Developing a Philosophy for Inquiry

A prerequisite for becoming an inquiry-based teacher is embracing a philosophical mind-set founded on the ideals and principles of constructivism. Today there are as many interpretations of constructivism as there are interpretations of inquiry, yet many high school science teachers may still be unaware of the publicity that constructivism has attained in the last 20 years and its implications of constructivism for science education, instructional reform, and, specifically, inquiry-based classrooms.

Although it has implications for the classroom, constructivism is not about teaching strategies, nor is it about designing curriculum. Rather, it is one theory or philosophy about how an individual learns, one in which the student is embedded in active engagement and is constantly constructing and reconstructing knowledge through environmental interactions. Because the tenets of constructivism align closely with the practice of inquiry, it becomes essential that inquiry-based teachers have a firm foundation in the propositions of constructivism.

This chapter will (a) introduce the philosophy and historical developments of constructivism that have shaped our understanding of how students learn science, (b) discuss how one's prior knowledge and misconceptions can influence learning, and (c) present constructivist learning strategies compatible with inquiry- and learner-centered classrooms. By understanding constructivist principles, we can better envision our role as inquiry-based teachers. For that reason, it becomes crucial that science teachers interested in inquiry be able to articulate their philosophy of teaching and learning, and apply it to classroom practice. After all, our values, beliefs, and even prejudices about teaching and learning are reflected in our classroom culture. Our classrooms, in a sense, mirror and resonate what we believe is good teaching and learning.
WHAT IS CONSTRUCTIVISM?

Constructivism is a theory about how we come to know what we know. It is founded on the premise that children, adolescents, and even adults construct or make meaning about the world around them based on the context of their existing knowledge. We do this by reflecting on our prior experiences. In this way, each of us “constructs” our own mental models, or schema, as we activate our experiences to develop new conceptual structures. In a constructivist point of view, the learner is constantly filtering incoming information based on his or her existing conceptions and preconceived notions to construct and reconstruct his or her own understanding. Thus, the meaning of “knowing” is an active, adaptive, and evolutionary process.

The constructivist perspective is startlingly distinct from earlier views and theories about learning. Behaviorism, one earlier view, is built on the premise that learning is an acquisition or change in observable behavior initiated through stimuli and responses. Although behavioral psychology or operant conditioning is considered useful when applying positive and negative reinforcements, it does not account for the cognitive aspect of learning. Objectivism, occasionally paired with behaviorism, presumes that all knowledge exists externally and independently from the learner, and that learning consists of imparting that body of knowledge from one person to another. Contrary to behaviorists’ and objectivists’ views, constructivists do not subscribe to the supposition that students “absorb” information from the teacher; nor do constructivists believe that knowledge is imparted, acquired, or transmitted from one individual to another. Constructivists believe that learning is self-regulating and socially mediated as the student actively engages, interacts, and operates within the confines of his or her environment. Learning, to the constructivist, is focused on cognitive, not behavioral, processes. Constructivists do not view the mind as a “blank slate” or an “empty vessel,” as in John Locke’s famous expression *tabula rasa*; teachers cannot dispense or pour information directly into a student’s head. In the constructivist approach, the student is an active participant in the learning process. Students enter our classrooms with years of prior knowledge and even misconceptions that greatly affect how they interpret and make meaningful interpretations of the phenomena being studied. According to the National Research Council (2000b), “students come into the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn for the purposes of a test but revert to their preconceptions outside the classroom” (p. 14). This chapter and the accompanying case studies will focus on the attention science teachers need to place on what their high school students are thinking about as they undertake inquiry investigations.

