Teaching for Understanding and Application of Science Knowledge

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We are now engaged in a period of significant reform in science education. I mark the beginnings of the reform with the most recent passage of Halley's Comet in 1986. That was the year James Rutherford initiated Project 2061 with the vision of long-term, deep reform of teaching and learning in science. In the years since that event, the importance of Rutherford's vision has been reinforced by many writers and reports, especially the National Science Education Standards (National Research Council [NRC], 1996). Interestingly, this reform concept emerged virtually simultaneously around the globe, and its language is now part of the prominent rhetoric used by scientists, educators, and policymakers in nearly all parts of the world.

This reform focuses on four major goals, which are by now quite familiar to science educators: Science for all, teaching for understanding and application of science knowledge and processes, inclusion of a broader view of science in the curriculum, and "less is better." Each of these presents significant challenges to science educators and to science teachers. Accomplishing the goals set forth in this reform agenda will occupy our thoughts and actions for years to come.

In this paper, one of these four goals will be addressed—teaching for understanding and application of science. The choice of one of the four goals as the theme of this paper does not diminish the importance of the other three goals. The choice is based on my recent work in teaching for understanding in science.

Many people have recognized for decades that science teaching has not been effective for the majority of students. Nearly a century ago, John Dewey (1916) and Alfred North Whitehead (1916) wrote about their concerns with commonplace practice in science teaching and its overemphasis on memorization in place of understanding and application. In spite of nearly a century of thought and action, much science teaching still fails to result in understanding and application of science. Even more problematic, only a small portion of students come away from science courses at a high school or university with understanding of, or capability to use, science (National Commission on Excellence in Education, 1983). On the contrary, a majority of students develop fear and dislike for science and a firm commitment not to study it further. As a result, the majority of our population can be termed as scientifically illiterate, having little appreciation for, and understanding of, science and technology that are ever present in our world. While the low levels of scientific literacy among large segments of our population have been noted for decades, political leaders now recognize that knowledge of science, mathematics, and technology have economic consequences that can affect national power, influence, and the well-being of all people. Thus, education in science, mathematics, and technology have taken on new importance in the discourse among leaders in the seats of political power in most nations of the world.

A look into most classrooms where science is taught at school or university will show that memorization, not understanding, is the prominent operational goal. A closer look will show that application of science knowledge is typically virtually nonexistent. Review of textbooks and course-related tests developed by teachers and professors will reinforce the same view. Most instruction in science focuses on
Learning is equated with memorizing. That learning involves personal sense-making and reconciling personal constructions with accepted canonical knowledge is an unfamiliar idea for most students. Further, readers should recognize that this idea has not been widely recognized among scientists and educators until recently. Moreover, it may not be accepted by many who teach science in secondary schools and universities.

Third, making connections among ideas is not a spontaneous response for many students. Unless connections are made evident to students, many will not identify them. However, both making sense and making connections are essential elements in forming understanding, which teachers and professors probably have always expected students would do as part of their study outside of class, either independently or in small groups. Unfortunately, many students do not accept the view that understanding is what is expected. Instead, they see memorization as the goal. Perhaps one difference between some successful and unsuccessful students lies in comprehending that understanding allows recall and application of knowledge on tests and in other settings to be much more effective.

**Challenge 2: Teaching for Application of Science Knowledge**

There has been tension in the emphasis between abstract knowledge and applications of knowledge for much of the history of science teaching (DeBoer, 1991). In a previous reform in science education that began in the 1950s, abstract knowledge became the centerpiece. In the current reform, applications of knowledge have been given greater emphasis, which brings them in balance with abstract knowledge (NRC, 1996; Rutherford & Ahlgren, 1989). However, the influence of the earlier reform on materials for teaching science is still evident. As a result, there are only limited resources available for teaching about applications. Further, many teachers have little knowledge about applications, as most university programs provide little opportunity to learn about them. Consequently, applications are not commonly included in science teaching.

An additional factor inhibiting the inclusion of applications of knowledge in science, as well as in mathematics courses, is the historical valuing of abstract knowledge over practical knowledge among people in the academic community (Cajet, 1998). Members of the academic community who educate teachers and often are leaders in curriculum formulation for the precollege years tend to value abstract, theoretical knowledge more than applied knowledge. One result is that teachers, teacher educators, and curriculum developers tend to have little knowledge of applications of science. Often this sparse knowledge is limited to a small set of "practical applications" of science principles and concepts. Therefore, teachers are not able to help students make connections to their experiential world, which is an important part of understanding. In addition, the language and concepts to describe applications of science in useful ways are not in our educational lexicon.

Knowing about practical applications, however, may be only a small part of the importance of application in the process of learning to understand and use science concepts. The engagement in thinking about the connection between the abstract idea and the real world may be of greater importance. An example may be helpful here. For many adolescent students, the presence of water vapor in the air and its connection to condensation and evaporation is a difficult concept. For teachers the world over, condensation on the outside of a cold soft drink can is a familiar practical application of the phenomenon of condensation. However, if the example is not taken beyond this point, its value may be lost. On the other hand, this familiar experience becomes the basis for significant learning when it engenders discussion of questions such as, "Where did the droplets of water come from?" and "What occurred as the water went from the air, where it was invisible and could not be felt (sensed by touch), to the side of the can where it became visible drops that could also be touched and felt?" (For many 11-year-old students, the answer to the first question is evident. The droplets curve from inside the can. They do not see the impossibility of this and many do not comprehend the existence of water vapor in the air.)

