SOME INTERDISCIPLINARY PERSPECTIVES FOR BROADENING THE SCOPE OF SCIENCE EDUCATION RESEARCH [1,2]

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Abstract

Explored in this paper is the question of the relationship of empirical studies in science education to the stated purpose of NARST. Part one presents an analytic framework for use by science education researchers to evaluate the relevance of their work and that of others to that purpose. Part two applies the framework to an informal analysis of the scope of science education research by considering two complementary information sources: (a) the research strands for the present 2007 NARST *Annual Conference,* and (b) a sampling of articles published in the *Journal of Research in Science Teaching* (JRST). Together these two sources provide an operational perspective of the ontological structure of NARST. Using parts one and two as a guide, part three suggests areas of interdisciplinary research that potentially offer a means for magnifying the focus of science education research on the instructional dynamics for engendering student learning outcomes.

As stated in the Bylaws (NARST, 2005) of the *National Association for Research in Science Teaching* (NARST), "*The purpose of the Association is to promote research in science education and to disseminate the findings of this research to improve science teaching*." Although this purpose seems clear, the scope of research in science education is an issue that has engendered a great deal of attention reflecting a wide range of perspectives (e.g., Abell, 2001; Abell & Lederman, 2007; Baker, 1991; Bat-Sheva & Linn, 1988; Bennett et al., 2005; Erickson, 2000; Fensham, 2004; Findley et al., 1992; Fischer et al., 2005; Fraser & Tobin, 1998a, 1998b; Gabel, 1994; Good, 2007; Gunstone & White, 2000; Holliday, 2003; Horteon, 1993; Hurd, 1991, 1993; Hugh, 2003; Jenkins, 2000; Klopfer, 1991, 1992; Koballa et al., 1990; Lawson, 2005, 2007; Lederman, 2002; Lederman et al., 1993; Linn, 1992, 1994; Lock, 2002; Meheut & Psillow, 2004; Millar, 2003; Millar et al., 2000; Novak, 1965; Ratcliff et al., 2002; Ruiz-Primo et al., 2002; Shymansky, 1992, 2007; Simmons et al., 2005; Tsai & Wen, 2005; Underhill & Pieper, 2006; Wandersee, 1993;Wilson, 1992).

Given the diversity of science education research, one approach to considering research in science education would be to define it as whatever science education researchers investigate through empirical studies. But, while such an approach is justifiable on general grounds, it does beg the question of the degree to which any empirical study is relevant to the stated purpose of NARST. Addressing this purpose, this paper consists of three parts. First, the paper considers the question of what perspectives could be applied by science education researchers to evaluate the relevance of their work to the purpose of NARST. In doing so, the paper offers an analytic perspective in the form of an interpretative framework. Second, the paper informally overviews the scope of research in science education by considering two complementary information sources: (a) the research strands for the present 2007 NARST *Annual Conference,* and (b) a sampling of articles published in the *Journal of Research in Science Teaching* (JRST). Together

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these two sources provide an operational perspective of the ontological structure of NARST. And, third, with the preceding parts as a guide, the paper suggests some interdisciplinary approaches that potentially offer a means for magnifying the focus of science education research on the purpose of NARST.

In the pursuit of the preceding, it is important to note that the point of this paper is not to assign value to different topics investigated or to various methodologies used by science education researchers in empirical studies. Rather, all studies conducted in a methodologically-sound manner should be considered as having an equal potential to contribute toward the growth of disciplinary knowledge on a long term basis (Sidman, 1960). As the history of science has shown repeatedly, the ultimate relevance of any study to a discipline is always an open question that depends on the nature of knowledge identified at future times. So the focus of this paper is on the relevance of research in science education to the purpose of NARST, not on the value of different types of research studies in science education.

Addressing Ambiguity in the NARST Purpose Statement: Teaching vs. Teachers

One interpretation of the meaning of the term *teaching* in the NARST purpose statement is to equate it to the term *teachers*. With this interpretation, the focus of science education research is necessarily upon teachers (e.g., what they do, their characteristics, their perceptions). But such a literal interpretation does not provide a research focus on what is required to engender the forms of achievement (and other) outcomes of science instruction. Rather than focusing solely on teachers, this latter (functional) perspective considers classroom instruction as a means to an end. Such a functional orientation would interpret *teaching* as the instructional conditions that result in student performance outcomes. With this interpretation, the NARST purpose statement can be considered to refer to science education research that improves student learning outcomes which, in turn, are engendered through instructional strategies implemented by teachers or other alternative means (e.g., interactive electronic media, cooperative learning, independent learning). Although such a "phrasing" may seem radical, it is not so because teachers are likely to continue to be the predominant medium for delivering instruction in classroom settings. Rather, the functional emphasis on *teaching* focuses the purpose of NARST research upon the development of knowledge that can be used to improve student performance outcomes.

Some Technical Characteristics of Research that Produces Knowledge for Improving Student Learning Outcomes in Science

Virtually all education research textbooks distinguish between three basic types of research: (a) experimental, (b) correlational, and (c) descriptive. Each of these forms of research is distinguished by the kinds of research conclusions that can be made from methodologically well-designed studies, an important epistemological concept. But, more importantly, the distinctions between the three types of research and their associated research conclusions are well grounded in the history of scientific research itself. In fact, this view of research also is consistent with standard content on the nature of science appearing in most school science textbooks. When the three different types of conclusions from the wide variety of empirical studies are considered, it is important to recognize that the three types of research each encompass a large number of research variants whose specific practices differ in detail (e.g., conclusions from qualitative research involve statements of relationships or descriptions of phenomena; experimental studies may involve group comparison or single subject designs).

A major point in this paper is the reminder that experimental studies in which one or more instructional interventions (or variables) are manipulated is the form of scientific research that provides what education research textbooks call "causal" knowledge. While the term "causal" itself has some philosophical ambiguities, the relevance of the results of experimental research studies to the NARST purpose statement can be illustrated by using what are called "production rules" developed in cognitive/computer science (see Luger, 2002) as simple knowledge-representation tools.

The idea of a production rule is to represent knowledge in an IF-THEN format as follows: IF <X occurs> THEN <Y occurs>. Note- in such contexts, production rules are not evaluated as either "TRUE" or "FALSE"; rather their value is expressed in terms of probabilistic outcomes (i.e., there is some PROBABILITY (between 0 and 1) THAT IF < X occurs> THEN <Y will occur>). In the case of making a prediction, the knowledge represented as a production rule implies that IF <X occurs> THEN <the occurrence of Y should be predicted>. In specific instances (application), such predictions are, in effect, empirical tests of the accuracy or validity of the knowledge represented in the rule.

As conclusions based on experimental research, production rules are slightly different but far more powerful. Representing the (causal) knowledge that results from experimental studies, production rules have the form: IF <X is done> THEN <Y is made to occur>. In turn, such production rules can be restructured to provide guidelines for application in the form: IF <you want TO MAKE Y OCCUR> THEN <you should DO X>. Note that this is the exact form of applicable knowledge that represents the purpose of science education research stated in the NARST Bylaws.

In turn, production rules also provide a meaningful way to represent the process of applying knowledge to explain phenomena that have occurred. For example, assume two complementary production rules representing the following knowledge: IF < a substance is heated> THEN <it will expand> and IF < a substance is cooled> THEN <it will contract>. Students with this knowledge, would be able to predict whether a substance will expand or contract given whether the substance is heated or cooled (recognizing water as an exception). Additionally, to make a substance expand or contract, the student would "know" to heat or cool the substance, as appropriate. Finally, given that a substance expanded or contracted, the student would be able to apply the knowledge represented by the production rule to suggest cooling as a plausible (i.e., possible) explanation. Although production rules are workable as knowledge-representation tools, other approaches (e.g., case-based reasoning) are more appropriate for complex forms of knowledge from the standpoint of representational efficiency (e.g., Klodner, 1993, 1997; Luger, 2002; Pal & Shiu, 2004).

Within the accepted practice of scientific research in any discipline, the status of findings from a specific study must progress through an evolution that meets certain standards. The most important of these is *replicability*. The results of a single experiment are never accepted for addition to a disciplinary knowledgebase. Rather it is the replication of the findings across the widest possible scope of application settings that builds support for the validity of the manipulation-outcome relationship reported in the original study. Additionally, as they accumulate, such replications might be expected to yield additional information regarding the conditionally of the effect (i.e., under what conditions doing X would result in Y occurring). And, finally, in maintaining an emphasis on establishing the *relatedness* of different phenomena, an important but derived scientific initiative involves the *parsimonious* categorization of the elements (X, Y) involved in an X-Y relationship (e.g., different forms of energy) and the categorization of the relationships themselves (e.g., one broad definition that would apply to any form of learning would be changes in categories of performance outcomes as a function of different conditions of practice).

Toward Guidelines for Science Education Research that Directly Addresses the NARST Purpose

One classic area of science education research that has been recognized repeatedly (Holliday, 2003; Shymansky, 2007) as having a direct impact on practice has been the studies of "wait-time." As defined by Rowe (1974), wait-time is the time interval that begins when a teacher stops asking a question and ends when either a student responds or the teacher begins speaking again. In fact, this research topic is broadly illustrative of the potential impact of experimental research and the potential interplay of experimental, correlational, and descriptive research in the development of applied knowledge. Although Rowe's original multi-year study began with descriptive/correlational studies which evolved into a series experimental microstudies, her initial work did not link wait-time to student achievement outcomes. However, in an extensive review of research, Tobin et al. (1994) found that the original research studies had been extended to show the positive effects of wait-time on student achievement.

Focusing on the subsequent research on wait-time reported by Tobin et al. (1994), the experimental research findings of wait-time can be represented informally as a production rule: IF <wait time is increased to between 3-5 seconds> THEN <students will be engaged more actively in meaningful learning and student achievement will be improved>. In turn, the production rule representing the results of a series of studies can be re-stated as a form of applied knowledge (i.e., IF <you want TO ENGAGE STUDENTS IN MORE MEANINGFUL LEARNING AND INCREASE ACHIEVEMENT> THEN < you should INCREASE WAIT-TIME TO BETWEEN 3-5 SECONDS>.

Using the science education research on wait-time and student achievement as an operational example, the following guidelines for determining whether a research study directly addresses the purpose of NARST are offered:

- *The focus of the study is on science learning outcomes (e.g., meaningful science understanding, in-depth conceptual learning).* If this is not the case, then "science" is only used in the study as a setting for investigating another topic (i.e., studies that do not focus on student achievement in science cannot address the NARST purpose).

- *The study investigates the effect of an intervention (or manipulated variable) on science learning outcomes (i.e., the study follows an experimental design).* If the study has no intervention, the study cannot result in a "research-based" conclusion through which a learning outcome can be said to be obtained through some action.

- *The study has been replicated sufficiently so that the effect of the intervention is well-established.* Broadening the context of the findings through replication is an important and necessary element for constructing research-based knowledge. If an effect cannot be replicated with consistency, then the intervention has no research-based application potential. An additional benefit of replication is the possible identification of conditions that affect the degree to which the outcome is produced by the intervention (e.g., student characteristics, classroom instructional context effects).

Considering the preceding, it is important to note that while providing a set of constraints, some other research characteristics also are important (e.g., the conceptual and grade-articulated curricular structure within which meaningful science learning occurs, the use of ecologically valid classroom settings for research in which cumulative learning of science knowledge occurs). These are addressed briefly in a later section of the paper. Again it must be emphasized that the preceding guidelines have nothing to do with the value of the different types of studies conducted by science education researchers. But, at the same time, as argued previously, studies that fail to meet these guidelines cannot directly impact the stated purpose of NARST.

Exploring Ontological Perspectives of Science Education Research

In the present context, ontology has to do with the concepts and associated cognitive structures of science education researchers in NARST (see Sowa, 2000). More specifically, the question of the ontology of the discipline is equivalent to the question of how science education research is perceived cognitively by the members of the discipline itself. In order to explore this question, two complementary information sources were used: (a) the strand structure of the NARST 2007 Annual Conference program and (b) categorization of samples of articles published in JRST, the official research outlet of NARST. The specific question addressed in this section of the paper is: "*Given the guidelines in the preceding section, to what extent is science education research directly relevant to the purpose of NARST?*"

Analysis of strands for the NARST 2007 Annual Conference. For the NARST Annual Conference, *strands* define the categories of science education research to which papers are submitted. By definition, these strands present a picture of the cognitive structure of science education research held by NARST.

As Table 1 shows, of the 14 distinct conference strands, only four focus on or include studies of classroom-level instructional interventions that engender student science learning outcomes. Of the four, #1 seems the most focused in this area (although the elaboration is somewhat ambiguous), while parts of #2, # 5, and #12 may possibly (since they include elements that do focus on student learning). Overall, of the 14 strands, 11 do not focus on or optionally include the effect of classroom interventions on student science learning. Even more revealing ontologically, of the 14, six of the strands (#3, #4, #5, #7, #8, #9) focus primarily on teachers. In addition, the area of science curriculum, which *The Third International Math and Science Study* (TIMSS) identified as a major systemic weakness of U.S. science instruction (Schmidt et al., 1997, 1999, 2001**)**, only appears by being embedded within strand #10, along with the other major topics of evaluation and assessment.

If there is any working conclusion regarding the ontological structure of the strands for the 2007 NARST Annual Conference, it is that the structure of the strands clearly reveals an emphasis on *teach*<u>ers</u> as subjects of study in their own right rather than reflecting the functional idea of *teach*<u>ing</u> as a set of instructional dynamics that engender student science learning outcomes directly relevant to the purpose of NARST. Coupled with the strands that focus on ancillary topics insofar as experimental studies of classroom interventions are concerned (# 6, #11, #12, #13, #14), the majority of papers presented at the 2007 Annual Conference, despite the fact that they may well report the findings of sound research, have little promise of producing knowledge that would result in the improvement of student science learning in classroom settings. One source of data becoming available at the time this paper was written was the number of paper submitted and accepted in each of the strand categories (see Appendix A for an informal review). In fact, the strand categories themselves only provide an ontological perspective of the organization (i.e., NARST). But the numbers of papers accepted within each category provide a complementary ontological perspective of the active engagement of the NARST membership in science education research.

Table 1. *NARST Strand Descriptions for the 2007 Annual Conference*

Strand	Strand Description
1. *Science Learning,* ***Understanding, Conceptual Change***	***How students learn for understanding and conceptual change***
2. ***Science Learning: Contexts, Characteristics, and Interactions***	Learning environments, teacher-student and student-student interactions, ***factors related to and/or affecting learning***
3. Science Teaching- Primary School Characteristics and Strategies	Teacher cognition, content knowledge, pedagogical knowledge, content knowledge, instructional materials, strategies
4. Science Teaching- Middle and High School: Characteristic sand Strategies	Teacher cognition, content knowledge, pedagogical knowledge, content knowledge, instructional materials, strategies

Table 1. *NARST Strand Descriptions for the 2007 Annual Conference (continued)*

Strand	Strand Description
5. ***College Science Teaching and Learning (Grades 13-20)***	Instructor cognition, content knowledge, pedagogical knowledge, pedagogical content knowledge, ***student understanding and learning, conceptual change***
6. Science Learning in Informal Contexts	Learning and teaching in museums, outdoor settings, community programs, communications media, after-school programs
7. Pre-Service Science Teacher Education	Pre-service professional development of teachers, pre-service teacher education programs and policy, field experience, issues related to pre-service teacher education reform
8. In-Service Science Teacher Education	Continuing professional development of teachers, inservice teacher education programs and policy, issues related to inservice teacher education reform
9. Reflective Practice	Teacher inquiry, action research, self-study, transformative education
10. Curriculum, Evaluation, and Assessment	Curriculum development, change, implementation, dissemination and evaluation, including alternative assessment of teaching / learning
11. Cultural, Social, and Gender Issues	Equity and diversity issues: sociocultural, multicultural, bilingual, racial/ethnic, gender equity
12. ***Educational Technology***	***Computers, interactive multimedia, video and other technologies***
13. History, Philosophy, and Sociology of Science	Historical, philosophical, and social issues of science related to science education
14. Environmental Education	Ecological education, experiential education, education for sustainable development, indigenous science

Note. Strands (#1, #2, #5, #12) indicating at least some emphasis on experimental studies involving the effect of classroom interventions on student achievement outcomes are shown in bold italics.

Analysis of JRST publications. Although there are other journals (e.g., *Science Education, International Journal of Science Education*) that specialize in science education research, the JRST under NARST sponsorship serves as a formal research outlet for NARST (and other) researchers in science education. As before, the categories of publications in the journal also provide a picture of the cognitive structure of science education research of NARST in a manner complementing that provided by the strands of the Annual Conference.

Figure 1 shows the classification scheme used to review and group JRST research studies. Referring to Figure 1, the categorization process first determined whether studies involved student science achievement and then whether the study was experimental, correlational, or descriptive. Next, for studies not falling in the preceding categories (i.e., not involving student achievement), the process then determined whether the focus of the study was (a) methodology (curriculum, assessment, philosophy), (b) student/teacher perceptions, teacher characteristics, or teacher actions, or (c) studies of advocacy (e.g., gender, race). Studies not falling within the preceding categories were classified as miscellaneous. For the investigation, editorial and comment/response articles were eliminated from the years 1965, 1975, 1985, 1995, 2005 and 2006 and the remaining studies for those years were reviewed and categorized. The researchers inter-rater reliability for the JRST categorization process = .94.

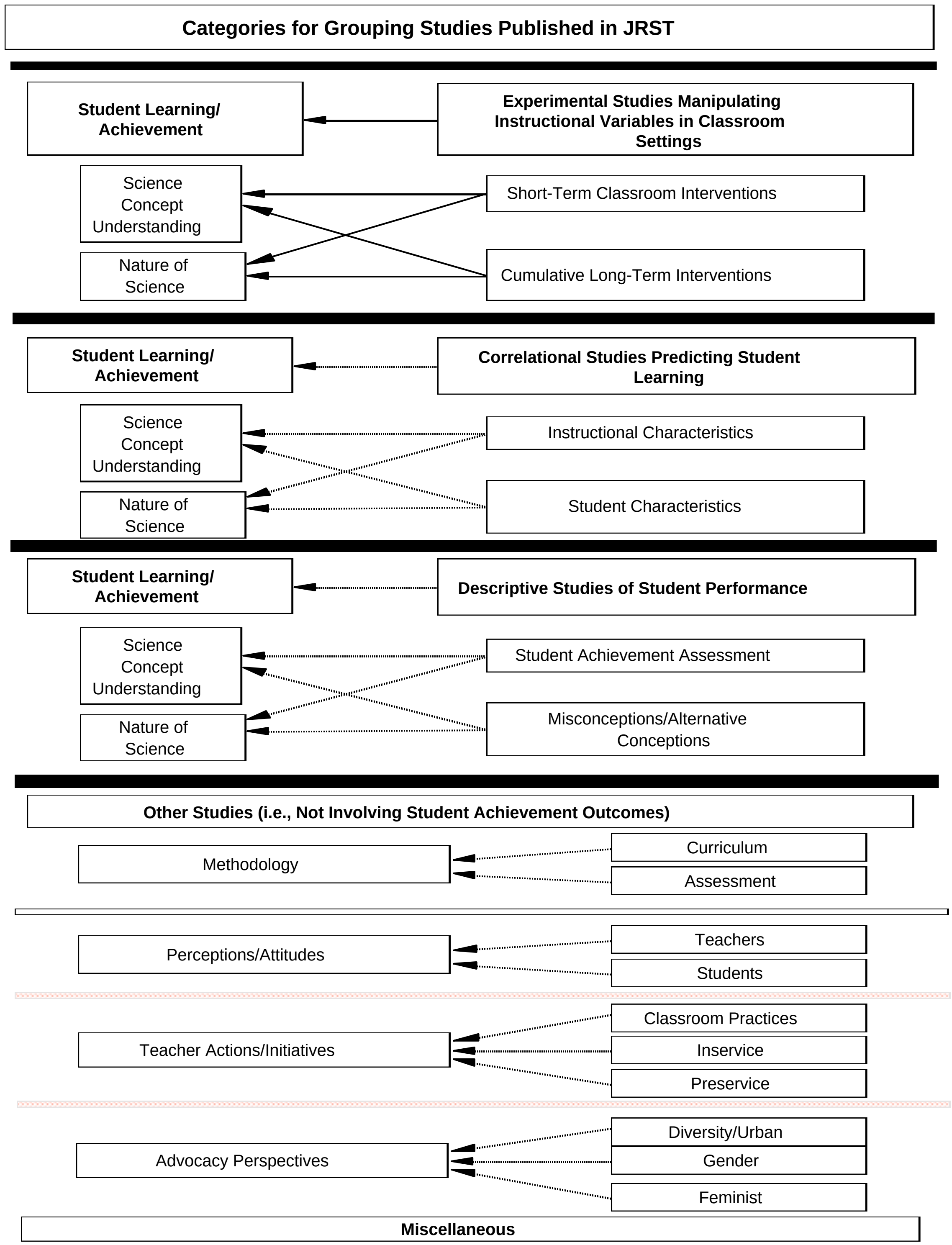

Figure 1. Categories for grouping JRST articles from 1965, 1975, 1985, 1995, 2005, and 2006. For summary, a number of sub-categories were combined (see Table 2).

Table 2 shows the percentage of different types of studies appearing in JRST for each of the years reviewed. As Table 2 shows, the percentage of *Teacher-Focused* studies showed a general increase over the years reviewed (with the exception of 1985). However, in contrast, the percentage of experimental studies investigating the effect of instructional interventions on student achievement (e.g., science concepts, nature of science, thinking, problem solving) ranging from K-12 to post-secondary classrooms decreased by approximately one-half (from 22 percent to 12 percent). Also of importance to the point of the present paper, the percentage of experimental studies overall was only 22 percent or 64 of the total of 288 studies reviewed over the 40-year span for the years sampled. A parallel "drop-off" was observed for correlational studies that involved relating either instructional or student characteristics to achievement outcomes. Finally, as Table 2 also shows, the percentage of studies representing advocacy perspectives increased substantially beginning with 1995 (studies were recorded as representing advocacy if they primarily emphasized perceptions, descriptions, or issues specific to an under-represented minority group.)

Table 2. *Percent of Empirical Studies by Category Published in the JRST in 1965, 1975, 1985, 1995, 2005, and 2006.*

Type of Study	Percentage of Studies					
	1965	1975	1985	1995	2005	2006
Studies involving student achievement)						
Experimental	**22**	**35**	**27**	**17**	**16**	**12**
Correlational	**23**	**19**	**26**	**10**	**7**	**15**
Descriptive	10	7	14	12	10	13
Other Studies (Not involving achievement)						
Teacher-Focused	**25**	**27**	**19**	**37**	**39**	**36**
Student-Focused	0	7	3	3	5	2
Methodology	20	6	6	9	11	10
Advocacy Perspectives	**0**	**1**	**7**	**15**	**14**	**13**

Note 1. The number of empirical studies by year were: 1965- 30, 1975- 51, 1985- 53, 1995- 60, 2005- 45, 2006- 41.
Note 2. The Teacher-Focused Category was computed by adding together the Teacher Actions/Initiatives and the Teacher Perceptions/Attitudes category, i.e., both involved studies focusing on teachers.
Note 3. Table entries were the average percentages reported by the researchers for each year-category.

Figure 2 shows line-graphs of the percentage of studies by year for the Experimental, Teacher-Focused, and Advocacy studies as a form of "trend interpretation" of the data in Table 2. As Figure 2 illustrates, the percentage of experimental studies focusing on student science achievement has dropped while the percentage of studies focusing on teachers has increased. In addition, the percentage of advocacy studies has increased to match the present level of experimental studies.

From the standpoint of the issues raised in this paper, the primary emphasis of science education research appearing in JRST clearly is not in the form of experimental studies that

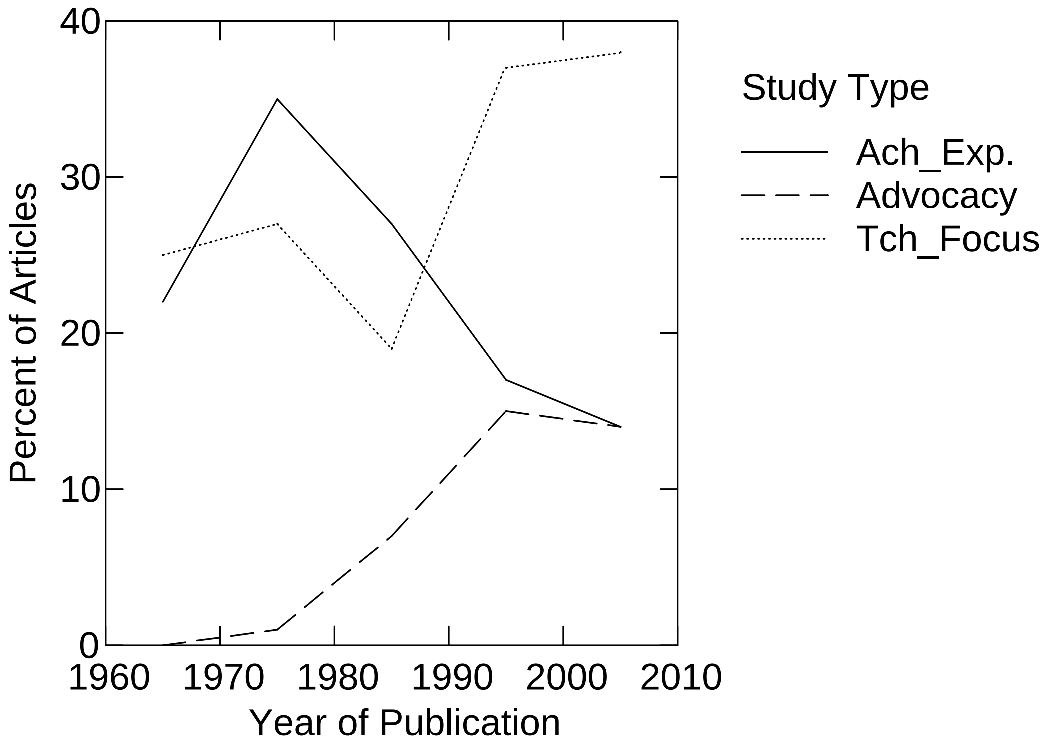

Figure 2. Percent of three types of JRST articles (Experimental, Teacher-Focused, Advocacy) illustrated as trends form 1965 to 2006.

would result in knowledge that is directly relevant to improving student science achievement and, by implication, to the stated NARST purpose of improving science *teaching*. Rather, the primary emphasis in JRST is studies of *teachers* (e.g., what teachers do, teacher perceptions, professional development) involving designs whose outcomes are not linked empirically to student achievement outcomes. As a result, it is not surprising why, after more than 40 years of JRST-published research, science education still faces the same form of problems relating to the effectiveness of science instruction and associated student achievement outcomes (Campbell et al, 2000). Moreover, of the experimental studies reviewed here, few addressed any issues in cumulative, in-depth and meaningful learning across grades K-12 or in post-secondary settings. If improving the quality of such instructional settings is to remain a major purpose of NARST, substantial work remains to be done.

Considering the Role of Interdisciplinary Perspectives to Broaden the Scope of Science Education Research

One conclusion from the preceding analyses is that the ontological focus of science education researchers as a group is not oriented toward conducting experimental studies that empirically link interventions in classroom settings to science learning as measured by student achievement outcomes. In the sense described by Kuhn (1996), the present structure of science education research is *paradigmatic* because it necessarily embodies the discipline's view of itself as a research endeavor that, from a dynamic perspective, is self-perpetuating. According to Kuhn, such paradigmatic perspectives can be changed only through an increasing accumulation of anomalous events that at some point are not able to be ignored, rejected, or excluded by a research discipline. When the resistance of established disciplinary perspectives is overcome, then the discipline undergoes whatever changes in cognitive frameworks are necessary to reconcile previously accepted data with the anomalous findings. As a result of such a revision process (i.e., *scientific revolution*), some new disciplinary ideas are formed and some old established ideas are discarded. However, unlike the substantial modification to previously-established conceptual perspectives, all methodologically sound empirical studies are retained by the discipline.

In considering the preceding, it is important to note that referring to the ontological structure of science education as paradigmatic does not imply the necessity of a scientific revolution in order to amplify the focus of research in science education so that it is more directly relevant to the stated purpose of NARST. This is because the present body of existing research in science education is certainly relevant to that goal to some degree. For example, Good (2007) recognized the research on student misconceptions (referencing Wandersee et al., 1994) as a body of knowledge highly relevant to classroom instruction. So, in effect, such research provides a context for experimental studies that have the potential to alleviate such science learning problems at the classroom level (Romance & Vitale, 1998). And the same point could be made with other science education research topics represented by the Annual Conference strands (e.g., pre-service and inservice professional development, teacher science knowledge, teacher perceptions).

Yet, while science education research may not require a revolutionary change in order to move forward, continuing to pursue the same research topics in the same ways within the existing ontological structure is not a satisfactory dynamic for change. In fact, such lack of change is consistent with the present paradigmatic structure of the discipline. With the condition that virtually all empirical research in science education is relatable in some way to student classroom learning of science, the point of this paper is that interdisciplinary research perspectives (e.g., cognitive science, instructional design, applied learning theory) that focus on cumulative meaningful learning offer significant enhancements to any research in science education that purports to focus on science learning. Such recent developments in interdisciplinary research, even though their primary focus is not on science learning per se, provide a means for enriching the science education knowledgebase and for accelerating progress toward addressing the purpose of NARST.

Overview of Interdisciplinary Research Perspectives Relevant to Science Education

The primary assumption of this section is that the focus of science education research is upon the development of knowledge that results in the improvement of student in-depth, cumulative understanding of science. In the following overview, the emphasis is upon perspectives from related disciplines whose research agendas and findings are directly relevant to meaningful conceptual learning of science as a student performance outcome.

A brief review of preliminary issues. As a subject of formal study, the discipline of science consists of two complementary components (American Association for the Advancement of Science, 1993). The first is the conceptual and factual knowledge that pertains to understanding the different domains of science (e.g., understanding the physical world, the living environment, and the human organism). The second addresses the nature of scientific inquiry which represents the cumulative process through which knowledge of science is established (i.e., understanding the process of scientific research). Even though the teaching and learning of science within elementary, secondary, and post-secondary educational settings differ substantially in degree of sophistication, all three are linked pedagogically by these two common components of science content and process (see Duschel et al., 2006; Smith et al., 2004). At any level of sophistication, these two components are fundamental to the concept of scientific literacy.

If the purpose of the field of science education is to apply the methods of scientific inquiry to advance pedagogical knowledge of how students are best able to gain a meaningful understanding of science content and the nature of science, then the field of science education must follow the processes established by science itself to advance such knowledge so that, when applied, science is able to be taught more effectively. The resulting pedagogical knowledge, therefore, represents the content of the field of science education (e.g., how to teach physics, earth science, or biological principles more effectively).

In contrast to science education research, research from related disciplines such as cognitive science (e.g., Bransford et al., 1999), educational psychology (Mayer, 2004), and instructional psychology (Grossen et al., 2007) offers a rich source of interdisciplinary perspectives and findings (see Vitale & Romance, 2006a) which have been unavailable to science education researchers, despite their potential for systemically improving the understanding of how that students gain in-depth science knowledge from school instruction. With this in mind, the remainder of this section presents principles and exemplary interdisciplinary research findings whose foundations are grounded in these related research fields and which offer implications for systemically improving student science learning.

A knowledge-based perspective for meaningful learning. A recent publication by the National Research Panel, *How People Learn*, edited by Bransford et al. (1999), serves as an important guide for research in science education. Focusing on the question of meaningful student learning, Bransford et al. stressed that to teach effectively in any discipline, the information being taught must be linked to the key organizing principles (or core concepts) of that discipline. In this regard, well-organized and readily accessible prior student conceptual knowledge is a major determinant of the forms of cumulative meaningful student learning that are characteristic of scientists, a principle also expressed by Hirsch (1996, 2006). From this research perspective, all forms of science pedagogy should focus all instructional activities (e.g., lecture, hands-on, reading, assessment) on the core concepts that reflect the underlying logic of the discipline.

One major area of research relating to the role of prior knowledge in meaningful learning reviewed by Bransford et al. (1999) focused on the cognitive differences between experts and novices. This research has shown repeatedly that expert knowledge (i.e., expertise) is organized in a conceptual fashion that is very different from that of novices and that the use of knowledge by experts in application tasks (e.g., analyzing and solving problems) is primarily a matter of accessing and applying prior knowledge (Kolodner, 1993, 1997) under conditions of automaticity. Related to this view is earlier work by Anderson and others (Anderson, 1987, 1992, 1993, 1996) who distinguished the “strong” problem solving process of experts as highly knowledge-based and automatic from the “weak” strategies that novices with minimal knowledge are forced to adopt in a trial-and-error fashion. Also directly related are key elements in Anderson’s cognitive theory that (a) considers all cognitive skills as forms of proficiency that are knowledge-based, (b) distinguishes between declarative and procedural knowledge (i.e., knowing about vs. applying knowledge), and (c) identifies the conditions in learning environments (e.g., extensive practice) that determine the transformation of declarative to procedural knowledge (i.e., learning to apply knowledge in various ways).

As characteristics of learning processes, the preceding research perspectives emphasize that extensive amounts of varied experience (i.e., practice) involving the core concept relationships to be learned are critical to the development of expert mastery in any discipline. In related research, Sidman (1994) and others (Dougher & Markham, 1994; Artzen & Holth, 1997) have explored the conditions under which extensive practice to automaticity focusing on one subset of relationships can result in the learning of additional subsets of relationships. In their work, these additional relationships were not taught, but rather were implied by the original subset of relationships that were taught. In other relevant work, Niedelman (1992), Anderson (1996), and Goldstone and Son (2005) have offered interpretations of the research issues relating to how the amount and kinds of initial learning (e.g., degree of original mastery, interaction of concrete experiences in varied contexts and abstract perspectives) are related to transfer of initial learning to applied settings.

A parallel area of research considered here is the knowledge-based architecture of computer-based intelligent tutoring systems (ITS) developed in the early 1980's (Kearsley, 1987; Luger, 2002). As illustrated in Figure 3, ITS systems use an explicit representation of knowledge to be learned as an organizational framework for all elements of instruction, including the determination of learning sequences, the selection of teaching methods, the specific activities required of learners, and the evaluative assessment of student learning success. Specifically, from the standpoint of assessment, knowledge-based instructional models consist of a sequence of interrelated activities that provide an authentic context for evaluating cumulative student meaningful understanding.

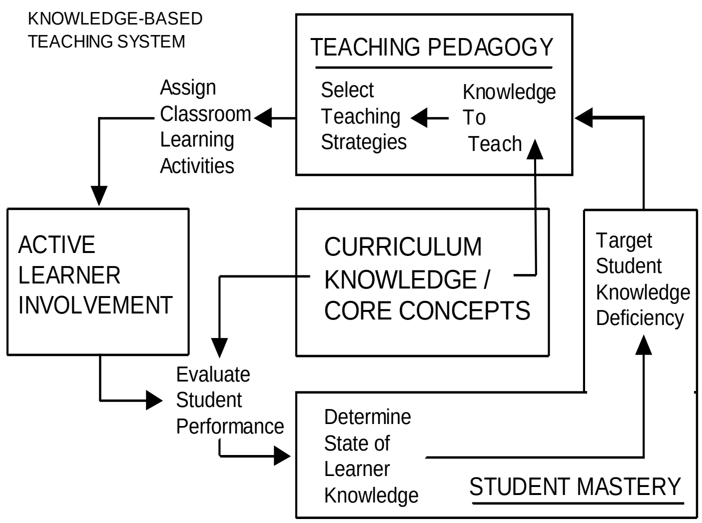

Figure 3. Instructional architecture for a knowledge-based intelligent tutoring system.

Although there is a well-established research literature (Bransford et al., 1999) that focuses on the importance of "content-free" metacognitive strategies (i.e., use of general strategies by students to facilitate their learning), a knowledge-based approach primarily emphasizes the development and organization of prior knowledge in a manner that is reflected in three research areas: (a) the development of expertise summarized by Bransford et al. (1999) and Anderson (1987, 1992, 1993, 1996), (b) the work of Kolodner and her colleagues (1997) on case-based knowledge representation and reasoning (i.e., remembering and applying past problem solving scenarios provides a powerful context for approaching the next problem), and (c) the general development of knowledge categories offered by Sowa (2000).

In general, adopting a view of meaningful science learning as knowledge-based provides a valuable (and parsimonious) perspective for integrating different forms of science education research and for linking science education research with practice. Following Bransford et al. (1999), a knowledge-based perspective holds that the cumulative experiences of students in developing in-depth conceptual understanding (i.e., expertise) results in the development of a framework of general knowledge categories (e.g., Dansereau, 1995; Vitale & Medland, 2005) in the form of core concepts and concept relationships. Within such a framework, additional knowledge is first assimilated and then used by students as prior knowledge for new learning as a form of expertise (see Mayer, 2004). In turn, the development of such conceptual expertise facilitates students cumulatively acquiring, organizing, accessing, and thinking about new information that is embedded in both reading comprehension and meaningful learning tasks to which such new knowledge is relevant (see Vitale et al., 2006a; Vitale & Romance, 2007).

The major principles following from a knowledge-based perspective that are relevant to both researchers and practitioners for sound science instruction are straightforward. They are: (a) all aspects of science instruction should focus on the development and organization of core science concepts, (b) both the curricular structure of instruction and curricular mastery by students should be considered to be and approached as a form of expertise (i.e., representing the form of science understanding characteristic of experts), and (c) the development of conceptual prior knowledge is the most critical determinant of future success in meaningful learning. While these are consistent with the views of many science educators in one form or another, a strong knowledge-based perspective provides the means to link them in an integrative fashion to the specific science learning experiences of students in classroom settings rather than selectively referring to them in a fragmented manner.

In this regard, an emerging research trend in interdisciplinary research (e.g., cognitive science, instructional design) is how cumulatively focusing on the core concepts and relationships that reflect the logical structure of the discipline and enhancing the development of prior knowledge are of paramount importance for meaningful learning to occur. Additionally, as suggestive of potential standards for sound science instruction focusing on both science concepts and nature of science, such research emphases are consistent with the findings of TIMSS which are presented as a research framework in the following section (Schmidt et al., 1997, 1999, 2001). At the same time, while advocating the adoption of a knowledge-based perspective by science education researchers for incorporating emerging interdisciplinary research trends, it also is important for science education researchers to recognize that K-12 science instruction offers interdisciplinary researchers an ecologically-valid setting for investigating the dynamics of cumulative, meaningful learning. Thus, in a complementary fashion, experimental studies conducted by science education researchers investigating science learning are well-positioned to contribute toward the theoretical foundations of related disciplines as well as to advance the field of science education itself..

Some exemplars illustrating an interdisciplinary perspective of science education research. This section presents a small number of research exemplars that serve two major functions. The first is that they illustrate one or more major points presented above within a research context that is directly relevant to science learning in school settings. The second is that, considered together, the exemplars provide systemic implications for improving the quality of science instruction in schools, and, therefore, for broadening the foundation of science education research. The exemplars are presented using the major curricular findings of the TIMSS study (Schmidt et al., 1997, 1999, 2001) as an overall framework in a fashion that complements the parallel ideas presented in the Bransford et al. (1999) report.

The curricular findings of the highly-respected TIMSS study (Schmidt et al., 1997, 1999, 2001) provide a strong cognitive framework for the research exemplars presented. In comparing the science (and mathematics) curricula of high achieving and low achieving countries, the TIMSS study reported a major conclusion that is consistent with the research above. Specifically, the TIMSS study found that the curriculum of high achieving countries was focused on big ideas (core concepts), conceptually coherent, and well-articulated across grade levels. In contrast, the curriculum in low-achieving countries (including the U.S.) emphasized a superficial, highly-fragmented coverage across a wide range of topics with little conceptual emphasis or depth (i.e., U.S. curriculum was “a mile wide and an inch deep”). In general, the findings of the TIMSS study and the supporting perspectives from Bransford et al. (1999) offer a useful framework for the exemplars that follow. The small number of studies reported here are intended to provide concrete examples that facilitate understanding of the implications of the research findings.

The first exemplar consists of work by Novak and Gowin (1984) who studied the developmental understanding of science concepts by elementary students over a 12 year period. Although completed some time ago, their work, which was based on Ausubel’s theory of cognitive learning (1968), is highly consistent with contemporary cognitive science research principles. In their longitudinal study, they used concept maps to represent the cumulative development of student understanding of science topics based on interviews. As their original work evolved, these two researchers initiated the use of concept maps by students to enhance their meaningful understanding of science. Related work has been reported by Fisher et al. (2000), Mintzes et al. (1998), Novak and Canis (2006), and Romance et al. (2000). Overall, these studies (e.g., Nesbit & Adesope, 2006) have demonstrated the importance of insuring students have the means to perceive, represent, and reflect on the development of their understanding of science concept relationships.

The second exemplar is a videodisk-based instructional program by Hofmeister et al. (1989) that focuses on the development of core science concepts in physical science (e.g., heating/cooling, force, density, pressure) necessary for understanding phenomena in earth science (e.g., how the concept of convection influences crustal, oceanic, and atmospheric movement). Figure 4 shows the core concept oriented curricular framework for the videodisk program.

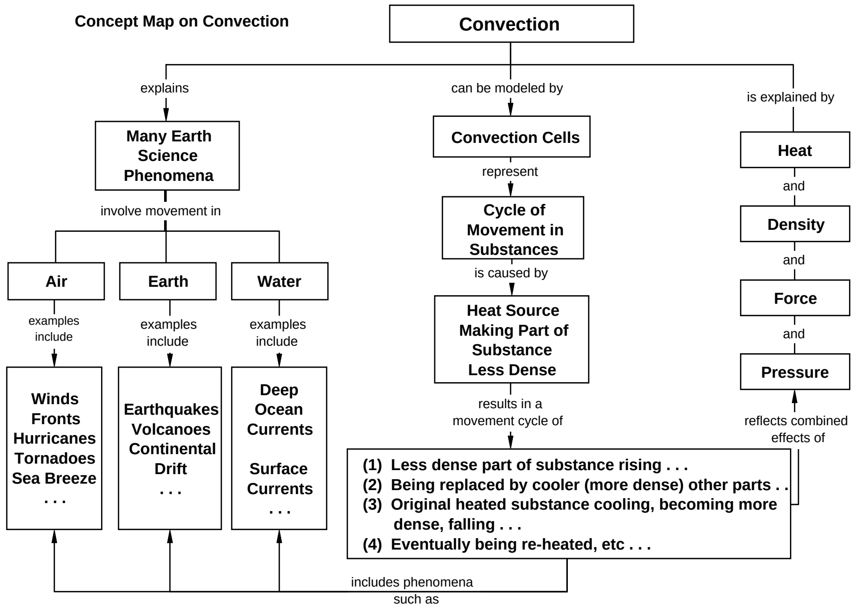

Figure 4. Curricular framework for major elements of the Hofmeister et al. (1989) instructional program on core concepts in physical and earth science.

Two representative studies are relevant here. Muthukrishna et al. (1993) demonstrated experimentally that instructional use of the videodisk-based materials to directly teach core concepts was an effective way to eliminate common misconceptions (e.g., seasons, day and night) of elementary students in science. Vitale and Romance (1992) showed in a controlled study that the use of the same core concept focused instructional program resulted in mastery of the same core concepts by elementary teachers (vs. control teachers who demonstrated virtually no conceptual understanding of the same content). In much the same way as did TIMSS (Schmidt et al., 1997, 1999, 2001) and Novak and Gowin (1984), the curricular development methodology (e.g., Engelmann & Carnine, 1991) used to construct the science content used in these studies is suggestive of how instruction using concepts and concept relationships as organizational principles can engender meaningful student learning.

The third exemplar is an experimental study by Klahr and Nigam (2004) which found teacher-guided direct instruction far more effective than a discovery approach, not only on student initial acquisition of a procedure for designing and interpreting simple unconfounded experiments; but also on subsequent application/transfer. In interpreting their findings, the perspectives offered by Klahr and Nigam were consistent with a more general analysis of the potential role of direct/guided instruction in meaningful science learning presented by Mayer (2004). In turn, both perspectives are consistent with interdisciplinary approaches in instructional science (e.g**.,** Engelmann & Carnine, 1991; Grossen et al., 2007) that address technical issues in the design of optimally effective learning environments.

The fourth exemplar is a series of studies at the elementary and postsecondary levels. In an analyses of learning by elementary students and of associated instructional materials, Vosniadou (1996) emphasized the importance of focusing instruction on the relational nature of science concepts in order for students to gain meaningful understanding. Dufresne et al. (1992) found that postsecondary students who engaged in analyses of physics problems based upon a conceptual hierarchy of relevant principles and procedures were more effective in solving problems. Complementing these two studies, carefully designed experiments by Leonard et al. (1994), Chi et al. (1981), and Heller and Reif (1984) showed that success in application of science concepts was facilitated by amplifying student understanding of the hierarchical organization of science concepts. The findings of these experimental studies parallel the descriptive findings of the TIMSS study and ideas presented by Bransford et al. (1999).

The fifth exemplar is a series of experimental studies with upper elementary students by Romance and Vitale (2001, 2006a) that encompass many of the preceding research-based principles. Their integrated instructional model, *Science IDEAS*, combines science, reading comprehension, and writing within a daily 2-hour time block that replaces regular (basal) reading and language arts instruction. During that time, students engage in science learning activities that involve hands-on science experiments/projects; reading science texts/trade books/internet-accessed science materials; writing about science; journaling; and using concept mapping as a knowledge representation tool. As an intervention implemented within a cumulative inquiry framework, teachers use core science concepts as curricular guidelines for identifying, organizing and sequencing the different instructional activities in which students engage (see Figure 5). Both within and across lessons, all aspects of teaching emphasized students learning more about what had been learned previously in order to engender cumulative, in-depth science understanding.

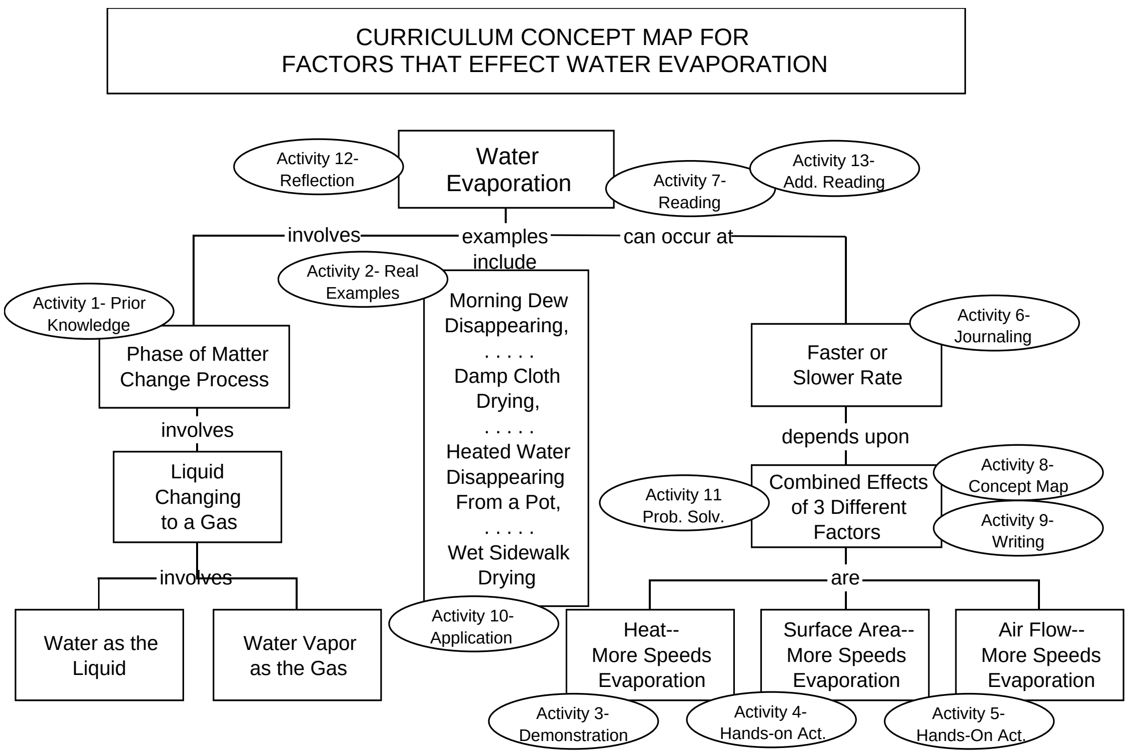

Figure 5. Illustration of simplified knowledge-based instructional plan for teaching water evaporation.

In a series of studies exploring the effectiveness of the model, Romance and Vitale (2001) showed that experimental students participating in *Science IDEAS* instruction obtained significantly higher levels of achievement in both science and reading comprehension as measured by nationally normed standardized tests (e.g., *Metropolitan Achievement Test- Science, Iowa Tests of Basic Skills- Reading Comprehension*). In addition, compared to controls, *Science IDEAS* students displayed significantly more positive attitudes toward science learning both in and out of school, greater self-confidence in learning science, and more positive attitudes toward reading in school. In addition, the researchers extended elements of the *Science IDEAS* intervention to postsecondary science instruction in chemistry and biology (Haky et al., 2001; Romance, Haky, et al., 2002). These extensions emphasized (a) the use of core concepts and concept relationships as a curricular framework for teaching and (b) student use of propositional concept mapping to enhance reading comprehension of science texts and to guide review and study. Considered together, this combined series of studies is supportive of the effectiveness of a knowledge-based approach to science instruction.

The following integrates the major points of the preceding research exemplars from two perspectives: (a) as a set of characteristics required for the ecological validity of research investigating science instruction as a cumulative learning process and (b) as informal instructional guidelines for science education practitioners as research consumers. In specifically providing a concomitant set of constraints for science instruction and for science education research, these points are:

- A comprehensive science curriculum should include the study of both science knowledge and the nature of science (not just one of the two) as a requirement for science literacy,

- The curricular focus of science instruction at all levels should be on the core concepts and concept relationships (i.e., science principles) within the areas of science to be taught and learned (consistent with the conceptual organization of experts and representing the logic of the discipline),

- The overall framework of core concepts and core concept relationships should be articulated across grade levels in a clear and coherent fashion. Cumulative development of science understanding as students progress through school should be accomplished through the elaborative detailing of core ideas previously introduced (as much as is possible),

- A knowledge-based instructional architecture should be used as an organizational structure for relating all student learning activities, assessment practices, and teaching strategies to an overall core concept framework,

- Students should experience a variety of learning activities for developing meaningful science understanding of core concepts, including the use of concept mapping as a knowledge representation tool, and,

- Students should not engage in application and problem solving experiences until after they have gained meaningful science understanding of the relevant science concepts.

Implications of an Interdisciplinary Research Perspective for Improving Science Instruction

In this section, the implications of interdisciplinary research are considered from three perspectives: (a) directions for research in science education, (b) transformation of research into practice, and (c) corresponding recommendations for research that help ensure potential utilization by practitioners.

Interdisciplinary directions for science education research. Perhaps the most important implication of the preceding is that science education researchers should strive toward forming interdisciplinary perspectives which result in the integration of their research with that of other related disciplines. In doing so, researchers should recognize that such an initiative is consistent with both a constructivist view of knowledge development and the cumulative inquiry processes on which all science is based. Further, the integration of diverse disciplines should be recognized as a means for pursuing systemic disciplinary advancements (e.g., see Kuhn, 1996; Hirsch, 1996; Mayer, 2004).

In working to advance understanding of science learning, science education researchers should consider the potential benefits of incorporating three emerging interdisciplinary areas of investigation into science education research. The first of these research areas is Engelmann and Carnine's (1991) *Direct Instruction* (DI) model from instructional psychology. The DI model provides an algorithmic (i.e., procedural) framework for instructional development that includes strategies for effectively teaching concepts, concept relationships, intellectual skills, and cognitive processes applying complex knowledge and skills. Additionally, the model includes strategies for the developmental articulation of curriculum emphasizing core concepts in a fashion that optimizes retention, application, and the utilization of the knowledge and skills learned as relevant prior knowledge that facilitates new learning.

All of the algorithmic components of the DI model could be applied and investigated in science learning frameworks. Of particular promise for science education research is using elements of the model to pre-teach core science concepts that would then serve as prior knowledge for students participating in the more informal, open-ended, and problem-based settings using the small group inquiry formats that are favored by constructivist-oriented science educators (see Mayer, 2004). However, because the fields of DI and science education have different emphases, the present ontological framework of science education cannot represent the operational dynamics of the DI model at the level of detail required for research without substantial interdisciplinary integration.

The second research area to consider is Anderson's cognitive-science-based *Adaptive Control of Thought* (ACT) model. The cognitive science research of Anderson (1992, 1993, 1996) provides a theoretical framework that focuses on the transition from novice to expert in terms of the interplay between the dynamics of the learning environment on one hand and forms of declarative and procedural knowledge on the other. In one fashion or another, these are among the critical issues associated with the use of formal science instruction to build conceptual understanding from a knowledge-based and meaningful learning perspective. Although complex, Anderson's (Anderson, 1987; Anderson & Fincham, 1994, 1996; Anderson et al., 1997; Anderson & Sheu, 1995; Blessing & Anderson, 1996) and related work (e.g., Wisniewski, 1995) have yielded many important research findings. Included among these are (a) techniques for the differential representation of declarative and procedural knowledge, (b) processes for the development and refinement of cognitive skills, (c) models addressing the transformation of declarative to procedural knowledge, (d) models distinguishing between expert and novice problem solving, and (e) models explaining the reorganization of skill patterns and knowledge structure in the development of expertise. Additionally, Anderson (with others) also has used his work as a foundation for critiquing research and policy issues in education (e.g., Anderson, Reder et al., 1995, 1996).

Along with DI, Anderson's ACT model could be readily applied (or investigated) within a variety of instructional scenarios involving science curriculum. Of particular interest to science education researchers would be studies conducted with meaningful science content that address such issues as knowledge (concept) acquisition, automaticity, and the development of expertise, all in a fashion that would investigate characteristics of the instructional environment which, in terms of variables in the ACT model, engender such outcomes. Again, the point here is that adapting Anderson's ACT model to research in science teaching for which the observed structure of the environment in combination with prior knowledge is the basis for learning could advance the goals of science education. As with the DI model, the present ontological framework of science education cannot represent Anderson's ACT model at the level of detail required for research without substantial interdisciplinary integration.

The third area considered here is the area of *equivalence relations* in learning (or stimulus equivalence) conducted in behavior analysis research. Although highly experimental at the present time, the potential of this research (Sidman, 1994) is that it addresses the question of how to engender learning outcomes that arise indirectly from instruction because they are based upon the structural properties (i.e., inferable inter-element relationships) of the knowledge to be learned. Since science is a meaningfully-structured content domain, it is an area that could benefit greatly by gaining an understanding of equivalence relations phenomena. Stated another way, this research area (e.g., Baer, 1997; Dougher & Markham, 1994; Sidman, 1994) addresses the general question of the development of generative inferential processes in learning. More specifically, from the standpoint of research in science education, stimulus equivalence research focuses on understanding how the structure of science knowledge and the conditions under which the parts of such structures that are taught can be made to result in learning outcomes that, in relation to the original knowledge structure, are far broader than what was taught explicitly (e.g., Artzen & Holth, 1997; Eilseth & Baer, 1997; Lane & Critchfield, 1996; Lynch & Cuvo, 1995).

The preceding examples from the area of equivalence relations have significant implications for the development of science curriculum design strategies which maximize student learning outcomes that result from formal instruction in terms of learned-but-not-taught relationship-based content. In addition, the implications from this research area for science education complement instructional design models such as DI and Anderson's ACT model. While both the DI and ACT models emphasize the direct teaching of conceptual relationships and strategies, research on equivalence relationships in science education would focus on developing prescriptive guidelines for accomplishing learned-but-not-taught outcomes in K-12 (and post secondary) science instruction. Again, as with the DI and ACT models, the present ontological framework of science education cannot represent behavior analysis equivalence relations at the level of detail required for research without substantial interdisciplinary integration.

Perspectives for transforming research into practice. A second important interdisciplinary perspective for science education research is the transformation of research into practice. As represented in the specifications for specific federal proposals (e.g., *National Science Foundation (NSF), USDOE.- Institute of Education Sciences*), the development of research knowledge can be approached as a multi-phase process that involves the transformation of initial proof-of-concept demonstrations into controlled replicable research studies, that, in turn, evolve into scale-up initiatives within applied settings (see Coburn, 2003; Dede et al., 2005; Glennan et al., 2004; Romance & Vitale, 2006a, 2007; Schneider & McDonald, 2006a, 2006b; Vitale & Romance, 2004, 2005). In the present context, such scale-up studies emphasize the development of the capacity of school systems (e.g., professional expertise, organizational infrastructure) to initiate, sustain, and expand the use of research-based applications (see Romance & Vitale, 2007; Vitale & Romance, 2004, 2005).

Although such systemic perspectives may be of limited interest to many science education researchers, they necessarily are of primary importance to the discipline of science education because of the limitations in the institutional capacities for science instruction that affect school curricular policy and priorities. For example, Jones et al. (1999) found that school reform initiatives resulted in instructional time for science being reallocated to reading and language arts, raising a significant policy issue for science education. And, Appleton (2007) summarized an extensive body of research that indicated a systemic lack of science understanding by elementary science teachers that precluded their effective teaching of science. In contrast, however, Vitale et al. (2005) reported research findings that building a school-based capacity to replace reading/language arts with science increased achievement in reading comprehension and language arts as well as in science. In addition, a related series of research demonstrations, Guthrie et al. (2004) found that well-designed professional development providing teachers with the capacity to enhance traditional elementary-level literature-oriented reading programs with modules emphasizing reading-in-science consistently enhanced both science and reading achievement.

The point is that while such research findings (see also, Duke et al., 2003; Walsh, 2003) have implications for curriculum policy (see Romance et al., 2002; Vitale et al., 2006b), engendering systemic changes in curricular practices based on research findings in science education will require researchers themselves to build the forms of institutional capacity needed for application of their work. Addressing such scale-up issues is presently an active area of research and development (Coburn, 2003; Dede et al., 2005; Glennan et al., 2004; Romance & Vitale, 2006a, 2007; Schneider & McDonald, 2006a, 2006b; Vitale & Romance, 2004, 2005).

Some interdisciplinary-based recommendations for science education research. As an integrative summary, the following recommendations are offered as a foundation for broadening the interdisciplinary foundations of science education research. Specifically, in planning future research agendas, science education researchers should consider the possibility of addressing issues that recognize and/or consider the:

- ontological implications of interdisciplinary research perspectives,
- ecological validity of findings by conducting research within instructional environments that provide a valid curricular and assessment context for the cumulative in-depth learning of science,
- distinction between categories of macroscopic and microscopic science concepts (i.e., directly observable, real but not observable, constructed but not real) to be learned within different developmentally-appropriate instructional contexts,
- adoption of a knowledge-based perspective for science instruction that considers conceptual understanding as expertise and recognizes the role of such conceptual knowledge in gaining an understanding of the nature of science,
- importance of focusing research on the identification and refinement of conditions whose implementation can result in improved student understanding of science (as the goal of science education research), and,
- programmatic forms of research design that encompass the evolution from proof-of-concept to controlled experimentation to demonstrated replicability in applied settings (i.e., scale up).

Ultimately, the effective utilization and advocacy for research in science education must come from practitioners as societal representatives (Johnson & Pennypacker, 1992). Although the U.S.-mandated *No Child Left Behind* initiative includes science, there is a tendency for schools to meet accountability requirements by emphasizing short-term (within grade) test preparation rather than pursuing the forms of curricular or instructional changes that result in systemic improvement. As a result, the practice of “evidence-based” decisionmaking by schools is far from optimal. In this regard, Hirsch (1996, 2006), Carnine (1995), and Mayer (2004) have offered a number of perspectives to which researchers should be sensitive (see also Slavin, 1990). Primarily, science education researchers and practitioners should be advocates for the use of empirical research findings as a basis for school decisionmaking and, in this regard, consistently work toward ensuring that any form of advocacy of their own or others’ research findings meet this general principle. By doing so, researchers will be contributing toward establishing the general evidence-based criteria of effectiveness that instructional initiatives must display prior to large-scale adoption in reform (see Carnine, 1995).

Summary and Implications

If a continuing goal of science education research as represented by the purpose of NARST is the generation of pedagogical knowledge that can be used to improve the meaningful learning of science by students, then the interdisciplinary perspectives presented in this paper are suggestive of some ways through which progress in science education research could be accelerated. Despite the fact that experimental research investigating the effect of classroom interventions on student learning is not the predominant type of research conducted in science education, consideration of the interdisciplinary perspectives presented in this chapter along with others in the literature may be helpful in initiating a programmatic research trajectory that would transform the focus of the present research in science education into the forms of experimental research that address the purpose of NARST.

Regarding the pursuit of this goal, it must be noted that until science education researchers in general and NARST members in particular increase the number of experimental studies, science education research will continue to have a limited potential for either improving science *teaching* or for having a substantial impact on educational policy in general or on science instruction in particular. Certainly, conducting and reporting various non-experimental studies involving student achievement or other studies that do not address student achievement outcomes can be a valuable contribution to the discipline. However, such detailed study of student performance descriptions, of *teacher* practices or characteristics, or of classroom instruction that is far less than optimal for learning can only contribute toward building a more complete picture of the problems in science education that remain to be solved. Insofar as this paper is concerned, the question raised is whether science education researchers are able to respond to the challenge of applying the proven methods of science to science education research that addresses the expressed purpose of NARST.

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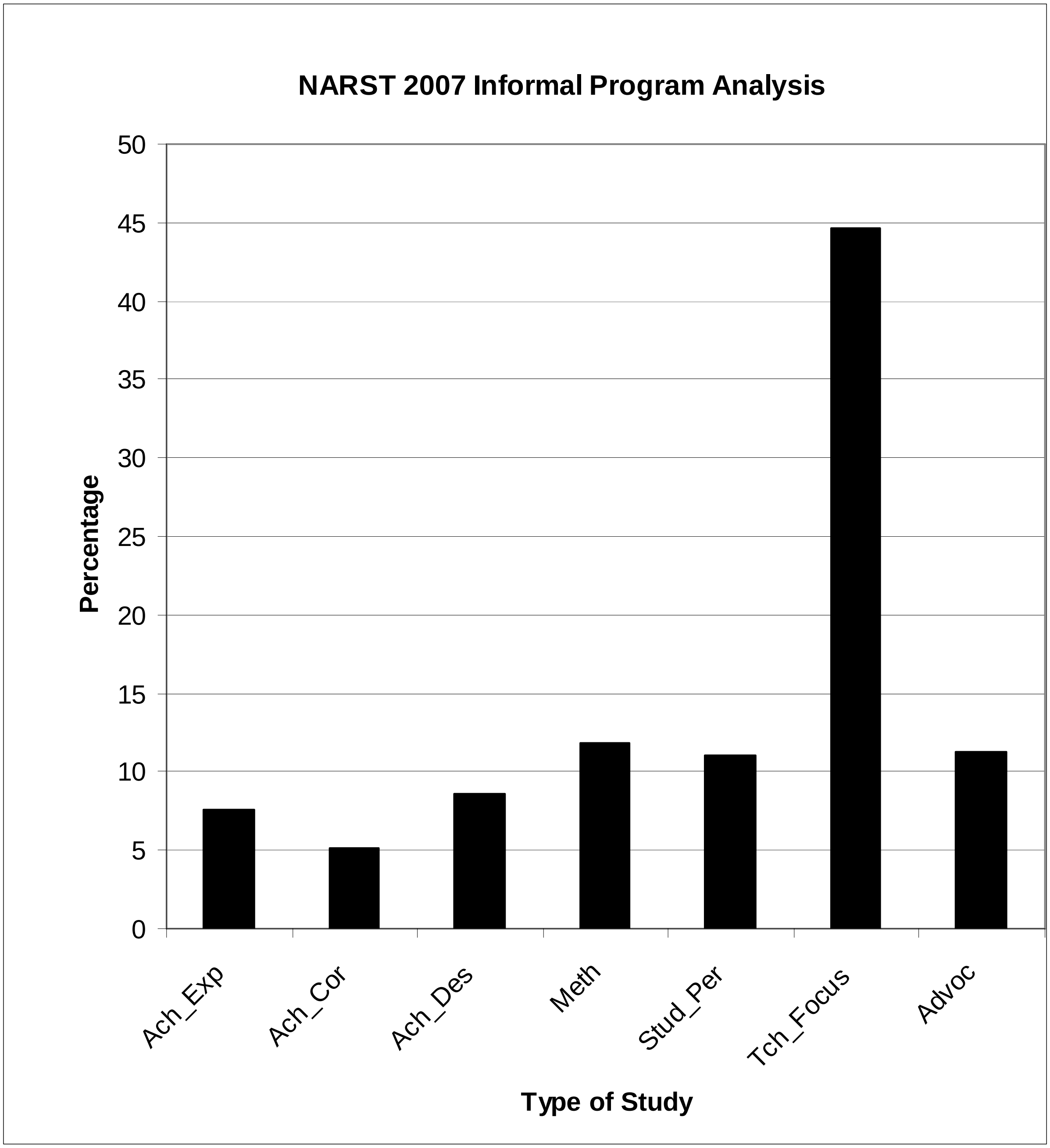
Appendix A

Informal Categorization of NARST 2007 Annual Program



Note. Informal analysis includes only empirical studies appearing in the NARST 2007 Annual Program. The same categorization process for the JRST analysis was used (see Figure 1). As the graph indicates, Teacher-Focused studies were by far the most frequent type of research appearing in the program.