TRADITIONAL VERSUS
CONSTRUCTIVIST CLASSROOMS

To “construct” an understanding of constructivism, let’s consider two classrooms: one traditional, teacher-centered, and one constructivist, student-centered. In this
case study, Mrs. Hennessey, a biology teacher at Northshore High School, is presenting an introductory unit on “how the leaf carries out photosynthesis” to her general biology students. In this classroom, student desks are arranged in straight rows, with the teacher’s desk in the front center of the room. Mrs. Hennessey uses a single textbook for studying biology, along with several demonstrations and labs she has mastered from use over many years. During the unit, students take notes, fill out handouts and worksheets that emphasize rote memorization, and, when time and supplies are available, perform laboratory activities that verify information that was presented on previous days. Mrs. Hennessey starts the unit by telling students that photosynthesis is the process in which green plants use light energy to make food. She goes on to explain that “photo” means “light” and “synthesis” means “to put together,” and she indicates that “photosynthesis” is quite an appropriate name for the process. Students then copy the formula for photosynthesis, in both words and chemical notation, as she writes it on the board. Mrs. Hennessey continues by explaining in detail the process of photosynthesis and the role that light, carbon dioxide, and water play in making food for plants. Later in the first day’s lesson, Mrs. Hennessey goes on to describe the production of sugar and oxygen as products in photosynthesis.

The following day, she teaches the importance of photosynthesis by introducing the carbon dioxide cycle and the interdependence of plants and animals in their quest to survive. The teacher presents a lab experience to view the cross section of a leaf and identify the different leaf cells. During the lab, students use the cross section and their textbooks to label the different cell layers and structures of the leaf. At the end of the lesson, students use their notes and textbook to prepare for a paper-and-pencil unit test. In the test, students are asked to define the term “photosynthesis” and state its formula. Another section includes labeling a cross section of a leaf similar to the illustration from the lab.

In this classroom, Mrs. Hennessey is the information provider and views the students as passive learners who have come to the classroom to know and master a fixed body of information. Information is divided into distinct and separate parts, with little emphasis on the students internalizing the information.

Mr. Travers is also a biology teacher at Northshore High School, and, like Mrs. Hennessey, he is presenting an introductory unit on photosynthesis to his general biology students. In Mr. Travers’s classroom, student desks are sometimes arranged in straight rows, sometimes in groups of four, and sometimes in the shape of a “U.” Mr. Travers allows the purpose of the lesson to determine the appropriate room setup. Mr. Travers uses several textbooks and primary sources for studying biology. He keeps a collection of Science and Scientific American magazines on the shelf for students, along with other science books and resources. Mr. Travers starts the lesson by having students think about and record what they know about the leaf as the food manufacturing site and encourages them to write down whatever comes to mind when they think about the term “photosynthesis.”

After 2 minutes, he tells them, “Now turn to your partner and tell him or her your prior understandings about the word ‘photosynthesis.’ Take 2 minutes to share your thoughts and experiences about the word ‘photosynthesis’ with your partner.” At the end of the “pair and share” activity, he asks several students to share their understandings about photosynthesis with the class. As students share their ideas, Mr. Travers writes and arranges their thoughts in a concept map on the front board. The rest of the period is spent having students work in groups to view a prepared
section of a leaf cross section and compare it to the illustration in the book. As students are viewing the leaf section, Mr. Travers walks around the room answering their questions and posing his own to students.

The next day, students take notes from a brief presentation and overview on the cross section of the leaf as it relates to the first day’s activity of exploration and sharing previous understandings. Mr. Travers now presents a question to the class: What would happen if you took away or changed one of the requirements for photosynthesis? This investigation provides an opportunity for students to choose an inquiry relevant to them and observe the changes in the leaf’s food-making process. In the investigation, some students choose to cover one or both sides of the leaf with Vaseline, peanut butter, or even nail polish. Others choose to cover the leaf with aluminum foil, wax paper, or clear transparent wrap. Some want to find out how light affects the rate of photosynthesis, while others want to know how different colored light affects the rate of photosynthesis. Still others investigate how the availability of carbon dioxide affects photosynthesis. As students carry out their investigations, they document and record their daily progress and findings in their science journals.