Learning is significantly enhanced when the discussion of the applications uses the familiar experience as a basis for applying the abstract concept to deepen understanding of the phenomenon and its explanation using a model such as kinetic molecular theory. This makes a connection between abstract concepts and the real world that has the potential to foster deep understanding. However, the potential for this kind of dialogue to occur in science classrooms is increased if teachers know about research that has been done to describe common misconceptions students may hold about familiar phenomena. We have a vast store of this research, and teachers should be introduced to it as part of their education.

School Science and Mathematics
Table 1: Varied Teaching Strategies for Different Educational Goals

<table>
<thead>
<tr>
<th>Building a Knowledge Base</th>
<th>Generating Understanding</th>
<th>Finding Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecturing/Telling</td>
<td>Concept mapping</td>
<td>Searches for applications for science principles at home and outside school</td>
</tr>
<tr>
<td>Reading text or other sources</td>
<td>Writing to learn</td>
<td>Using newspapers as a source of applications</td>
</tr>
<tr>
<td>Watching films and videos</td>
<td>Group tasks requiring more than factual recall</td>
<td>Writing about applications</td>
</tr>
<tr>
<td>Hands-on activities</td>
<td>Reading for Understanding</td>
<td>Representing applications with pictures and models</td>
</tr>
<tr>
<td>Most seatwork</td>
<td>Journal writing</td>
<td>Group work describing applications</td>
</tr>
<tr>
<td>Labeling diagrams</td>
<td>Representing concepts with pictures and models</td>
<td>Asking the right question</td>
</tr>
<tr>
<td>Most labs</td>
<td>Explaining diagrams</td>
<td>Tests with application items</td>
</tr>
<tr>
<td>Most homework</td>
<td>Group work formulating explanations</td>
<td></td>
</tr>
<tr>
<td>Answering test questions</td>
<td>Analysis of peers' work</td>
<td></td>
</tr>
<tr>
<td>Most library research</td>
<td>Extended questioning</td>
<td></td>
</tr>
<tr>
<td>Most objective tests</td>
<td>Essay tests</td>
<td></td>
</tr>
</tbody>
</table>

Understanding, contains many forms of activity in which students become the agents for development of their own understanding. The activities under this heading — such as writing to learn, concept mapping, and group work — are now becoming familiar pedagogical strategies that are often observed in classrooms. However, some strategies, such as group work, are often used more for social ends (helping children to learn how to work cooperatively) than for intellectual, academic purposes (such as forming a collective understanding). The activities in the third column, Finding Applications, are somewhat less familiar than the others, which suggests how we have ignored applications as part of our pedagogical approach in recent years.

This model has demonstrated a high degree of utility in helping teachers gain an initial vision of how to proceed toward teaching for understanding and application of science knowledge. It is especially useful when combined with other models of teaching for understanding, such as has been refined by my colleague, Charles Anderson. In this model, there are five steps — engaging, modeling, coaching, fading, and sustaining (Collins, Brown and Newman, 1989).

A central message of both of these models is that understanding is not easily attained by students, and it takes much recurring support. One concern with many models of teaching and learning is that the amount of emphasis needed to develop understanding is typically underestimated. To foster understanding of the key concepts of science requires considerable effort and much reflection and intellectual struggle, because many of them run counter to common sense and experience. Reflect for a moment about the concept of inertia, as an example. It does not match students' (or adults') experiences from their everyday lives. Nearly every time they experience stops moving soon after the force that propels it ceases. Moreover, most objects they experience do not move in straight-line paths. Orbits of the moon and earth, and pathways of objects thrown through the air are curved. And the forces that act on these objects to cause the motion are not easy for students to envision. Therefore, it is quite demanding for students to comprehend the concept of inertia. As a result, it takes time reflection, and support from teachers and peers for students to form an appropriate level of understanding of this and other science concepts.

Another example may be useful in highlighting the difficulty of developing understanding. Seven years ago, at an assembly of people concerned about science teaching, a professor of physics from a university arrived and shared with me, in a most enthusiastic manner, his experience driving to the meeting in his van. He stated that a ball was left on the floor of his vehicle. When he drove up an incline or accelerated the ball rolled to the back of the van. Also, when I decelerated or drove down an incline, the ball rolled to the front. He noted, again with great enthusiasm, that the movement of the ball when his van changed speed was the result of inertia, and when the ball was moved as the vehicle went up or down hills (inclines...
were important in guiding teachers regarding what to look for in students' answers.

For at least one activity included with each key idea, we included samples of students' work, often in their own handwriting. This allows teacher and staff developers to have actual examples of students' work for discussion, analysis, and interpretation. In addition, we included examples of the analysis of students' work by the teachers who cooperated with us on the project development. We also included examples of recommended actions that teachers would take as next steps in working with the student whose work had been displayed. This last component of students' work provides a model of the actions we are encouraging among middle school science teachers to improve teaching and learning. This also allows teachers to see several examples of the implementation of the embedded assessment cycle.

The effects of embedded assessment on the learning environment are positive. Evidence from our investigations of classrooms in which teachers use embedded assessment in a systematic manner shows important changes in classroom interactions, discourse, classroom climate, students' engagement and motivation, and learning. Classroom interactions between teacher and students and among students change when teachers use embedded assessment as an important teaching tool. Teachers and students interact about students' ideas and reasoning more frequently in classes where embedded assessment is employed systematically than in classes where it is not employed. Further, there is more interaction among students about varied understandings of scientific concepts. There is more intellectual "wrestling" with ideas and understandings in these classrooms than is commonly found in classrooms.

