What Does Research Say About Effective Science Instruction?

If you were to ask science teachers or teachers of elementary school science what effective teaching looks like, the answers would clearly depend upon a variety of factors such as how long they have been teaching, their understanding of learning theory, their ability to understand and apply recent brain research, their content and pedagogical content knowledge, the coaching and mentoring that they received during and after their teacher preparation work, the professional development that they receive, and the professional collaboration and conversations that are part of their day-to-day teaching. This is not a comprehensive list by any means, but it speaks to some of the different influences on teachers' conceptions of effective science teaching and their levels of preparation to design and provide effective teaching and subsequent learning for their students.

When reviewing the research base around effective science teaching there are several resources that provide guidance and insights that can be used to answer the questions "What does effective teaching mean?" and "How does it look?" As mentioned previously, the National Science Education Standards (NRC 1996) provide a framework for what effective science teachers know and do. *Looking Inside the Classroom* (Weiss et al. 2003), a National Science Foundation study, provides additional insights about effective science teaching. According to the study, the goal of all instruction should be to develop students' conceptual understanding. As a result, teachers need to provide students with opportunities to learn the content and be clear about the learning goals for each lesson (specific concepts being addressed). In addition, researchers conducting this study found that lessons judged to be of low quality often lacked meaningful opportunities for discussions or student sense-making and instead consisted of activities for activities' sake, with no clear learning target. As a result of their findings, the observers in the study concluded that "teachers need a vision of effective instruction to guide the design and implementation of their lessons" (p. xiii). It also was clear from the study that teacher content knowledge alone is not sufficient to prepare teachers to provide high quality instruction. A clear understanding of effective instructional practices (pedagogical knowledge) and pedagogical-content knowledge are also needed.

In other words, to adequately develop student understanding of science concepts, we have to go beyond a general understanding of effective instructional strategies and have an in-depth knowledge of the content and common research-based student misconceptions. With that understanding, we need to know when and how to introduce and develop the concepts in class to address students' prior conceptions. We must plan our instruction to engage students beyond a superficial

level by using a variety of representations and instructional strategies which make sense to the learner and take into account individual learner needs (Shulman 1986, 1987). We must understand students' scientific thinking and be able to generate effective representations that result in student learning. This cannot happen unless we are prepared with both content and pedagogy and take the time to assess for student thinking.

Figure 1.1 (p. 4) provides lists of the characteristics of effective science lessons that the researchers looked for in the classrooms involved in the *Looking Inside the Classroom* study. The characteristics of effective lessons, along with the research findings, add to our understanding of what it means to offer effective science instruction.

Effective teaching also means assessing what students know as instruction occurs and taking that information into account to adjust instruction. This focus on formative assessment processes in science classrooms is consistent with the research on how students learn science (Minstrell 1989; Donovan and Bransford 2005). Findings from the meta-analysis on how students learn science emphasized the following important principles of learning:

- Assess for prior student understanding of the science concepts.
- Actively involve students in the learning process.
- Help students be more metacognitive so that they can acknowledge the science concepts they understand, the goals for their learning, and the criteria for determining achievement of the learning goals.
- ensure that learning is interactive and include effective classroom discussions.

In a recent publication titled, "Effective Science Instruction," Banilower and colleagues (2008) provide a summary of studies on science learning and suggest an instructional model based on that research. They identify five features of effective science instruction. The first feature is motivating students since students are unlikely to learn without some level of motivation. Second, it is important to elicit students' prior knowledge to find out what their ideas are about the topics or concepts being studied. We know that students have ideas of their own about how the natural world works and some of their ideas will make it difficult for them to learn new ideas. Third, to engage students intellectually with the content, we need to link learning activities to the learning targets. Fourth, effective science instruction helps students think scientifically. This means students are able to critique claims using evidence. Finally, effective science instruction includes opportunities

Figure 1.1
Characteristics of Effective Science Lessons

Quality of Lesson Design	Quality of Noninteractive/Dialogic (NI/D)
❑ Resources available contribute to accomplishing the purpose of the instruction. ❑ Reflects careful planning and organization. ❑ Strategies and activities reflect attention to students' preparedness and prior experience. ❑ Strategies and activities reflect attention to issues of access, equity, and diversity. ❑ Incorporates tasks, roles, and interactions consistent with investigative science. ❑ Encourages collaboration among students. ❑ Provides adequate time and structure for sense-making. ❑ Provides adequate time and structure for wrap-up.	❑ Teacher appears confident in ability to teach science. ❑ Teacher's classroom management enhances quality of lesson. ❑ Pace is appropriate for developmental levels/needs of students. ❑ Teacher is able to adjust instruction according to level of students' understanding. ❑ Instructional strategies are consistent with investigative science. ❑ Teacher's questioning enhances development of students' understanding/problem solving.
Quality of Science Content	**Quality of Classroom Culture**
❑ Content is significant and worthwhile. ❑ Content information is accurate. ❑ Content is appropriate for developmental levels of students. ❑ Teacher displays understanding of concepts. ❑ Elements of abstraction are included when important. ❑ Students are intellectually engaged with important ideas. ❑ Appropriate connections are made to other areas. ❑ Subject is portrayed as dynamic body of knowledge. ❑ Degree of sense-making is appropriate for this lesson.	❑ Climate of respect for students' ideas, questions, and contributions is evident. ❑ Active participation of all is encouraged and valued. ❑ Interactions reflect working relationship between teacher and students. ❑ Interactions reflect working relationships among students. ❑ Climate encourages students to generate ideas and questions. ❑ Intellectual rigor, constructive criticism, and challenging of ideas are evident.

Adapted from Weiss, I. R., J. D. Pasley, P. S. Smith, E. Banilower, D. Heck. 2003. *Looking inside the classroom: A study of K–12 mathematics and science education in the United States*. Chapel Hill, NC: Horizon Research Inc.

for students to make sense of what they are learning by comparing their ideas to those presented by the teacher.

Another significant element of effective teaching comes from the research on formative assessment. Formative assessment provides ways for teachers to focus instruction on student learning. Incorporating formative assessments as part of teacher practices results in teaching and learning that supports an environment focused on learning for all, as Black and colleagues note,

> formative assessment is a process, one in which information about learning is evoked and then used to modify the teaching and learning activities in which teachers and students are engaged.... Feedback can only serve learning if it involves both the evoking of evidence and a response to that evidence by using it in some way to improve the learning. (2003, p.122)

The recent work on learning progressions as part of a formative assessment process provides additional guidance for effective teaching (Heritage 2007). Learning progressions can be created by districts to address coherence across the K–12 curriculum. For our purposes, we are referring to the sequencing of learning targets within a unit of study that leads to student mastery of the big ideas and key concepts. When teachers identify the learning goals (learning targets) in a learning progression and identify criteria for successfully meeting the goals, they can determine student achievement gaps. If students perceive the learning gap as too large, they also perceive the goal as unattainable. If students perceive the gap as too small, they might believe that closing it is not worth their effort (Sadler 1989). Clearly, effective teaching means identifying the "just right" gap for students.

Building a classroom environment that is conducive to learning is essential. Even when teachers clearly understand their content, and design and implement high-quality lessons, teaching will not be effective if the classroom environment does not provide a safe place for students to learn (Marzano 1997). Marzano's work, and that of others (Haertel, Walberg, and Haertel 1981; Bransford, Brown, and Cocking 2000), underscores the idea that effective teaching includes building an environment that is conducive to learning. Teachers' belief systems (how to teach and student accountability) greatly impact their abilities to create an environment where they can work collaboratively with students. That's why it is important to address teacher beliefs, even though it is challenging to do so. Fortunately, research-based strategies are available to help with this task.

As noted previously, effective science teaching develops students' understanding. A recent research-based publication from the National Research Council (NRC), titled *Taking Science to School* (2007), reminds us that in general, students

have the capacity to develop understanding of science concepts, but they lack opportunities to do so. This report is not talking about special needs students but the majority of our students who are not achieving in science because they are not provided with sufficient learning experiences. To be effective, science teaching must, first and foremost, provide students with opportunities to learn important concepts. A next logical step is to use research-based instructional strategies to engage students with learning in ways that support development of conceptual understanding (Marzano 2003).