instruction (Vitale and Romance 1999, 2000) in the preparation of preservice elementary teachers.

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Appendix

Guidelines for Introducing and Using the IDEAS Model.

This appendix provides practitioners with concrete guidelines along with a detailed classroom example for initiating and implementing the IDEAS model. The appendix consists of three complementary parts: (1) training and support guidelines; (2) classroom planning, introduction, and implementation guidelines; and (3) a concrete example of classroom activities based on the IDEAS architecture (see figure 2).

Summary of training guidelines

This section briefly overviews the major elements of the IDEAS training and support guidelines (see Romance 1996) developed over the 5 year project:

(1) Initial teacher training (30 hrs/scheduled 1 week prior to school year). The initial training consisted of three components: the development of core concept understanding in physical and earth science by teachers, building a teacher repertoire of associated hands-on activities for classroom use, and development of teachers' capability to plan and implement the IDEAS model architecture (e.g. concept mapping of instructional units, selection of hands on activities and demonstrations, reading materials, journal writing). In building teacher conceptual understanding, all of our training implementations used an instructional videodisk programme, *Core Concepts in Earth Science* (Hofmeister *et al.*, 1989) as a major tool in phase 1. However, although use of this programme greatly simplified phase 1 of the training, it should not be considered a necessary training requirement.

(2) Follow-up teacher training (30 hrs/scheduled during the first 3 months of the school year - after school or weekends). As a continuation of initial training, this component provided guidance for teachers as they initially implemented the IDEAS model.

(3) Follow-up teacher support (ongoing throughout the school year).

- classroom visitations by mentors and project researchers (scheduled 1-2 times per year per classroom): Classroom support consisted of teaching demonstrations of IDEAS strategies, observation of teaching activities, and technical assistance, as appropriate.
- sharing success seminars (scheduled one day per month after completion of follow-up training). Emphasis in the seminars was on sharing and discussing teacher lesson plans, activities developed, and examples of student work (e.g., concept maps, journals).

(4) Mentor leadership development (scheduled one full day per month with lead teachers beginning the second year of an implementation). This component consisted of meetings between project researchers and experienced IDEAS teachers who were serving as teacher-mentors for the project. Emphasis was on issues involving support of IDEAS teaching. (The approximate ratio of teachers to mentors was 5 teachers to 1 mentor).

Classroom planning, introduction, and implementation guidelines

This section briefly overviews the major steps for initial classroom planning and implementation of the IDEAS model (Vitale and Romance 1995; Romance *et al.*, 1996) developed over the 5 year project:

(1) General steps for planning IDEAS instruction.

- unit planning. From 4-5 multi-lesson units should be selected for the school year, beginning with physical science (reflecting the training emphasis).
- unit curriculum concept map. For each unit (starting with physical science), the core concepts should be identified (i.e. 'big ideas') and then organized conceptually by developing a concept map for the unit (see Vitale and Romance 1999 for detailed concept mapping procedures and the example in the following section for an illustration). The unit concept map serves as a curriculum blueprint for organizing classroom learning activities (see figure 2).
- identify classroom activities, link each organizationally to the unit concept map, and then sequence for instruction. The range of activities used in the IDEAS model included concept-focused teaching, demonstrations, hands-on activities, utilization of science process skills, reading science textbook and trade book materials, student construction of concept maps, and student journal writing. By linking all activities to the unit concept map, teachers are able to focus instruction on core science concepts and schedule instructional activities in a fashion that builds meaningful student science understanding.
- incorporating reading and language arts skills within science instruction. Development of meaningful science understanding by students through the successful completion of IDEAS activities naturally incorporates the general mastery of reading comprehension (e.g. reading textbooks and trade books) and language arts (e.g. journal writing) skills.
- referencing qualitatively different forms of student assessment to the unit concept map. As shown in figure 3, a variety of different forms of student assessment can be naturally embedded into classroom instruction as a form of student activity. Referencing the assessment activities to the unit concept map (and linked activities) helps insure the validity of the assessment process.

(2) Classroom introduction and implementation guidelines.

- using the IDEAS model architecture (see figure 2) to introduce a new unit, lesson, or major concept to students. No special procedures are used to introduce the IDEAS model to students. However, the following 3-step sequence of activities is often used to introduce new lessons or topics. However, this sequence also has been effective for new IDEAS teachers introducing the model to students (see figure 2).
- accessing student prior knowledge. Requiring students to recall their prior knowledge associated with a new concept is a key element of the IDEAS model. Figure 7 outlines an interactive routine used in the IDEAS model for this purpose.

IDEAS PRIOR KNOWLEDGE ROUTINE

NOTE-- THIS ROUTINE FOCUSES ON PAST EXPERIENCES. WHEN THE FOCUS IS EXPANDED TO PRESENT OR FUTURE EXPERIENCES, THIS ROUTINE GENERALIZES TO THE ADVANCED INVOLVEMENT ROUTINE

TEACHER: DESCRIBES OR REFERS TO LEARNING ACTIVITY EXPERIENCES OR CONCEPT(S)

TEACHER: ASKS QUESTIONS OF STUDENTS IN CLASS RE: WHAT THEY KNOW ABOUT OR REMEMBER THAT IS RELEVANT TO THE CONCEPTS IN THE ACTIVITY

STUDENTS: RESPOND IN TERMS OF 'APPROPRIATE' (I.E., RELEVANT TO CONCEPT)

[A] OUT-OF-SCHOOL EXPERIENCES

[B] IN--SCHOOL EXPERIENCES

TEACHER: POSITIVELY ACCEPTS AND ENCOURAGES ALL STUDENT RESPONSES

[A] IF 'APPROPRIATE' RESPONSE
THEN
RECOGNIZE POINT MADE BY STUDENT
AND
ASK FOLLOW-UP QUESTION TO SAME OR NEW STUDENT

[B] IF NOT 'APPROPRIATE' RESPONSE
THEN
RECOGNIZE FACT THAT STUDENT RESPONDED
AND
POINT OUT WHAT STUDENT RESPONSE IS ACTUALLY RELEVANT TO
AND
POINT OUT WHY RESPONSE IS NOT 'APPROPRIATE'
AND
ASK FOLLOW-UP QUESTION TO SAME OR NEW STUDENT

Figure 7. IDEAS Prior Knowledge Routine specifying teacher-student interaction in reviewing and accessing prior knowledge.

- creating an initial concept map representing student prior knowledge. Building a concept showing students' prior knowledge both clarifies what their prior knowledge is (e.g. concept connections) and illustrates how concept maps represent conceptual knowledge - both of which are important elements of the IDEAS model. Figure 8 outlines an interactive routine for guiding student concept map development.

IDEAS CONCEPT MAPPING ROUTINE

NOTE-- THIS ROUTINE USES 'POST IT' NOTES ON A BLACKBOARD OR EQUIVALENT MATERIALS AS A MEDIUM TO MANIPULATE AND/OR EDIT A CONCEPT MAP BEING DEVELOPED. CONCEPT MAPS CAN BE USED BEFORE, DURING, OR AFTER DIFFERENT ACTIVITIES (E.G., READING, WRITING, HANDS-ON ACTIVITIES)

TEACHER: PREPARES BY DEVELOPING LIST OF ALL IMPORTANT CONCEPTS FOR UNIT OR LESSON

TEACHER: INITIATES CONCEPT MAPPING ACTIVITY BY INTRODUCING SELECTED KEY CONCEPTS ON 'POST IT' NOTES OR BY CONTINUING WITH 'POST IT' NOTE CONCEPT MAP DEVELOPED IN A PREVIOUS ACTIVITY

TEACHER: USES PRIOR KNOWLEDGE REVIEW ROUTINE (OR INVOLVEMENT ROUTINE) TO ELICIT STUDENT IDEAS (I.E., KEY QUESTIONS) ABOUT CONCEPTS TO INCLUDE OR ABOUT ARRANGEMENT OF CONCEPTS IN THE MAP

STUDENTS: OFFER SUGGESTIONS TO THE TEACHER IN TERMS OF:

[A] CONCEPTS TO ADD OR DELETE
[B] CONCEPT CONNECTIONS
[C] LINKING RELATIONSHIPS
[D] ARROWS THAT REPRESENT FLOW OF IDEAS

TEACHER: EDITS THE CONCEPT MAP BASED UPON STUDENT INPUT IN CONTEXT OF CONCEPTS WITHIN UNIT OR LESSON.

EDITING OPERATIONS BY TEACHER INCLUDE
[A] ADDITIONS/DELETIONS OF CONCEPTS VIA 'POST IT' NOTES
[B] RE-ARRANGEMENT OF 'POST IT' NOTES TO CHANGE THE 'BIG IDEA' STRUCTURE OF CONCEPT MAP
[C] ADDITION/DELETION/MODIFICATION OF LINES THAT REPRESENT LINKING RELATIONSHIPS AMONG CONCEPTS
[D] USE OF ARROWS TO INDICATE THE 'FLOW OF IDEAS'

Figure 8. IDEAS Concept Mapping Routine specifying teacher-student interaction in building concept maps.

- teacher demonstration or student hands-on activity. The specific activity selected should be directly related to the concept being taught and have motivational interest to students. Included as part of the activity should be opportunities for discussion and explicit identification of the concept.
- implementing the IDEAS model. The classroom implementation of the IDEAS model should consist of the variety of conceptually organized and meaningfully sequenced activities developed in the unit plan. Consistent with the IDEAS architecture, units should be multi-lesson and implemented within a daily 2 hour time block that allows sufficient instructional time for in-depth science learning (refer to text and the following section for additional details and an example).

Concrete example of classroom activities based on the IDEAS architecture

This section presents a typical sequence of activities used by an IDEAS grade 4 teacher to teach a core concept (evaporation and factors that effect evaporation) that is part of a multi-lesson unit on properties of matter (phase change). Figure 9 shows an example of a curriculum concept map used by the teacher to plan the learning activities described in detail below. In considering the example, readers should note that the activities represent only one of the possible alternative sequences of activities that could have been used and that assessment components, although implied, are not specified. Considered as a whole, the set of activities

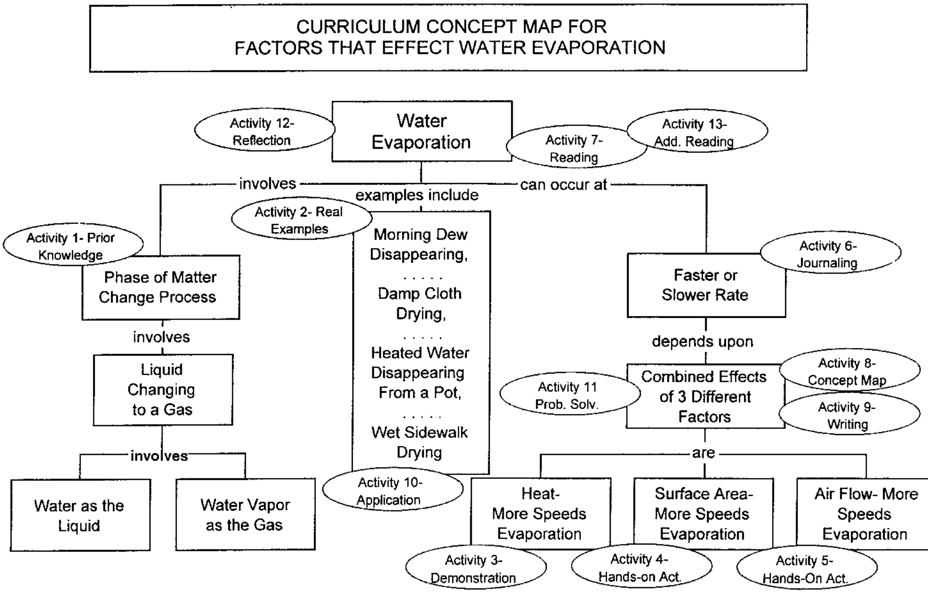

Figure 9. Example of a curriculum concept map used by grade 4 IDEAS teacher to organize core science concepts and to plan sequence of science instructional activities.

selected should be sequenced conceptually to focus on the core concepts to be learned by students.

- Activity 1 - reviewing prior curriculum knowledge about phases of matter. Teacher asks students to present examples of solids, liquids, and gases. Teacher selects several examples and asks what they would observe if they were to change phase (e.g. solid to liquid, liquid to gas, gas to liquid, liquid to solid).
- Activity 2 - accessing real world examples involving evaporation. Teacher presents students with a variety of scenarios involving evaporation (e.g. water droplets on car in morning, puddle of water on concrete sidewalk, boiling water in a pot, damp cloth in air) and asks students to explain what happens (i.e. water as liquid changes into gas). Teacher records key words students offer (e.g. liquid, gas, water, steam, water vapour, boiling, heat, air, temperature) on a chart tablet (incomplete list for future reference). Teacher uses the word 'evaporation' to represent the process all scenarios have in common (i.e. in all cases, water changed into gas, water vapour that goes into air).
- Activity 3 - teacher demonstration. 'Exploring heat as a factor that speeds evaporation'. Teacher uses two equally damp paper towels, placing one near a heat source and the other nearby but away from the heat. Students observe that heated towel dries quicker and discuss the role of heat as a process that speeds evaporation. Teacher repeats demonstration with two different heat sources applied to damp towels followed by discussion. Teacher refers students back to evaporation scenarios (Activity 2) and asks students to point out possible role of heat.
- Activity 4 - student hands-on activity. 'Exploring surface area as a factor that speeds evaporation'. Students use two equally damp paper towels, one crumpled into a ball and one spread out and observe which dries more quickly. Students discuss findings. Teacher refers students back to evaporation scenarios (Activity 2) and asks students to point out possible role of surface area.
- Activity 5 - student hands-on activity. 'Exploring moving air as a factor that speeds evaporation'. Students use two equally damp paper towels that are spread out. Students fan air over one towel but not the other. Students observe which dries more quickly. Students discuss findings. Teacher refers students back to evaporation scenarios (Activity 2) and asks students to point out possible role of moving air.
- Activity 6 - journal writing activity. For each experiment, students sketch a picture of the experiment and describe what each experiment illustrated with regard to evaporation. For each experiment, students are asked to select one of the evaporation scenarios in Activity 2 and explain how each of the three experiments is relevant to understanding it (i.e. in terms of factors that effect evaporation).
- Activity 7 - textbook reading activity. Teacher selects passages related to the process of evaporation. Students take turns reading the passages aloud as teacher engages student in a sentence-by-sentence discussion of the passage (including relating the passage to the previous activities). During discussion, students list the key words from the passage in their journals.

Teacher gives students comprehension questions. Students re-read the passages independently and answer questions. Teacher guides the review and discussion of each question.

- Activity 8 - teacher-guided student concept mapping activity. Teacher uses the IDEAS concept mapping routine (figure 8) to guide student construction of a group concept map for evaporation and factors that effect evaporation. Teacher has students refer to key words in journal as a reference source for building the concept map.
- Activity 9 - concept-map based writing activity. Teacher guides student use of the concept map constructed in Activity 8 as a blueprint for writing about evaporation and factors that effect evaporation. Writing activity is placed in journal.
- Activity 10 - out-of-school application activity. Students are asked to identify examples of evaporation in their everyday world (e.g. clothes in a dryer, food in microwave, clothes on a line, hair-dryer, hanging damp towel to dry), how to interpret each in terms of different factors effecting evaporation, and record their examples and interpretations in their journal for discussion in class.
- Activity 11 - problem-solving hands-on activity. Students work in cooperative groups to solve problems related to speed of evaporation: (1) given equally damp towels, students compete to design and implement a strategy to dry their towel as quickly as possible within a specified time limit; and (2) given equally damp towels, students compete to design and implement a strategy to keep their towel from drying out as little as possible within a specified time limit. At the end of each activity, student judges determine the winning group and the teacher leads a discussion of the different strategies used in terms of factors that effect evaporation.
- Activity 12 - relating new knowledge to prior knowledge activity. Teacher displays chart with key words from students' original ideas from the prior knowledge activity (Activity 2) and the concept map developed in Activity 8. Teacher guides reflective class discussion on how their knowledge has developed and become more organized.
- Activity 13 - additional reading activity. Teacher selects materials from a variety of sources on evaporation and related topics for students to read, summarize in journals, and share with class.