In the classrooms of 12 teachers we studied during the developmental phase of this project, the level of discourse improved substantially as teachers increased their systematic use of embedded assessment. Discourse changed from a focus on memorizing factual information to exploitation of students' ideas and reasoning that emphasized understanding of scientific concepts. Much of the discourse was on reconciling students' naïve, idiosyncratic concepts and canonical scientific knowledge. It was teachers' use of embedded assessment that allowed access to students' "private universe" of views. However, the discourse was not teachers telling students the correct way to interpret experience or the correct words to say to explain observations. Instead, it was guiding students in reconstructing their understandings based on new information and experiences. It was a process of negotiating meaning using new information and experiences. Said another way, it was supporting students as they struggled to make sense of new information and experiences and make connections among old and new ideas.

Change in the classroom climate also was a notable, essential part of the transformation of these classrooms. If students are to allow their personal ideas and reasoning to become public, with access given not only to the teacher but also to other students in the class, fear of ridicule must be eliminated. Students must not laugh at, or otherwise make light of, other students' ideas and reasoning. Therefore, a collaborative learning community was nurtured and practiced by students and teachers, where diverse ideas could be put forth by students, analyzed, and discussed openly in a supportive environment. Development of this positive, open classroom environment was observed as a result of the leadership of the project's collaborating teachers.

Increased engagement of students and a decline in disruptive student behavior were noted as correlates of this change in classroom climate. One factor that appeared to contribute to these improvements was the teachers' attention to students' ideas and thinking as a central part of the classroom discourse. Having their teachers listen carefully and thoughtfully to their own ideas had a positive effect on students as a central part of the classroom discourse. Having their teachers listen carefully and thoughtfully to their own ideas had a positive effect on students because an important person in their lives (their teacher) was attending and reacting to what they thought and said. The importance of this close intellectual interaction between students and teachers cannot be underestimated, especially in our culture where opportunity for significant discourse between children and adults may be infrequent.

More students appeared to be drawn into productive classroom interactions when teachers listened to and acted on students' ideas. Students appeared to be more motivated, spent more time engaged in productive tasks with less time off-task in counter-productive or disruptive actions. These outcomes were reported by nearly every teacher when embedded assessment became a central part of their teaching.

The key questions usually asked by administrators, parents, and other concerned about educational reform have been, "Does embedded assessment make a difference in students' understanding of science knowledge and their capability to apply it? And does
It also will require thoughtful education of those who make the policies that affect teachers, teacher educators, curriculum, testing, university admissions and many other aspects of our educational environment.

5. Because the task is so daunting, we must make thoughtful decisions about our work in the years ahead. We must focus our efforts on the needed research, development, and teacher education that is essential to make it possible to teach for understanding and application of knowledge. As a profession, we must allocate resources to those who can make a difference in improving teaching and learning for a wide range of students. Since the task is so demanding and inevitably costly, it is essential that we utilize resources wisely. This requires thoughtful planning and monitoring of our efforts.

6. If we are not both successful and politically astute in the near future, our opportunity will be lost, as policy makers will find our efforts ineffective. Thus, the resources needed to carry out the task effectively will not be available. Therefore, we need to be both intellectually and politically wise, or the present window of opportunity will close.

References


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Embedded Assessment and Reform of Science Teaching and Learning*

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Introduction

Two recent developments challenge traditional science education and demand change in teaching practices. They are: 1) the reform movement embodied in Project 2061 and National Science Education Standards and 2) the new understanding of how learning occurs. The reform movement speaks to the goals of science education – what we should be teaching, what scientific literacy is. The new theories of learning, such as constructivism, address how to teach. The changes demanded of teachers – to move to new ways of teaching and ultimately to attain the reform goals – are fundamental and difficult. It is the purpose of this paper to: 1) explain the role of embedded assessment in the new vision of effective science teaching and 2) present materials that help teachers learn to use embedded assessment as a vehicle for improving their teaching effectiveness and students’ learning.

Overview

By embedded assessment we mean assessment that is merged with teaching. Unlike traditional assessment (Bybee 1997) which often takes the form of a test or quiz administered to determine what students have learned (or not learned) after teaching is completed, embedded assessment involves the use of teaching and learning activities that

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reveal students' thinking while they are learning. Therefore with embedded assessment, the line between teaching and assessment is blurred. Our definition of embedded assessment also includes teachers' use of newly gained knowledge of students' understanding to guide subsequent instructional decisions. So embedded assessment is a cyclical, ongoing process whereby teachers gather data about students' understanding as they teach, analyze the data formally or informally, and use the analysis to plan or adjust teaching next hour, tomorrow, and/or next year. Adjustments can also be made immediately, as a lesson progresses. It also is important to note that the next day's teaching also includes embedded assessment and so the cycle repeats itself.

It should be obvious how embedded assessment, as defined here, could help teachers fine-tune their teaching. But we will describe a larger role for embedded assessment as a tool that starts and then supports teachers as they make the large changes demanded by the reform effort and described by the new learning theories. Before presenting this explanation it is necessary that we sketch our interpretation of the reform goals and learning theories. These descriptions are not intended to be exhaustive summaries, merely clarifications of terms and perspectives.