Following the plant investigations, Mr. Travers reviews the process of photosynthesis and relates the process of photosynthesis as a “production system” in which ingredients such as carbon dioxide and water produce a sugar and a by-product—oxygen. He also reviews how the students’ findings in their investigations relate to the food-making process. He then introduces appropriate concepts and vocabulary terms related to photosynthesis, including stomata, chloroplast, chlorophyll, phloem, and xylem. To apply their understanding of photosynthesis, students extend their investigations to new situations by explaining how pollution from cars affects the growth rates of plants. For the unit test, students are given an envelope containing 18 small cards, each with a word or words for a different part of the leaf or pertaining to the process of photosynthesis. The words are as follows.

<table>
<thead>
<tr>
<th>Upper epidermis</th>
<th>Chloroplast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower epidermis</td>
<td>Chlorophyll</td>
</tr>
<tr>
<td>Palisade layer</td>
<td>Photosynthesis</td>
</tr>
<tr>
<td>Spongy layer</td>
<td>Autotroph</td>
</tr>
<tr>
<td>Xylem</td>
<td>Glucose</td>
</tr>
<tr>
<td>Phloem</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>Vascular bundle</td>
<td>Water</td>
</tr>
<tr>
<td>Guard cell</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Stoma</td>
<td>Light</td>
</tr>
</tbody>
</table>

The purpose of the assessment is to use the cards to create a concept map showing the interconnection of all the terms to the process of photosynthesis.

In this classroom, Mr. Travers’s role is that of a facilitator rather than dispenser of information. In constructivist classrooms, teachers value the points of view students bring to the lesson and alter their agenda based on the prior knowledge and preconceptions of the students. In constructivist settings, emphasis is placed on the
students working in groups and internalizing the information as they develop understandings of scientific phenomenon. Information is organized around holistic ideas and discrepant events that capture the students' interest. By using analogies and having students raise their own questions, constructivist teachers constantly connect the students' prior knowledge and experiences to new knowledge and concepts.

According to Brooks and Brooks (1999), traditional and constructivist classrooms differ by the following:

<table>
<thead>
<tr>
<th>Traditional Classrooms</th>
<th>Constructivist Classrooms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curriculum is presented part to whole, with emphasis on basic skills.</td>
<td>Curriculum is presented whole to part, with emphasis on big concepts.</td>
</tr>
<tr>
<td>Strict adherence to a fixed curriculum is highly valued.</td>
<td>Pursuit of students' questions is highly valued.</td>
</tr>
<tr>
<td>Curricula activities rely heavily on textbooks and workbooks.</td>
<td>Curricula activities rely heavily on primary sources of data and manipulative materials.</td>
</tr>
<tr>
<td>Students are viewed as &quot;blank slates&quot; onto which information is etched by the teacher.</td>
<td>Students are viewed as thinkers with emerging theories about the world.</td>
</tr>
<tr>
<td>The teacher generally behaves in a didactic manner, disseminating information to students.</td>
<td>The teacher generally behaves in an interactive manner, mediating the environment for students.</td>
</tr>
<tr>
<td>The teacher seeks the correct answer to validate students' learning.</td>
<td>The teacher seeks the students' points of view to understand students' present conceptions for use in subsequent lessons.</td>
</tr>
<tr>
<td>Assessment of student learning is viewed as separate from teaching and occurs almost entirely through testing.</td>
<td>Assessment of students' learning is interwoven with teaching and occurs through teacher observations of students at work and through student exhibitions and portfolios.</td>
</tr>
<tr>
<td>Students primarily work alone.</td>
<td>Students primarily work in groups.</td>
</tr>
</tbody>
</table>

Later, through the yeast investigation in Chapter 9, you will see how the notion of constructivism has implications for teaching and learning science. For now, how many of the following characteristics that portray a constructivist unit of study can you identify from the isopod investigation?

1. Knowing how adolescents learn has a bearing on how we approach teaching and learning.
2. Knowing educational theory gives meaning to our understanding about teaching and learning.
3. Demonstrating that it is essential to use concrete and manipulative materials to introduce formal concepts.
4. Starting with what the students know is an effective departure point for any science lesson.
5. Using explorations and time to “mess around” to introduce and sequence new knowledge, thus aligning with present learning theories.

6. Encouraging inductive and discovery learning that opens the doors to problem-solving and higher-level thinking skills.

7. Providing challenging activities stretches students’ thinking and problem-solving skills.

8. Using active learning encourages students to discover and construct new knowledge.


10. Allowing students to work in groups to share and communicate knowledge, and to test ideas and theories against one another, makes learning a personal and social experience.

**HISTORICAL PERSPECTIVES OF CONSTRUCTIVISM**

At many science education conferences, workshops, and seminars on learning theory, one of the most talked about topics among science educators today is constructivism. Although the theory is not new, recent developments about how the brain works have strengthened the constructivist model. Aspects of constructivist principles date back to the works of Socrates, Plato, and Aristotle. Perhaps the first recorded constructivist was the Neapolitan philosopher Giambatista Vico, who worked in the field as early as 1710. Have you ever posed a question to a student and gotten the response, “I know it, but I just can’t explain it”? According to Vico, we know something only when we can explain it (Yager, 1991).

**John Dewey**

John Dewey (1859–1952) was one of the first modern American constructivists. Dewey (1900, 1902, 1916) believed that learning and experience go hand in hand and that knowledge emerges from a personal interaction between the learner and the external environment. He felt that posing problems of significant interest that draw upon the student’s prior knowledge activates the learning process. According to Llewellyn (2002), “Dewey felt that teaching should be an active process, including solving problems that interest students. He believed that problems posed to pupils too often involved the interests of the teacher rather than the interests of the students” (p. 42). Dewey’s model for learning also incorporates the student’s immediate surroundings. His teachings have had a profound influence on environmental and outdoor education. Because the lure of the outdoors and providing problems for students to solve go hand in hand with inquiry-based instruction, many inquiry teachers are aligned to Deweyian philosophy.
Jean Piaget

Probably the most influential 20th-century constructivist was Swiss psychologist Jean Piaget (1896–1980). Like Dewey, Piaget (1970) believed that knowledge is not "out there" somewhere, waiting to be discovered, but rather is a result of an interaction between the learner and the people or objects within the environment. Piaget was one of the first psychologists to shift the locus of learning from a behavioral aspect to a cognitive one. Piaget theorized that cognitive structures, called schemas, were the mental models that form by “acting on an object” and that schemas represent our ability to interpret incoming information. These schemas, in a sense, act as filters to assimilate new ideas. Unfortunately, one’s mental models or schemas also can be a result of misinformation, resulting in presently held naive beliefs or misconceptions. We will address the significance of misconceptions and how they affect learning later in this book.

Piaget used the term “operations” to describe the way a child internalizes its interaction with the environment. The following is a brief summary of Piaget’s four developmental stages:

Sensorimotor (birth–2 years): At this stage, the child learns to adapt to its environment and coordinate its motor actions through trial and error. Toward the end of this stage, the child begins to develop and use language to communicate needs and feelings.

Preoperational (2–7 years): At this stage, the child begins to become aware of its own actions through thinking. The child also develops the ability to plan solutions and actions to solve problems. Logic and contradictions are not yet part of the child’s thinking. Often, the child solves a problem by focusing on one variable at a time. The solution to a problem is often judged by the child’s illogical reasoning.

Concrete Operational (7–11 years): At this age, the preadolescent begins to develop the ability to think logically. Preadolescents can now perform many science process skills such as measuring, classifying, predicting, inferring, hypothesizing, and controlling variables. The preadolescent can also organize objects into sequences based on patterns and can explain the significance of the patterns to others. The student at this age can think about and provide reason to problems that involve using manipulative and concrete objects. At this point, however, little abstract thinking is experienced.

Formal Operational (12 and older): At this stage, the adolescent is able to think and to perform operations logically and abstractly. When faced with cause and effect relationships, the student can understand the interaction without the use of manipulative or concrete objects. At this stage, thinking goes beyond actual, personal experience, and reasoning about ideas not experienced can be understood.

In contrasting students at the levels of concrete and formal operations, Driscoll (1994) summarizes that

Inhelder and Piaget (1958) presented children and adolescents with a chemistry problem, in which they were to mix clear liquid chemicals from four beakers until they achieved a yellow color. Concrete operational children
were rather random in their approach to the problem, sometimes repeating combinations of chemicals they had tried before. In addition, they typically combined only two chemicals at a time, or all four, without considering combinations of three. By contrast, formal operational adolescents generated a systematic plan of testing chemical combinations until they found the solution. Moreover, they kept records of their tests and generated appropriate observations concerning their results. (p. 178)

Piaget believed that although they progress at different rates, all humans go through these same four stages in mental development. Psychologists studying Piaget would later explain that the stages are not discrete and separate, but continuous, as humans often display behaviors characteristic of the "gray" areas between the "stages." Critics of Piaget's findings would also argue that children can manifest characteristics of more than one stage and that, at times, they may temporarily regress from one level to another.

According to Arlin (1987), there are several concepts that, when applied consistently by the student, differentiate concrete from formal operational learners.

- Multiplicative compensations: This concept relates when two or more dimensions constitute a situation. For example, when a student understands the volume of a solid block, he or she must consider three dimensions: length, height, and width. The concept of multiplicative compensations is required when a student studies a topic such as density or ecological life cycles, or whenever thinking about how one variable will affect another variable.

- Correlations: This concept relates when the student identifies a relationship between two events or variables. In science, students frequently are asked to describe a cause and effect relationship between the manipulated (independent) and responding (dependent) variables. As applied to inquiry, at the end of a plant investigation the teacher may pose the question, "What seems to be the relationship between the amount of fertilizer provided and the growth rate of the plant?"

- Probability: Probability is a formal operations skill that asks the student to develop the likelihood of a relationship. In genetics, the probability of a particular genotype or phenotype occurring serves as a typical example.

- Combinational reasoning: In combinational reasoning, the student is asked to give all the possible combinations of variables for a particular event. When a teacher poses the question, "What are the possible combinations of a specific phenomenon?," students utilize the skill of combinational reasoning. Combinational reasoning especially applies to topics in biology, chemistry, and physics.

- Proportional reasoning: Proportional reasoning incorporates the ability to discover the equality of two ratios that form a proportion. When students use map skills, draw models, balance chemical equations, or use scale structure, the skill of proportional reasoning is applied. Proportional reasoning is often used in earth science and chemistry.

- Indirect and direct verification: In earth science, chemistry, and physics, students often deduce the validity of an occurrence through indirect verification. For example, when students study black holes, the formation of molecules, or inertia, they deduce the existence of these phenomena by observing their effects, thus
inferring their existence. More often, formal operations are equated with abstract concepts, such as forms of conservation, that are beyond direct verification.

- Mechanical equilibrium: Mechanical equilibrium requires the ability to simultaneously make the distinction between and coordinate two or more complementary sets. Physics problems regarding hydraulics and pistons require this type of thinking.

Hester (1994) states that these formal operations “represent a new level of abstraction, of thinking about the possible as well as the actual, of making predictions, forming hypotheses, and thinking scientifically, which sets the adolescent apart from the child with his/her dependence on purely concrete objects and referents for thinking” (p. 155). Although Piaget’s research identified age 11 as the point at which children begin to move into formal levels of thinking, high school teachers know that many of their students still operate at a concrete level. As high school teachers use inquiry strategies and provide opportunities for students to test their predictions and hypotheses, describe relationships, describe possible combinations and arrangements, and use proportional thinking, they provide vehicles for students to make the transition from concrete to formal cognitive levels. During this transitional phase, preadolescents demonstrate inconsistent thought patterns concerning abstractions by showing evidence of using two or three of the formal operational skills cited earlier. As students progress in four or five of the concepts, they are making progress into formal levels of operations (Arlin, 1987).

What does Piaget’s theory mean to high school science teachers? It means that every day, high school science teachers open their doors to students who may exhibit either concrete or formal operational behaviors, or both. By understanding Piaget’s stages of cognitive development and being aware that students progress from concrete to formal operations during their middle and high school grades, high school science teachers can ease and accommodate the transition from one stage to another by providing a “concrete,” hands-on, and motivational experience before introducing a new, “formal” or abstract concept. By sequencing a lesson or unit of study from a hands-on mode to a lecture mode, rather than the other way around, teachers provide a lesson in a sequence compatible with the student’s cognitive development. This may seem, at first, counterproductive to a high school science teacher’s normal practice because most science teachers introduce a new concept by providing background information and preteaching vocabulary terms before doing a hands-on lab. By using a constructivist approach to lesson design, however, science teachers can plan a lesson or a unit that first engages the learner, provides a hands-on exploration or initial motivational quick lab, then explains the concept, and finally extends the concept into an inquiry investigation or full laboratory experience. It takes time for high school science teachers to feel comfortable with this new notion of constructivist lesson design. After all, most of us were taught by high school and college teachers who lectured first, then did the hands-on experience sometime later. This constructivist lesson format is called the 5E Learning Cycle and will be introduced later in the chapter.

Thus, Piaget’s theory has four key principles:

1. People develop through “stages” of cognitive growth.

2. Knowledge is a result of ever-changing social interactions between the individual and the environment.
3. Knowledge is constantly being constructed and reconstructed from previous and new experiences.

4. Cognition is self-regulating within the individual and the interaction with the physical and social environment.

**Lev Semenovich Vygotsky**

Russian psychologist Lev S. Vygotsky was born near Minsk in western Russia in 1896, the same year as Jean Piaget. He received a law degree in 1917 from Moscow University but later turned his attention to medicine and psychology, with a specific focus on learning disabilities. In 1924, the outspoken young psychologist took exception to Pavlov and Gestalt. With the prevailing behaviorist notion that animal behavior can be applied to understand how humans learn, Vygotsky (1924/1979) contrasted animal and human behavior by describing the abilities of humans as uniquely specific to the species. According to Bodrova and Leong (1996), Vygotsky’s theories on cognitive development were unique and distinct from those of his contemporaries, and although under extreme pressure to be politically correct, he never gave in to that pressure. Although many of his theories on teaching and learning were never backed up with empirical data due to his early death in 1934, researchers recently have expanded on his theories and framework on preschool and early childhood education, applying them to innovation in teaching at all grade levels.

Vygotsky made a significant contribution to cognitive development and the theory of constructivism by writing frantically for his last three years before his death from tuberculosis at the age of 37. Most of his writings were still incomplete at the time of his death and weren’t translated into English until the early 1960s. His work *Thought and Language* (1934/1962) did not capture the attention of Western constructivists until its translation in 1962. Vygotsky and Piaget shared similar thoughts on constructivism; however, Vygotsky was not concerned with identifying stages of mental development. He explored the influence of language and social processes on cognitive development, as well as the accomplishments a child could achieve when solving a problem alone as compared to accomplishments achieved with assistance from an adult.

Two basic principles from the Vygotskian framework include the role language plays in mental development and the importance of social interaction within the context of learning. Whereas Piaget’s theory about learning focused mainly on the interaction with physical objects, Vygotsky believed that the construction of knowledge is predicated on manipulation, but additionally is socially mediated. In his work, Vygotsky emphasized the importance of social interaction between the learner and his or her peers; thus, he was labeled as a “social constructivist.” According to Vygotsky (1978), an “important factor in social learning was the young person’s ability to learn by imitating and modeling. Interacting with adults and peers in cooperative settings gave young children ample opportunity to observe, imitate, and model” (pp. 79–80).

One of his foremost known theories is the Zone of Proximal Development (ZPD). According to Vygotsky, students’ ability and skills to solve problems or tasks can be categorized into two levels:
1. Skills the student possesses to perform tasks independently

2. Skills the student lacks (at an independent level) so that tasks can be performed only with assistance from another student or adult

The independent level is a lower or minimum level of performance where students can operate unassisted. The assisted level is a higher or maximum level where children can reach a more complex performance with the help or assistance from another. The zone is an arbitrary continuum or area between these two levels. