National Standards Connect Disciplines through the Process Skills of Inquiry

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The subject matter commonly taught in schools is segregated based upon specific content standards. Yet, while the content may vary, the skills necessary for student success are more alike than they are different. Upon closer inspection, the essential learning strategies, described by a lexicon of apparently subject specific terms, all have the same focal point. The real basis for learning is in the process skills that are employed in each of the curricular areas, which should be considered interdisciplinary connections and cognitive links, rather than disparate entities.

Introduction

For many years, inquiry-based instruction has been more closely associated with science than with any other content area. This strategy is more than just a tool for those who engage in teaching science, it *is* science. However, research now suggests that an inquiry-based instructional approach results in higher student achievement in other areas, as well. For example, Costenson and Lawson (1986) cite two meta-analyses, one of 39 studies and another of 302 studies. The former found that inquiry-based instruction, when compared to the lecture approach, led to significantly better performance when high levels of thought were considered. The latter showed that inquiry-based instruction was superior to traditional practice in all measures of performance. These measures included attitude, process skills, analytic skills, and achievement. The Lawrence Hall of Science (LHS) at the University of California, Berkeley (2001) supports this contention in its summary of the 1999 Third International Mathematics and Science Study-R (TIMSS-R). The report suggests that students who take inquiry-based science courses are able to academically compete at a level equal to or better than that of the rest of the world; while those who do not take inquiry-based science courses perform at a level equal to or below that of the rest of the world. Llewellyn (2005) contends that inquiry-based classrooms empower students to become independent, life-long learners, and promote both critical thinking skills and habits of mind. More recently, BSCS (2006) reports, "For more than 30 years, the literature in science education has documented increased and improved retention of science concepts when students are taught using curriculum materials that have an inquiry approach" (p.1).

Evidence also suggests that inquiry-based teaching and learning produce greater student achievement, not only in science, but possibly in other areas of the curriculum. Support for this claim is found in the Valle Imperial Project in Science (VIPS), led by Amaral, Garrison, and Klentschy (2002) in El Centro California, which conducted a study entitled, *Helping English Learners Increase Achievement through Inquiry-based Science Instruction.* The study summarized the results of a four year project of science education conducted in grades K-6 at the El Centro School District in Southern California. VIPS used a variety of high quality, research-based instructional units which focused on scientific inquiry. Many of the materials used for the study were in the form of kits or modules drawn from such sources as the *Full Option Science System* (FOSS), *Science and Technology for Children* (STC), and the *Insights* program. The VIPS study demonstrated that English language learners continually increased their academic achievement in direct relation to the number of years they participated in the project. The longer they were in the program, the higher their scores were in reading, writing, science, and mathematics. In addition to the VIPS study, the National Science Resources Center (NSRC) (2005) cites similar examples of the positive impact of inquiry-based science from Delaware, Pennsylvania, and even Chile.

In addition to testable increased academic achievement across the board, Tretter (2003) suggests other positive effects of inquiry-based teaching, including "dramatic improvement in student participation and higher classroom grades earned by students. [Also], inquiry-based instruction resulted in more uniform achievement than did those that were traditional in structure, both in classroom measures and in more objective standardized test measures" (para. 1). DiPasquale, Mason, and Kolkhorst (2003) also saw improvement in student attitudes, involvement, independent thinking, understanding of concepts, and integration of knowledge from other disciplines. Furthermore, Llewellyn (2005) cites the unified recommendations of the American Association for the Advancement of Science and the National Research Council as supporting an infusion of inquiry-based instruction as an enduring understanding, as well as pedagogy for teaching science. "Given the 20 years of blue ribbon commissions and committees, emphasis for science education suggests that high school science teachers should follow a standards-based curriculum and develop teaching competencies and strategies that provide engaging, inquiry-based investigations for students" (p. x).

Not only are these research results worthy of consideration by those interested in increasing student understanding and performance across the board, they also raise some compelling issues. What is the nature of inquiry? What is the importance of inquiry in subjects other than science? How are the instructional strategies associated among content areas?

The Nature of Inquiry

Inquiry-based instruction has also been misconstrued and synonymously linked with hands-on instructional methodologies. To dispel this misconception, Minner, Levy, and Century (2009) describe a study by Dalton et al. (1997) in which they "directly compared two hands-on curricula to determine if it was the manipulation of materials of the conceptual change principles embedded in the curricula that made the difference in student learning" (p. 18). They specifically found that "hands-on activities alone were not sufficient for conceptual change. Students also need the opportunity to process for meaning through class discussion of the reasons behind what they observed" (p. 18).

Therefore, we begin with an operational definition of inquiry-based instruction. A recent study by AUTHOR (2009) defines inquiry-based instruction as a student-centered learning experience that is teacher facilitated in order to lead students through a process, rather than simply lecturing to them. In this setting, teachers put much time and effort into preparing themselves and their students for inquiry activities. They not only cultivate an inquiry atmosphere through appropriate questioning and response approaches, but they plan extensively for the variety of options which they may employ when guiding their students down an inquiring path. Students are, therefore, actively engaged in building their own understandings of the content or concepts being studied, be it in a hands-on or minds-on fashion. Furthermore, through investigations of their own design, students are encouraged to pursue answers to questions, communicate their results, justify their methodologies, and support their findings with data and evidence. This definition is in accord with that presented by the National Research Council (NRC) (1996) in its *National Science Education Standards* (NSES) which defines inquiry as follows.

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)

Inquiry across the Curriculum

Science educators are not, nor should they be, the sole proprietors of inquiry-based instruction, although the subject and the instructional strategy have become so closely linked that they are at the point of being synonymous. The previously referenced landmark study by Aamaral, Garrison, and Klentschy (2002) reported impressive student gains in reading and mathematics following student involvement in a process-based, inquiry science program. The results suggested that inquiry-based science programs better prepare students for learning all subjects. Today’s science programs should, therefore, reflect the developmental abilities of students, use grade-appropriate, multi-sensory, hands-on materials, and provide numerous opportunities for students to learn skills in a proper sequence prior to requiring the application of those skills. It is our contention that the emphasis on, and the enhancement of, the development of process skills in science is subsequently extrapolated to the other content areas, especially if those skills are fostered in those content areas. Process is process. We further submit that the more extensively teachers instruct their students using inquiry-based science programs, the more those strategies become part of the teachers, themselves. This behavioral change is monumental because elementary teachers are responsible for a variety of subjects and will tend to infuse inquiry strategies into their teaching of those other subjects. For most middle school and high school teachers, this is a greater challenge because of subject specialization.

A review of the literature associated with inquiry-based instruction in a variety of subject areas indicates that this is not only a viable mode of instruction in all subjects but one that needs to be encouraged across the board. The following connections among disciplines may help to stimulate cross curricular change.

In the Arts

Geahigan (1997) developed a model for creative and aesthetic inquiry which has been supported by many others (Barrett, 1997; King, 2002; Lampert, 2006; Stewart, 1997). The focus of inquiry in the arts appears to revolve around critical discussions and substantive conversation involving interactions between the teacher and the students, as well as among the students themselves. In support, Goldenberg (1991) suggests that "real teaching involves, fundamentally, helping students understand, appreciate, and grapple with important ideas while they develop a depth of understanding for a wide range of issues and questions" (para. 4). Substantive conversation not only promotes this, it embodies the essence of placing part of the responsibility for learning onto the shoulders of the students themselves, a key component of inquiry. The outcome of substantive conversation is the application of the higher order thinking skills which are highlighted in the *National Standards for Arts Education*. Eisner (2004) also considers inquiry and the teaching of the arts as having similar foci, since both expect students to judge the consequences of their choices, to revise and to consider alternatives.

In Language Arts

In addition to increasing student achievement in science and inspiring curiosity and creativity in the arts, inquiry-based instruction can increase student achievement in language literacy. Applbee, Langer, Nystrand, and Gamoran (2003) conducted a study involving over 1400 students which showed that inquiry-based approaches in middle and high school language arts classrooms allow all students to make academic gains. According to Jacobs (2002), “The principles and practices of …reading and writing provide [the] means by which students can move from understanding goals to demonstrating understanding” (p. 58). Furthermore, Barton and Jordan (2001) cite Armbruster (1993) as asserting:

The same skills that make good scientists also make good readers: engaging prior

> knowledge, forming hypotheses, establishing plans, evaluating understanding, determining the relative importance of information, describing patterns, comparing and contrasting, making inferences, drawing conclusions, generalizing, evaluating sources, and so on. (p. 347)

Language arts and communicating through writing are areas of the curriculum that naturally lend themselves to inquiry as the reporting, interpreting and reflecting required of students is very much an individualized process. Short, Schroeder, Laird, Ferguson and Crawford (1996) defend the advantages of writing from an inquiry stance in that, “Inquiry does not narrow our perspective; it gives us more understandings, questions, and possibilities than when we started” (p. 8).

As mentioned earlier, inquiry-based instruction in language arts has led to increased student achievement in this content area. Interestingly, studies have also shown that inquiry-based instruction in the sciences can also lead to increased student achievement in language arts, specifically in reading and writing. Perhaps the reverse is also true. The following examines each separately.

Krueger and Sutton (2001) contend, “Many of the process skills needed for science inquiry are similar to reading skills, and when taught together reinforce each other” (p. 52). In concert, Barton and Jordan (2001) state that “reading science text and textbooks requires the same critical thinking, analysis, and active engagement as performing hands-on [inquiry-based] science activities” (p. iv). Concordantly, Donovan and Bransford (2005) contend, “The value of reading about others’ discoveries is clear to students—it helps them clarify issues that arise in their own inquiry. Reading to answer a question of interest is more motivating than simply reading because someone assigned it” (p. 402). Subsequently, students will read more when they are involved in an inquiry-based program, and, therefore, will develop their reading skills. Kruger and Sutton (2001) concur:

> Science content has been found to be particularly effective for engaging language learners. Inquiry-based science instruction has been shown to increase vocabulary, not only that directly related to the science content but fluency as measured on standard language tests. One study showed up to four months language growth as a result of a five-week summer elementary science academy. (p. 52)

The strategy of introducing pertinent scientific vocabulary words, following a generalizing experience such as an investigation, is not a new idea, but has been an accepted and encouraged practice of inquiry-based programs for over 40 years. In concert, Krueger and Sutton (2001) dispel any apprehensions regarding carrying out investigations prior to knowing vocabulary words or specific content. The NRC (2000) further dismisses such concerns by explaining:

> Knowing vocabulary does not necessarily help students develop or understand explanations. Rather, once students begin to build and understand explanations for their observations, the proper names and definitions associated with those events become useful and meaningful. (p. 133)

This could be, as Miller (2006) suggests, because "one must be able to read and comprehend in order to examine science information, and must be able to compose in order to communicate scientific results" (p. 30). In fact, she developed the Science-Cognition-Literacy (SCL) Framework to incorporate the language arts skill of reading comprehension into the sciences. She summarizes as follows:

> The SCL Framework is intended to serve as a guide for putting all of the pieces together in a seamless fashion. Rather than treating reading and writing as ancillary activities to

support science learning, in this model, the literacy activities are fully embedded into the science curriculum and take on an equally important role to those of hands-on inquiry experiences. (p. 31)

In Mathematics

Regarding the use of inquiry-based instruction in mathematics, Luera, Killu, and O'Hagen (2003) developed a model which utilizes the 5E learning cycle to teach the concept of volume. They posit, "Students learn better when they are provided the opportunity to construct their knowledge through inquiry" (p. 195). So powerful is this constructing of knowledge through experience that others have adopted it in fields like accounting (Frecka, Morris, and Ramanan, 2004) and even exercise physiology (DiPasquale, Mason, and Kolkhorst, 2003).

Jarrett (1997) presents several tactics for employing inquiry-based instruction in the mathematics classroom. She summarizes the work of Borasi (1992), who recommends the following approaches:

a) Use the complexity of real-life problems.
b) Focus on nontraditional mathematical topics where uncertainty and limitations are most evident.
c) Use errors as "springboards for inquiry."
d) Create ambiguity and conflict that compels students to ask, "What would happen if things were different?" or "What would happen if we changed some of the traditional assumptions, definitions, goals, in mathematics?" Encourage students to pursue such questions, and to have a sense of the significance of the results of their inquiry.
e) Generate reading activities to sustain inquiry and to teach students to use sources of information other than the teacher. This will help them learn to become independent

learners, problem solvers, and critical thinkers. Sources could include historical and philosophical essays, reports describing specific mathematical applications, and biographies.

f) Provide students with opportunities to reflect on the significance of their inquiry.

g) Promote exchanges among students. (p. 12)

The inquiry strategy of seeking alternatives and being receptive to optional ideas subtly invites students to more freely participate and reflect. In comparing traditional and inquiry-based instruction undergraduate mathematics courses, Smith, Cochran, Ware and Shores (2009) stated:

> The practice of responding to students' questions without directly providing an answer was intended to help students become independent thinkers. By asking students questions and listening to their responses and having them explain their attempts at solutions, students were guided toward answering their own questions. Also, collaboration with peers on problems was another way of assisting them in developing their own understandings. (p.8)

In support, Chapko and Buchko (2004) describe inquiry-based mathematics as a process that relies on dialogue, the free interchange of ideas, and is the philosophy that there may be a specific right answer for a math problem, but there is obviously more than one way to obtain it. They expand their definition by describing inquiry-based mathematics instruction as being:

> Different from traditional math in that students work with partners and whole-group instruction to construct mathematical explanations that make sense to them. Students are presented with opportunities to verbally explain their thinking processes to the teacher and the class, and it is this exchange of ideas that provides the foundation for true understanding of mathematical concepts. (p. 32)

So, as in inquiry-based science, the goal of inquiry-based mathematics is to develop critical thinking skills, to challenge students to think in non-traditional ways, to solve problems, and to present answers that can be supported by sound evidence. Additionally, dialogue between students and teachers is the best means by which to determine student understandings, misunderstandings, or misconceptions. Student to student interaction is also an essential component as students construct meaning in the learning environment of mathematics. According to Siegrist (2009), students engaged in dialogue construct and reconstruct knowledge as they synthesize their ideas. Furthermore, inherent in the discussions is the need for each student to take responsibility for influencing the outcome.

In Science

As defined by the NRC (1996), inquiry "refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world". These activities, according to AUTHOR (2006), can be as diverse as the students and teachers participating in them because interaction between children and their environment begins at an early age as they raise questions and seek answers to queries in their own unique ways. As per the operational definition set forth previously, classrooms in which inquiry-based instruction is occurring are classrooms in which teachers act as facilitators, or guides, who lead students through investigations of questions proposed by the teachers, or even the students themselves. In this way, students construct meaning by building, sharing and refining their own understandings of the concepts that they directly experience. As a result, inquiry is not only a methodology, but rather a unique blending of content, concepts and process skills by which, according to Maroney, Finson, Beaver, and Jenson, (2003) "Students [should] compare their results with one another, defend their points of view, and use evidence, not the teacher, to determine who or what is right" (p. 21). "For students to develop the abilities that characterize science as inquiry, they must actively participate in scientific investigations, and they must actually use the cognitive and manipulative skills associated with the formulation of scientific explanations" (NRC, 1996, p. 173).

At this point, it should be noted that the use of inquiry-based techniques is directly dependent upon the appropriate alignment of the delivery system and the specific nature of the task. Krueger and Sutton (2001) explain, "Effective science teachers employ a large repertoire of instructional methods, strategies, and models to produce more successful learners" (p. 29). Among the strategies that have been touted as means of writing lessons to promote an atmosphere of inquiry-based science are the *5-E Model,* as described and adapted by Bybee (1997); the *4-Question Strategy* as outlined by Cothron, Geise and Rezba (2000); and the *Design Brief,* primarily used in technology education and recently adapted by AUTHOR (2006).

As a result, science teachers must be aware of, and know how to apply, a variety of teaching techniques so that they can draw from that battery to meet the needs of their diverse student population. "These varied methods can include inquiry, constructivism, wait time, the learning cycle, graphic organizers, cooperative learning, and science laboratory activities" (Krueger and Sutton, 2001, p. 29). Additionally, a study conducted by Weiss et al., (2003) suggests:

> Rather than advocating one type of pedagogy over another, the vision of high quality instruction should emphasize the need for developmentally-appropriate…science learning goals; instructional activities that engage students with the…science content; a learning environment that is simultaneously supportive of, and challenging to students; and, vitally,

> attention to appropriate questioning and helping students make sense of the…science concepts they are studying. (p. 14)

Although teaching science using inquiry is a growing practice, it is certainly not a new tactic. Researchers and practitioners have long been designing and implementing science teaching strategies based on the belief that, “Science is something that students do, not something that is done to them” (NRC, 1996, p. 20). Therefore, it must be considered that inquiry-based science includes many of the aforementioned methodologies.

In Social Studies

A 17 year veteran of social studies teaching recently described inquiry as requiring the teacher to act as the facilitator responsible for leading students to draw conclusions. These conclusions can be based on past learning or the interpretation and analysis of historical documents and reading materials pertinent to the subject objective at hand. She further asserted that history and science are connected in the way that English and mathematics are connected. Canistrari (2005) and Fragnoli (2005) echo this sentiment. They support inquiry as one of the tools of the historian, necessary for creating a true understanding of content through questions, explorations, and arguments. In her paper entitled, *Using Inquiry to Connect Young Learners to Social Studies,* Newby expands the definition of inquiry in the social studies by asserting that, in this field, inquiry is described as:

> A multifaceted activity that involves making observations; posing questions, examining books, technology databases and other sources of information to see what is already known in light of evidence; and using tools to gather, analyze, and communicate the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Inquiry involves activities and

> skills that focus on the active search for knowledge or understanding to satisfy a curiosity. (p. 1)

This directly mirrors the reasons that science teachers implement this strategy. Woelders (2007) concurs. He indicates:

> Historical inquiry challenges students to construct their own historical knowledge based on inferences, speculations, and conclusions drawn from evidence, not solely from any authoritative source such as the teacher, the textbook, or the information and images they see in a film. Moreover, this distinction requires that teachers . . . create opportunities for students to learn about *how* historians, filmmakers, publishers, and authors construct our common understandings of the past. (p. 365)

Newby and Higgs (2005) describe the use of five inquiry techniques used in social studies, namely, case studies, the story-path method, spatial dynamics, virtual museums, and web-quests. They submit:

> Children of most age levels can be taught to use basic research methodology through inquiry. They can be taught to ask questions about the world around them, to collect information to answer their questions, to interpret the information they have found, and to form conclusions about their findings. (p. 29)

These student-centered procedures reflect how scientists gather, analyze and interpret data to make meaning of experimental results. Striking a proper balance between information that is provided and what is gained between questioning and inquiry is the ultimate factor that determines the lasting impact of a learning experience in history (Steeves, 2005).

Connections

In his *Connections* video series, James Burke (1978) provides extensive examples of the interconnectedness of the curricular areas as he discusses seemingly unrelated people, events, and discoveries that are connected in the most surprising ways. So it is with connections in educational process skills across curricular areas. Perhaps the best means of approaching the issue of inquiry across the curriculum, then, is to look at the concept of the integrated curriculum, not integrated from a content or thematic perspective but from a process skills standpoint. These abilities are the connections between grade levels and curriculum lines, thus making the teaching and learning of the disciplines more alike than different.

Park Rogers (2006) found that a successful integrated curriculum of math, science, and literacy included three features: a) emphasizing the process skills across subject areas, b) employing a learning cycle model of instruction in all disciplines, and c) valuing inquiry as a common tool for learning. Interestingly, if one examines the *National Science Education Standards*, the *National Standards for History*, the *Standards for the English Language Arts*, the *Principles and Standards for School Mathematics,* and the *National Standards for Art Education*, a remarkable relationship is identified. Given that the process skills are an integral part of inquiry, a comparison of these essential techniques across a variety of subject areas presents an astonishing similarity. While slight variations may exist in the sequence or appropriateness of the process skills within subjects and grade levels, they are strikingly alike in purpose and should be seen as interdisciplinary connections and indispensible cognitive links (Table 1).

Table 1. Comparing the language of the national standards.

Process Skills Across the Disciplines				
Arts	**Language Arts**	**Mathematics**	**Science**	**Social Studies**
Analyze	Analyze	Analyze	**Analyze**	Analyze
Classify	Sequence	Order	**Classify**	Reconstruct temporal order
Accurately describe	Record pertinent material	Collect data	**Collect data**	Obtain historical data
Articulate	Communicate	Communicate or express	**Communicate**	Formulate examples
Compare/contrast	Compare/contrast	Compare/contrast	**Compare/contrast**	Compare/contrast
Design, create or improvise	Create alternate endings	Design proofs	**Design fair tests**	Formulate a position
Evaluate/justify	Draw conclusions	Draw conclusions	**Draw conclusions**	Evaluate
Formulate questions	Predict outcomes	Estimate, predict, or conjecture	**Hypothesize or predict**	Formulate historical questions
Interpret relationships	Cause and effect	Identify relationships	**Identify and manipulate variables**	Cause and effect
Form judgments	Infer	Infer	**Infer**	Analyze patterns
Perceive	Discriminate	Observe	**Observe**	Identify issues
Interpret	Recognize main idea/summarize	Organize and interpret data	**Organize and interpret data**	Marshal evidence

Cultivating Process Skills across the Curriculum

Inquiry-based instruction has Socratic teaching at its roots. Therefore, student communication should be encouraged and nurtured in the form of planning and sharing sessions, reporting, writing, editing, open-ended discourse, evidenced-based decision making, and seeking/suggesting alternative procedures, interpretations and solutions. The means by which teachers interact with students, then, can foster an environment which lends itself to the above in all classrooms for all subjects. The FOSS (Full Option Science System) program strongly encourages discourse between teachers and students and among the students, themselves. "Students need to describe their observations and reasoning and to interpret how other students are thinking. Good questions posed by the teacher can enhance this discourse by contributing to the development of concepts and vocabulary by helping students to connect ideas among the sciences" (Barber, 2007, p. 9).

Minner, Levy, and Century (2009) describe a study by Dalton et al. (1997) which directly compared two hands-on curricula to determine if it was the hands-on component or the inquiry principles that made a difference in student learning. They concluded that hands-on activities alone were not sufficient for conceptual change, and that students need time to process and reflect. Therefore, once students answer a question, the manner by which the teacher responds is absolutely essential to determining whether or not the inquiry environment is established. It is at this point that student thinking and discourse can be either enhanced or dismissed.

Krueger and Sutton (2001) advocate using a variety of means to promote inquiry and learning. They advise that students "communicate orally and in writing, both with one another and with the teacher" (p. 55). Consider the following *8 Essential Elements*, as amended from the article, *A Blueprint for Cultivating Inquiry*, by AUTHOR (2008). These strategies, which can assist the teacher in establishing an inquiry environment, are considered paramount for encouraging student participation, critical thinking, and student-generated inquiry. Thus, they should be regarded as universal teaching and learning tools.

1. Calling for Clarification

This teacher response is an overriding tactic because it requires the students to revisit or rehearse their answers – to rephrase and expand their thinking. This strategy should be used even if the student's answer is right on target. Sousa (1995) contends that learners ask two questions about entering information, "Does this make sense?" and "Does this have meaning?" (p. 16). The *sense* part reflects the learner's attempt to fit the new information into existing schema, while the *meaning* issue describes the relevance for the learner. In trying to make sense of new information, students sometimes create inappropriate connections or misinterpret incoming information all together and misconceptions can occur. Furthermore, one should, "Seek first to understand, then to be understood" (Covey, 1989, p. 255). Educators should heed these words since "getting inside" students' heads, to find out how they are processing, is a fundamental component of formative assessment and provides guideposts for crafting more accurate paths of instruction. The importance of this strategy cannot be overstated as a means of compelling students to dig deeper into the meanings of their responses in order to bring additional sense and clarity to their own thoughts. This approach also provides time for students to process information and time for teachers to formatively assess student understanding. Teachers can initiate this strategy by using phrases such as: *How else might you say that? Is there anything that you might add that could make that more understandable? Could you rephrase that?*

2. Calling for Evidence

One of the keys to literacy is interpreting and/or reporting the results of investigations with supportive data. *Calling for Evidence* necessitates that students explain their results or conclusions through the use of evidence in the form of numerical results, a list of observations, artifacts, and other documentation from a variety of sources. There are many ways to solve a problem in science and the solutions can be as varied as the students in the classroom. The problem solving techniques used by each student may be different, but this diversity of thinking is beneficial for enhancing the problem solving repertoire of each student (AUTHOR, 2006). It should be emphasized that while there are many ways to resolve an issue there is only one appropriate way to report it, and that is with the use of evidence. To do this, a teacher may ask: *How do you know that? What is your proof? What data did you find that would help you explain your decision? What do you think your data shows? Can you use your data to make up a rule to describe your results?*

3. Calling for Evaluation

Once students have collected and processed data, *Calling for Evaluation* is a way to raise the bar by requiring them to use more abstract higher order thinking skills (HOTS), which became popular with the publication of Bloom's taxonomy in 1956. This strategy requires students to go beyond the processing of data to the crafting of reasonable speculations. Initiating queries might be: *What else do you think could have caused that? If you did this investigation again, what would you do differently? Why would you do that? Why do you consider your answer reasonable? How could you change this investigation? How do you think you could make the investigation better? Why would it be better?*

4. Playing the Devil's Advocate

This technique is one that resembles the verbal exchanges that occur in a courtroom. Students are invited to defend their data-based decisions against differing points of view and to propose alternative interpretations for the conclusions drawn by others. These varying opinions could originate with the teacher but, over time, it is anticipated that evaluating through peer review, would become the joint responsibility of the teacher and the students. *Playing the Devil's Advocate* helps to prepare students to consider the ideas of others rather than accepting or rejecting them out of hand. This is an important skill in establishing a healthy sense of skepticism about proposals, positions, data, and data interpretations. In a global sense, the necessity for training students to play this role also includes interpreting the controversial issues associated with the benefits and consequences of human actions on the environment.

5 and 6. Using Wait Times I and II

Mary Budd Rowe (1974) introduced the concept of *Wait Time* (the time between the teacher's question and the student's response or the teachers' repetition/rephrasing of the question). This strategy may seem very simplistic; however research into *Wait Time* indicates that this simple technique increases the number of student responses, the length and complexity of student answers, and student-to-student interaction (Stahl, 1994). The optimal wait time for a given question should be adjusted to its cognitive level. This well established approach is absolutely essential for inquiry-based instruction, as well as its companion tactic, *Wait Time II*, (the time between a student's response and the introduction of another question or a direction by the teacher). By remaining silent and non-committal, the teacher can enable the student to extend and clarify his or her answer, as well as increase participation of other students in support of their peers. Amazingly, it works every time. The difficulty with these two strategies lies in the teachers' inability to remain silent. We love to impart our wisdom to our students. However, by being silent, we learn from them.

7. Not Looking for the "Right" Answer

As noted earlier, there are many ways to go about solving a problem but only one way to correctly report the results, and that is with the use of evidence. When teachers seek a pre-determined response to a question that could be answered in a variety of ways, they do so at the exclusion of a number of other creative and plausible possibilities. Similarly, if students believe there is only one acceptable response, they do so at the exclusion of a number of creative and plausible creative possibilities. The lesson may not always end by giving students the "right" answer. Teachers need to encourage diversity of thought supported by a reasonable justification. As Wilhelm (2007) insists, "The answer is not the point. It's how they get there that matters. When students ask themselves the questions that intrigue them most, the knowledge they acquire will be more than just a series of facts they had to remember" (p. 45).

8. Writing Reflectively

Students' writing can shed a powerful light on how they are processing information. Keeping in mind that inquiry shifts the responsibility for learning to the shoulders of the students, what they write is an outward expression of what and how they are thinking. Reflective writing is, therefore, essential because it provides the teacher with both formative and summative assessments, and the students with another encounter with the information. The more encounters students have with information, the deeper their understandings of that information. Writing reflectively forces the students to mentally repeat an event, to analyze and synthesize the experience and then to communicate their interpretation in meaningful and unique ways. "It can open a dialogue between learner and teacher that leads to more individualized instruction and support" (Krueger and Sutton, 2001, p. 89). Authentic writing tasks are a form of rehearsal, which, unlike traditional practice, occurs when students re-examine a previous experience but not in an identical manner. According to Lowery (1998) "Rehearsing strengthens the connections among the storage areas in the brain systems. If the connections are not strengthened they will disengage and fade away" (p. 29). Some simple reflection prompts, as offered by Shaw and Reid (2008), can also provide a glimpse (for both the teachers and the learners) into what students are thinking and where misconceptions or confusion still exist (see Table 2). Krueger and Sutton (2001) also propose other types of writing assignments including "analytic essays, which develop links between concepts, and concept maps or hierarchical outlines, which can be used to facilitate meaningful cooperative learning, identify misconceptions, evaluate understanding, and demonstrate construction of…knowledge" (p. 89).

Table 2. Sample reflection prompts

- Write a note to a student who missed class today and explain one important idea from the lesson.
- What suggestions would you give other students on ways to get the most out this assignment?
- What would you like to learn further about this subject/discipline?
- When did you feel uncomfortable and/or unprepared? Why?
- When did you feel most successful? Why?
- Write about a concept in this investigation/lesson that still confuses you. Describe why it is difficult to understand. What could YOU do to gain a better understanding?

Conclusion

Research confirms that inquiry is a viable instructional method in all academic disciplines and that this approach raises the expectations and conceptual level of student thinking. Associated with this approach are Socratic-like instructional strategies that are also consistent across the disciplines. The learning atmosphere most conducive to inquiry and academic success is dependent upon the teachers' understanding of content knowledge, competence in pedagogical tactics, proficiency in the use of appropriate process skills, appropriate use of suitable hands-on materials, and expertise in questioning-response strategies. It is our contention that inquiry-based instruction and associated teacher behaviors can, and should, be used in all disciplines. An analysis of the process skills for each subject area reveals that, despite the confusion created because of the diversity of terms used to describe the essential process skills, they are strikingly similar, and should be considered interdisciplinary connections. By combining current research with grade appropriate, sequential, hands-on, inquiry-based experiences, teachers are better prepared to actively engage students in cognitive processes that can help them become better thinkers, learners, and communicators. Ornstein and Hunkins (2004) corroborate this view by stating, "The ideal teaching method is concerned not so much with teaching the learner what to think as with teaching him or her to critically think. Teaching is more exploratory than explanatory" (p. 35). In order for this to occur, there must be a metacognitive component to what is happening in the classroom. Students must not only be thinking, they must be thinking about *what* they are thinking; they must be thinking about *how* they are thinking; and they must be thinking about *why* they are thinking what they are thinking. This is the very nature of inquiry. Rather than compartmentalizing and isolating subjects, we should be connecting subjects through the overt and purposive application of grade appropriate process skills.

Works Cited

Aamaral, O., Garrison, L. & Klentschy, M. (2002). Helping English learners increase achievement through inquiry-based science instruction [Abstract]. *Bilingual Research Journal, 26*(2), 213.

Applebee, A., Langer, J., Nystrand, M., & Gamoran, A. (2003). Discussion-based approaches to developing understanding: Classroom instruction and student performance in middle and high school English. *American Educational Research Journal, 40*(3),685-730.

Armbruster, B. (1993, January/1992, December). Science and reading. *The ReadingTeacher, 46*(4), 346-347.

Barber, J. (2007). Seeds of science/Roots of reading. *Program Overview*. Berkeley, CA: Delta Education.

Barrett, T. (1997). *Talking about student art*. Worcester, MA: Davis Publications, Inc.

Barton, M. & Jordan, D. (2001). *Teaching reading in science.* Aurora, CO: Midcontinent Research for Education and Learning.

Borasi, R. (1992). *Learning mathematics through inquiry*. Portsmouth, NH:Heinemann.

BSCS. (2006). *Why does inquiry matter? Because that's what science is all about!* Dubuque, IA: Kendall/Hunt Publishing Company.

Burke, J. (1978). *Connections*. New York, NY: Ambrose Video Publishing, Inc.

Bybee, R. W. (1997). *Achieving Scientific Literacy: From Purposes to Practices.* Portsmouth, NH: Heinemann.

Canestrari, A. (2005). Social studies and geography: Beyond rote memorization. In R. Audet and K. Jordan (eds). *Integrating Inquiry Across the Curriculum*. Thousand

Oaks, CA: Corwin Press. 17-42.

Chapko, M. & Buchko, M. (2004). Math instruction for inquiring minds. *Principal, 84*(2), 30-33.

Consortium of National Arts Education. (1994). *National standards for arts education: What every young American should know and be able to do in the arts*. Lanham, MD: Rowman & Littlefield Education.

Costenson, K. & Lawson, A. (1986). Why isn't inquiry used in more classrooms? *The American Biology Teacher, 48*(3), 150-158.

Cothron, J. Geise, R., & Rezba, R.(2000) *Students and research: Practical Strategies for science classrooms and competitions, 3rd edition.* Dubuque, IA: Kendall/Hunt Publishing Company.

Covey, S. (1989). *The seven habits of highly effective people*. New York, NY: Simon and Schuster.

Dalton, B., Morocco, C., Tivnan, T., & Mead, P. (1997). Supported inquiry science: Teaching for conceptual change in urban and suburban science classrooms. *Journal of Learning Disabilities*, *30*(6), 670-684.

DiPasquale, D., Mason, C. & Kolkhorst, F. (2003). Exercise in inquiry: Critical thinking in an inquiry-based exercise physiology laboratory course. *Journal of College Science Teaching*, *32*(6), 388-393.

Donovan, M. & Bransford, J. (Eds.). (2005). *How students learn science in the classroom*. Washington, DC: The National Academies Press.

Eisner, E. (2004). What can education learn from the arts about the practice of education?

International Journal of Education & the Arts, *5*(4). Retrieved June 14, 2010 from http://ijea.asu.edu/v5n4/

Fragnoli, K. (2005). Historical inquiry in a methods classroom: Examining our beliefs and shedding our old ways. *The Social Studies*, *96*(6), 247-51.

Frecka, T., Morris, M. & Ramanan, R. (2004). Back to the future: Implementing a broad economic inquiry-based approach to accounting education. *Journal of Education for Business*, *80*(2), 69-74.

Geahigan, F. (1997). Art criticism: From theory to practice. In T. Wolf & G. Geahigan, *Art criticism and education*. (pp. 125-278). Urbana, IL: University of Illinois Press.

Goldenberg, C. (1991). Instructional conversations and their classroom applications. Santa Cruz, CA: Center for Research on Education, Diversity & Excellence at the University of California. Retrieved May 3, 2007 from http://www.ncela.gwu.edu/pubs/ncrcdsll/epr2/.

Jacobs, V. (2002). Reading, writing, and understanding. *Educational Leadership. 60*(3), 58-61.

Jarrett, D. (1997). *Inquiry Strategies for Science and Mathematics Learning – It's Just Good Teaching.* Portland, OR: Northwest Regional Education Laboratory.

King, A. (2002). Structuring peer interaction to promote high-level cognitive processing. *Theory Into Practice*, *41*(1), 33-39.

Krueger, A. & Sutton, J. (Eds.). (2001). *EDThoughts: What we know about science teaching and learning*. Aurora Colorado: Mid-continent Research for Education and Learning.

Lampert, N. (2006). Enhancing critical thinking with aesthetic, critical, and creative inquiry. *Art Education, 59*(5), 46-50.

Lawrence Hall of Science. (2001). Research on FOSS and other hands-on science programs: A growing bibliography. University of California, Berkeley. http://www.lawrencehallofscience.org/foss/scope/research/FOSS.Research.pdf

Llewellyn, D. (2005). *Teaching High School Science through Inquiry*. Thousand Oaks, CA: Corwin Press.

Luera, G., Killu, K., & O'Hagan, J. (2003). Linking math, science, and inquiry-based learning: An example from a mini-unit on volume. *School Science and Mathematics, 103*(4), 194-207.

Maroney, S. A., Finson, K. D., Beaver, J. B., & Jensen, M. M. (2003). Preparing for successful inquiry in inclusive science classrooms. *Teaching Exceptional Children, 36*(1), 18-25.

Miller, R. (2006). Unlocking reading comprehension with key science inquiry skills. *Science Scope, 30*(1), 30-33.

Minner, D., Levy, A., & Century, J. (2010). Inquiry-based science instruction – What is it and does it matter? Results from research synthesis from years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474-496.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

National Science Resources Center. (2005). *2005-2006 NSRC inquiry-based education programs.* Washington, DC: National Science Resources Center.

Newby, D. *Using Inquiry to Connect Young Learners to Social Studies*. Central Michigan University. Retrieved July 20, 2010 from http://www.ehhs.cmich.edu/~dnewby/5Elesson.pdf

Newby, D. & Higgs, P. (2005). Using inquiry to teach social studies. *The Charter Schools Research Journal*, *1*(1), 20-31.

Ornstein, A. & Hunkins, F. (2004). *Curriculum Foundations, Principles and Issues*. Boston, MA: Pearson Education, Inc.

Park Rogers, M. (2006). *Achieving a coherent curriculum in second grade: Science as the organizer.* Unpublished dissertation, University of Missouri-Columbia.

Rowe, M. (1974). Wait-time and rewards as instructional variables, their influence on language, logic, and fate control: Part one - Wait-time. *Journal of Research in Science Teaching*, *11*(2), 81-94.

Shaw, T. & Reid, V. (2007). Lawrence Hall of Science Meteorology Workshop. Norman, OK (June 24-30, 2007).

Short, K., Schroeder, J., Laird, J., Kauffman, G., Ferguson, M., & Crawford, K. (1996). *Learning together through inquiry: From Columbus to integrated curriculum.* Portland, ME: Stenhouse Publishing.

Siegrist, R. (2009). Characteristics of a high school classroom community of mathematical inquiry. *Analytic Teaching and Philosophical Praxis, 29*(1), 53-58.

Smith T., Cochran, R., Ware, D., & Shores, M., (2009). *Mathematical investigations in inquiry-based courses for pre-service teachers*. Retrieved July 20, 2010 from http://mathed.asu.edu/crume2009/Smith_LONG.pdf

Sousa, D. (1995). *How the brain learns*. Reston, VA: National Association of Secondary School Principals.

Stahl, R. (1994). Using "think time" and "wait time" skillfully in the classroom. *Eric Digest*. Bloomington, IN: ERIC Clearinghouse for Social Studies/Social Science Education. ERIC Identifier: ED370885.

Steeves, K. (2005). History: Uncovering the past through inquiry. In R. Audet and K. Jordan (eds). *Integrating Inquiry Across the Curriculum*. Thousand Oaks, CA: Corwin Press. 65-84.

Stewart, M. (1997). *Thinking through aesthetics*. Worcester, MA: Davis Publications.

Tretter, T. (2003). Relationships between inquiry-based teaching and physical science standardized test scores. *School Science and Mathematics*. Retrieved on March 28, 2008 from http://findarticles.com/p/articles/mi_qa3667/is200311/ai_n9321426

Weiss, I., Pasley, J., Smith, P., Banilower, E., & Heck, D. (2003). *Highlights report looking inside the classroom: A study of K – 12 Mathematics and science education in the United States*. Chapel Hill, NC: Horizon Research, Inc.

Wilhelm, J. (2007). Inquiry starts here. *Instructor, 116*(7), 43-45.

Woelders, A. (2007). Using film to conduct historical inquiry with middle school students. *The History Teacher, 40*(3), 363-386.

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