Reform and Learning Theory Framework

Project 2061 and the National Science Education Standards have put before the teachers of the United States a significant challenge: science literacy for all students (Rutherford and Ahlgren, 1989; National Research Council, 1996). Further, the framers of this goal for science education have elaborated the vision of science literacy and have made understanding and application of science key elements of scientific literacy and placed them at the center of the current reform. Moreover, both Project 2061 and the National Science Education Standards set out a broader scope for science literacy than is common place. By incorporating inquiry, integrating themes, historical perspectives pertaining to the development of scientific ideas, and technology, the reform leaders have broadened the content base of science to lessen its abstract nature, connect science more
intimately with the experiential world of students, and make it more understandable and practical.

Understanding and application are defined in detail by the authors of the reform documents. They stress that science literacy involves a powerful and useful understanding of science. *Science for All Americans* emphasizes "being able to use scientific knowledge and ways of thinking for personal and social purposes" (Rutherford and Ahlgren, 1989, p. 20). The *National Science Education Standards* state that scientific literacy is demonstrated through the ability and propensity to apply scientific concepts and processes (National Research Council, 1996).

In addition to describing the goals of science teaching, the reform documents provide useful perspectives on how to teach science effectively. They draw heavily on the new theories of learning and teaching such as constructivism. At the center of the new theories is the idea that learning occurs when students work to make sense of new ideas and processes. Taking in pre-packaged information from the teacher does not lead to effective learning. Making sense involves working with new information and experiences and building a new mental framework from their current one that accommodates the new ideas as well as past experiences. Thus effective learning is an iterative process where learners engage with new ideas in multiple forms continuously testing and adjusting their mental frameworks. Participation in a community with feedback from teacher and peers aids the learning process (National Research Council, 1996).

**Conceptual Model of the Role of Embedded Assessment in the Reformation and Maintenance of Effective Teaching**

Looking at these interpretations of the reform goals and the learning theories, it is clear that significant changes are involved in moving from traditional teaching to this new vision of teaching of science. The two kinds of teaching are represented schematically in Figures 1 and 2. The pictures show how both the content and the roles of the teacher and students change significantly. In traditional teaching depicted in Figure 1, the teacher
transmits information to the students. The information may be limited in its power to explain natural phenomena and generally only presents one aspect of the idea. The traditional role for students is that of receiver of prepackaged information. In this approach, assessment usually occurs at a later time and has little implication for instruction or learning.

Figure 2 shows a model of reformed science teaching and learning that is consistent with modern learning theories. The subject of the teaching is powerful scientific ideas. Many aspects of these ideas are studied, including for example their applications to natural phenomena and how we have come to know about them. The teacher's role shifts to that of an orchestrator of a series of activities and a guide to the development of students' ideas. Students have an active role as sense makers.

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Figure 1. Information Transmission Model

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Figure 2. Teaching For Understanding and Model

As the *National Science Education Standards* point out, effective science teachers must be "skilled observers of students" in order to "guide and facilitate learning" (National Research Council, 1996, p. 33). Teachers cannot guide students nor plan activities that fit their current ideas unless they have an intimate and ongoing
understanding of that thinking. However these skills are frequently absent from the repertoire of traditional teachers. Therefore it is particularly important that embedded assessment be explicitly and systematically included in teacher education and staff development efforts.

Our conceptual model of embedded assessment has three main elements that describe teachers’ actions.

- **Gathering information about student understanding** as students work on tasks that expose students’ ideas and reasoning as they learn. Information can be derived from oral, written, or graphic products, from watching students at work, from listening to students during informal conversation, or in response to probing questions.
- **Engaging in deep analysis** of this body of information to inquire about what students seem to understand, and what they seem to be struggling with, yields clues as to
- **Deciding next instructional moves** based on analysis of the information, taking into account the learners, the learning goals, and possible courses of action for making progress toward those goals.

Figure 3 shows the role of embedded assessment in effective science teaching, but how can embedded assessment facilitate and support the change from traditional teaching? The starting point includes teachers who embrace the reform movement goals of focusing teaching on powerful concepts or processes and teaching for understanding. If they accept these goals, they will need to incorporate embedded assessment into their teaching because it is not possible to teach for understanding without it. These teachers can start by modifying a teaching activity focused on the goal so that the activity reveals students’ thinking (not just a final answer). In addition to allowing teachers to assess students’ progress, the modification usually pushes the activity to become more student-centered, since students need to explain or justify their responses in someway rather than just give correct answers. Usually this kind of assessment reveals the complexity of learning and creates an awareness of the need for teachers to guide students in clarifying relationships among ideas. It also produces evidence about what students know and how they know
it. Understanding and application are defined in detail by the authors of the reform documents. Information gathered from embedded assessment about traditional teaching also can be useful. It often identifies specific problems with students' understandings that can be addressed thus empowering both teacher and students. Rather than wondering why students do poorly on a unit test, the teacher has information on how to help students improve their understanding at a time when it can be acted on, and before confusion and inappropriate conceptions deepen and solidify. In addition, some students who do not usually achieve well in traditional classrooms appear to understand more. Most importantly, the results from embedded assessment reward and guide the teacher towards more effective teaching and more satisfied students (Report to National Science Foundation, March 1995).

Our Research and Development Project

We developed the conceptual model described above during the course of a four-year project supported by National Science Foundation and Michigan State University. We worked to better understand embedded assessment, and to develop resource materials and a conceptual model to aid teachers in employing embedded assessment in science classes at the middle school level. In this section we describe the resource materials.

During the project we worked with a team of teachers whose experience ranged from 3 to 25 years. These particular teachers were selected because their schools were already involved in collaborative projects with us. We are currently working with approximately 50 leaders in staff development to learn more about large-scale implementation of the work across the state of Michigan. We are still gaining experience in this latter dimension of our work, therefore reporting on it will be left to a later time.

The resource materials consist of seven booklets. One of the booklets is a compendium of general teaching/assessment strategies that teachers in our project use to teach, and at the same time assess, their students' ideas and reasoning in science. These strategies are each described briefly and one or two practical examples are provided to show how these general strategies can be adapted to a variety of subject matter. The
Figure 3. The Embedded Assessment Cycle

teachers in our project who were skilled in the use of embedded assessment planned their teaching by creating an orchestrated series of these teaching/assessment activities adapted to each big idea in a unit.
The other six booklets each correspond to an instructional topic that is commonly included in the middle school science curriculum. The topics were also included in the content for middle school in *National Science Education Standards, Project 2061 Benchmarks for Science Literacy*, and guidelines for science from several state education departments. This adds to the promise that these topics will be part of future curricula in science. The booklets' topics are:

- Structure of Matter
- Force and Motion
- Astronomy
- Forces that Shape the Earth (Geology)
- Ecology
- Human Body Systems

Each booklet is organized around "key ideas". For each key idea, we describe the difficulties that students typically have with the idea, several teaching/assessment strategies, and assessment criteria that help the teacher analyze students' responses. For at least one activity included with each key idea, we have included samples of students' work, analysis of the work, and suggestions for how to use the analysis to guide the next steps in teaching. Below we describe each component of the booklets more completely including its connection to the new ideas about science education and how it can help teachers.

**Key Ideas** – For each topic five or six key ideas are identified that comprise the major concepts appropriate for students at the middle school level. The key ideas form the basis of content organization for both teachers and students. The key ideas are meant to be indices to the booklets that can be used by teachers regardless of the curricula that they are using. Thus a teacher who is looking for examples of how to use embedded assessment when teaching about the effects of temperature on matter, would turn first to Key Idea 3 in *Structure of Matter* which states:

As a material is heated, its particles move faster. When it is cooled, the particles
move slower. (p. 23)

A second rationale for organizing around key ideas arose from our observations in classrooms where we noted that many teachers and students “became lost” in the details of science content, and were not able to delineate the main ideas that they were teaching or learning (Wiggins, 1998; Wiske, 1998). As a result, facts, concepts, principles, and theories were seen as being of equal importance. Little or no hierarchical structure was given to knowledge, which limited teachers’ ability to help students organize information, focus on overarching ideas, and identify supporting facts.

A focus on central ideas mirrors Benchmark’s delineation of a “common core” of ideas that form a foundation for scientific literacy and National Science Education Standards’ call for a focus on powerful ideas that are useful, have many applications, and enrich students’ lives (Project 2061, 1993; National Research Council, 1996). In addition we consulted with scientists to make sure that the key ideas were formulated in such a way that they accurately conveyed their centrality in the discipline. In this respect they somewhat resemble the generative topics described in the Teaching for Understanding Project (Wiske, 1998).

Students’ Difficulties – For each key idea, we provide a description of selected data from the extensive body of research on students’ misconceptions and naive concepts in science (see for example, Driver, 1994) and from teachers’ practical knowledge about the difficulties that students encounter when learning the concept or principle. For each key idea, we have included both narrative text on students’ difficulties and a table that summarizes and juxtaposes intended understandings and naive conceptions. Presenting the information in two forms was done to make this essential component of embedded assessment as “user friendly” as possible.

Information about students’ ways of thinking about particular topics forms an important part of science teachers’ professional knowledge (Magnusson, et al., 199x). It can: 1) heighten teachers’ awareness of their students’ ideas and reasoning so that teachers can structure their teaching around them and 2) guide their interpretation of students’
words, work, and actions in the classroom. As stated in the framework, one foundation of the new theories of learning is that students have existing frameworks of understanding that often are strongly held; and new, lasting understanding occurs only when students can incorporate new ideas with existing frameworks. Knowing about ways that students may go astray in the building process, allows teachers to formulate reinforcements into their teaching at those points.

Thus when preparing to teach about the effects of temperature on matter, teachers with an awareness that many students do not associate the effects of heating with changes in molecular behavior, plan several activities provide students with experience with heating and cooling. Subsequently, the students are guided in developing explanations of what their observations in terms of molecular motion. If teachers are also aware that students may think that “substances expand when heated, because the molecules in them get bigger,” they will be prepared for students whose actions, discourse, or representations imply this conception (Structure of Matter, p. 24). Teachers can then plan follow-up activities that help students revisit important ideas such as expansion and change of state from a perspective of molecular motion.

Teaching/Assessment Activities – For each key idea, at least four and typically a half-dozen or more, teaching/assessment activities were included. These activities are designed to simultaneously nurture and assess students’ understanding of the key idea. These teaching/assessment activities “blur the lines” between teaching and assessment. They were designed to show teachers that most activities can be used for the dual purpose of teaching and assessing, and to aid teachers in making assessment a more integral part of teaching.

One characteristic of the array of activities that are included is that they provide a range of opportunities for students to demonstrate their ideas and reasoning. Activities include opportunities for students to: (a) write about their understanding and applications of scientific ideas through activities called “mind-stretchers” in our booklets (and labeled “quick writes”, etc. by others), (b) represent them in graphic form using pictures,
diagrams, and models including concept maps, (c) use analogies, (d) engage in group discussion and group writing, (e) analyze each others’ work in a whole-class or group format called “peer analysis,” and many other strategies that use both individual and group techniques to elicit information about students’ understanding of, and ability to apply, science concepts and reasoning skills.

The variety of activities is intended to achieve several goals. First it is designed to “be engaging to students with different interests and experiences,” an important feature of ongoing assessment as described by *The National Science Education Standards* (National Research Council, p. 85). Second, the variety is meant to model the multiple opportunities to make sense of new ideas that modern learning theories show are needed by students as they construct understanding. In addition, strategies like group work and peer analysis help develop communities of learners and orchestrate discourse among learners. These are components of effective teaching included in the new learning theories and described by *The National Science Education Standards* (National Research Council, 1996, pp. 27 - 53).

The teaching/assessment activities for Key Idea 3 in *Structure of Matter* are shown as examples in Table 1. Readers must note that these booklets are not structured curriculum guides. Instead, they are resources for teachers to use as supplements with any of several programs and curricula for middle school science.

<table>
<thead>
<tr>
<th>Activity title</th>
<th>Type of teaching/assessment strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Food coloring in hot water</td>
<td>Experiment</td>
</tr>
<tr>
<td>B Ball through a ring</td>
<td>Laboratory demonstration and picture drawing</td>
</tr>
<tr>
<td>C Thermometers</td>
<td>Inquiry project</td>
</tr>
<tr>
<td>D Melting chocolate</td>
<td>Student predictions</td>
</tr>
<tr>
<td>E Cooling balloons</td>
<td>Role playing</td>
</tr>
<tr>
<td>F Balloon sellers</td>
<td>Design project and presentations</td>
</tr>
</tbody>
</table>

Table 1. The teaching/assessment activities for Key Idea 3, *Structure of Matter*. Key Idea 3 states, “As a material is heated, its particles move faster and faster. When it is cooled, the particles move slower.”
Assessment Criteria -- For each teaching/assessment activity, assessment criteria were formulated and presented to guide teachers in interpreting the students' responses. These criteria were designed to refocus teachers’ attention on students’ understanding and application of the science content, helping teachers grasp what students’ had already learned, and had yet to learn, to achieve a suitable level of understanding and application of the key idea. Many teachers initially have difficulty moving beyond judgments about whether their students’ responses are adequate or inadequate. The assessment criteria are meant to guide teachers to consider, more thoroughly, other aspects of their students’ work. As an example, the assessment criteria for the thermometer inquiry project for Key Idea 3 in Structure of Matter are shown in Table 2. In this activity students describe, draw pictures of, experiment with, and watch in action a variety of thermometers. They use their findings to explain how liquid-in-glass thermometers indicate temperature.

<table>
<thead>
<tr>
<th>Assessment criteria</th>
<th>Focus of criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do students’ explanations include a description of the liquid in the thermometer expanding as the surrounding temperature increases? Do they state that this due to the increase speed of the particles in the liquid?</td>
<td>Students’ ability to recognize and then explain the critical features</td>
</tr>
<tr>
<td>Do students keep complete, accurate, and organized records?...Does the log describe what they actually did, or what they thought they should do?</td>
<td>Students’ record keeping -- a goal in itself and a factor that affects their ability to generalize</td>
</tr>
<tr>
<td>Have students asked themselves useful questions as they try to figure things out, or do they operate without a plan on the spur of the moment?</td>
<td>Students’ sense making process -- a goal in itself and a factor that affects their ability to generalize</td>
</tr>
</tbody>
</table>

Table 2. The assessment criteria for the thermometer inquiry project for Key Idea 3 in Structure of Matter.
Student Work – For at least one teaching/assessment activity in each key idea, examples of students’ work were included, often in the students’ original handwriting. This allowed teacher and staff developers to have actual examples of students’ work for discussion, analysis, and interpretation. In addition, we included examples of the Analysis of Student Work that had been done by the teachers who cooperated with us on the project development. We also included examples of Teacher’s Actions or recommendations for actions that teachers would take as next steps in working the students whose work had been displayed. Thus, this last component of students’ work provides a model of the kind of actions that we are encouraging among middle school science teachers to improve teaching and learning.

Returning again to Key Idea 3 in Structure of Matter:

As a material is heated, its particles move faster. When it is cooled, the particles move more slowly. (p. 23)

This idea explains expansion, because the faster moving molecules require a greater amount of space. However, many students at middle school level hold the view that materials expand when heated because the molecules themselves expand (Structure of Matter, p. 28). A likely response to this task would be that a balloon could be slipped over the mouth of a bottle which is then placed in the hot water bath, causing the air in the bottle to expand, partially inflating the balloon.

Answers from three students in one teacher’s class serve as examples of students’ ideas and reasoning.

Student 1. Balloons blew up because when the water was heated, the heat rose up but couldn’t escape. So it went into the balloon and blew up.

Student 2. The air compressed and blew it up.

Student 3. The atoms separated. The only place they could go was into the balloon (Structure of Matter, p. 29).

Analysis and interpretation of the results of this task showed that many students explained their observations in a manner similar to Student 1, centering on a commonplace
but incomplete concept that fits their experience: “hot air rises.” Other students presented views like Student 2 whose logic and conceptual content is flawed in his statement about “air compressed.” This student used a word from science as part of his/her explanation, but used the wrong word to give an incorrect and incomplete explanation. Student 3 centered his explanation on the desired concept, (atoms separated) but it is unclear what his/her ideas were because his/her statement is incomplete. Two of the three examples given above provide a logically sound idea that the only place that would allow for expansion was the balloon, implying (thought not stating) that it could stretch, whereas the bottle had a fixed volume.

The teacher, who taught both science and language arts, provided the following plan for the next steps with this class.

Because the most common problem with students’ responses was their incompleteness, she realized that she needed to model the type of reasoning that she wanted her students to use. Therefore, as a class, they developed an explanation for what happened. Specifically, the explanation had to start with, “Heat made the molecules in the flask...” and end with “This caused the balloon to inflate.” The subject of every sentence in between had to be “the molecules.” She then directed students to work individually to write explanations (Structure of Matter, p. 30).

This example shows several features of our work with embedded assessment. First, it shows the utility of the resources that were developed to aid teachers in thinking deeply about teaching and learning in the framework of assessment as an integral part of instruction. Secondly, it shows the value of key ideas as tools to help teachers focus their instructional activities on understanding concepts and principles of science rather than on unconnected facts (NRC, 1996; TIMSS, 1997). In this case, the key idea guided the teacher to focus on expansion and contraction as related to motion of molecules as opposed to the often seen emphasis on vocabulary. Thirdly, the section on student difficulties alerted the teacher to identify the students’ naïve concepts noted in
explanations that they wrote. Even though none of them demonstrated one of the major naïve concepts that persists among students, “Molecules expand when heated,” it alerted the teacher to the fact that she could not assume that her students’ incomplete answers implied an understanding of the intended concept. Fourthly, it led the teacher to come up with a plan of action based on the information found in students’ explanations, which focused on the form and logic of an explanation. The conceptual understandings and misunderstandings that were evident in some explanations were left to be addressed after students’ ideas were more clearly formulated.

Finally, it implies the continuing, cyclic nature of the embedded assessment. The teacher developed a plan of action based on her interpretation of the information that was generated from the teaching/assessment activity. The plan of action was strongly influenced by the teacher’s background as a teacher of both science and language arts. Moreover, the strategy of writing explanations with a constrained format automatically lead to another round of collection of information about the effect it had on students’ expression of ideas and reasoning. The teacher next must examine the effect of her plan on all students. Did her recommendations about the form of explanation result in explanations that were more logically and scientifically sound than those presented previously by students? Another question to explore pertains to those students whose ideas were influenced by the common place viewpoint the “heat rises.” Was the teacher’s prompt, “Heat made the molecules in the flask…” sufficient to refocus students attention from their simple view that many observations can be adequately explained by heat rises” to the more complex idea that molecular motion and heating are connected? Have the students in fact, internalized this connection in any practical way that allows them to apply it to this situation? For the teacher to continue to guide students to a more complete understanding of this key idea, it will be necessary for her to continue appraisal of the responses to new tasks that inform her of the ideas and reasoning.

Lessons learned about Embedded Assessment

In the past six years, we have worked with teachers and staff development
personnel on several dimensions of embedded assessment including how teachers use it, needed support for teachers in incorporating it as a functional strategy in their teaching, its effects on the classroom environment, and the effects it has on students’ learning and motivation. Each of the dimensions is discussed below.

How teachers use embedded assessment

It was a surprise to our research and development team that embedded assessment was not a more natural part of most teachers’ teaching. Our assumption at the start of our work was that nearly all teachers were effective in monitoring students’ behavior and taking actions to correct counter productive behaviors, and that most would also engage in embedded assessment as its cognitive counterpart. While many teachers exhibited some aspects of embedded assessment in their classes, their use of it tended to be intermittent, instead of commonplace and systematic. Moreover, many teachers tended to look upon students’ naive conceptions as interesting curiosities. Few were able to use this information to understand their students’ ideas and reasoning, and even fewer used it to guide instructional decisions and actions to rectify naive concepts and unsound reasoning.

Over time, the teachers with whom we worked incorporated embedded assessment into their teaching more systematically. For some, it required a substantial paradigm shift from a model of teaching that can be summed up in the phrase “teach, test, and proceed to the next topic,” with assessment used in a summative manner for the purpose of grading, to an approach consistent with the conceptual model outlined above. In this model, teachers frequently monitored students’ ideas and reasoning to determine their progress toward the desired understanding and application of scientific knowledge, interpreted this information, and then used it to modify their teaching to make it more effective in moving students toward the intended goal.

It has been rewarding to see the changes in vision and action on the part of both experienced and prospective teachers. We have witnessed the paradigm shift in teachers with whom we worked on our research and development project whose experience ranged from three to more than thirty years of teaching. We have also witnessed changes in our
secondary science students with whom we work for two years in a "methods course" that begins during their senior year of college and continues through the following intern year. In addition to becoming an important part of these pre-service teachers' teaching, an emphasis on embedded assessment helps them broaden their focus from their own actions, to the effects of those actions on their students. This is an important step in the development of new teachers.

Support needed by teachers

To make the changes needed to incorporate embedded assessment into their teaching, both prospective and practicing teachers need considerable support. First, they need to be helped in making the paradigm shift from using assessment predominately as a tool used mainly for giving grades to the use of assessment as a guide to teaching and learning. This is a fundamental change in beliefs and actions related to teaching. In order to give this change in viewpoint substance, other changes are needed which also require considerable support. These are described below.

- *Learning new assessment strategies* to obtain information about students' ideas and reasoning regarding the science concepts, principles and processes that make up the content of their lessons and units as students learn. Thus, teachers need to develop a repertoire of teaching/assessment strategies.

- *Deepening understanding of the concepts, principles and processes* that are part of the curriculum. Work on embedded assessment typically "pushes" teachers' knowledge of the subject matter to new levels of understanding. As one of our colleagues put it, "Learning about students' ideas also exposes our own naïve concepts." As staff members of the project, we also can attest to how this experience helped us deepen our understanding of the fundamentals of the subject matter that is included in the middle school program. Teachers would be more able to teach for understanding and application if greater emphasis were placed on teaching for understanding and application in college courses in science. This is one of the serious problems that higher education needs to face (Tyson, 1994; Floden, R. and J. Gallagher, 1994;
• *Developing increased knowledge of the research literature on naïve conceptions, misconceptions, and students’ thinking.* The benefit here is three-fold: 1) It makes teachers more aware of the potential areas of difficulty that their students may encounter as they are trying to learn particular new content. 2) It provides clues for teachers about what to look for as they listen to students, watch them at work, and examine products of their work. 3) It suggests new activities and techniques to add to their repertoire of assessment strategies. Thus more attention should be given to expanding teachers’ professional knowledge of the research literature on students’ concepts in science as part of teacher preparation and staff development activities.

• *Learning to interpret students’ work and discourse.* Collecting information about students is only a first step in the process of embedded assessment. Making sense of what students say, what they write, the pictures they draw, the models they build, the successes they have, and the mistakes they make is at the foundation of embedded assessment. This requires the propensity to ask, “What does this action or statement by a student tell me about his/her ideas and reasoning?” It also requires some insight into how to make sound judgments in answer to this question. This is where both the art and science to teaching coalesce. However, it is a dimension of teachers’ professional knowledge that is seriously underdeveloped in many teacher education programs (Salish, 1997, p. ...).

• *Deciding what to do next.* For many teachers, this is the most difficult part of embedded assessment because they have only limited ideas about alternative actions to remedy inadequate performance or understanding by students after an initial attempt at teaching. The next instructional activity can often begin with students analyzing the work of their peers (with names removed) or work of students from other classes at the same level. Analysis of responses to a task, some of which are acceptable, some at least partly acceptable, and some that are quite unacceptable, can be a useful beginning at re-teaching an idea that was not fully grasped on the first
round.

Another strategy for helping students revise or clarify problematic ideas revealed by embedded assessments is to pose a question that requires an extended answer, and then to ask the class, "How many of you think you can answer this question?" A teacher in our group who uses this strategy then has students who respond affirmatively serve as group leaders to discuss appropriate answers to the question for a few minutes. He then re-asks how many think they can answer the question, and if several students still are uncertain, he has the students spend more time with peer teaching. Finally he has one or two students teach the whole class, while the remainder of the students evaluate the presentation and give feedback to the presenters (Gallagher, Cline, and Jamison, 1990). In this way, the class is engaged in serious analysis of the question and potential answers to it for an extended duration, perhaps as much as half of a class period. With careful selection of questions which require synthesis of ideas, and demonstration of integrated understanding, this strategy can be very effective in helping students develop a high level of understanding. These are only two of many possible strategies for re-teaching and deepening understanding of a concept. More attention needs to be given in methods courses and professional development activities to helping teachers develop a repertoire of effective, alternative, instructional strategies that can be used for teaching and re-teaching scientific ideas to advance students' understanding and application of scientific concepts and processes.

- Finally, all of the teachers with whom we worked were emphatic in their reports to us that they could not undergo these demanding changes without the support of a group of like minded peers who met regularly.

Effects on the classroom and school environment

Observations of classrooms where teachers are using embedded assessment, and interviews with them, point to several important outcomes of embedded assessment. For teachers, one of the most significant is an improved classroom environment. Students in
middle school science classrooms where teachers are using embedded assessment as a continuous, integral part of their instruction become more engaged in science and are less disruptive over time. It appears that when teachers begin to listen carefully to students, and provide supportive responses to their ideas, positive changes occur in their behavior that result in a more wholesome classroom environment. This finding supports the literature on learning communities (VEA, 1992).

Teachers who use embedded assessment as an integral part of their teaching report that they work harder and yet find their work increasingly rewarding. Moreover, teachers who work in the same department or school who use embedded assessment find that they have a new basis for interaction with their peers, grounded in the multiple components of this approach. This is more positive than the usual sharing of complaints about students’ behavior which do little to improve the teachers’ situation. Benefits of this work affect interactions with peers, parent, and administrators in positive ways. This finding related to the literature on effective teaching (citations needed).

Effects on students’ learning and motivation

From the literature on student motivation, it is clear that one of the most potent motivators is success (citations needed). Because the goal of embedded assessment is to maximize student success in understanding and applying science, it is not surprising that we find that students are more enthusiastic about learning in classes where teachers use embedded assessment systematically in their teaching. When the emphasis is on students’ understanding, they feel more supported by the teacher. This is in contrast to traditional teaching where an undeclared message often may be, “We will go on to the next topic regardless of what you learned about the current one.”

Positive effects of embedded assessment are most evident among students who experience this kind of teaching. Conversely, some students who have performed well by memorizing or who are used to traditional teaching may feel that the their usual method for success has been undermined or the rules have been unfairly changed on them. Teachers report that these students resist change or may even be openly hostile.
Teachers have reported to us in debriefing seminars and during interviews that they need to be very explicit about expectations, and be patient and persistent helping students develop the new skills that help them understand and apply science. Moreover, nearly all students can come away from the activity with a sense of accomplishment and improved self-confidence that has a positive effect on motivation.

In summary, embedded assessment show promise for attainment of central goals of contemporary reforms including deepening students understanding of, and ability to apply, scientific knowledge. It also shows promise for advancing attainment of the goal of science for all. However, it also is clear that teachers need substantial staff development and support if they are to use this approach systematically and effectively in the classroom

References: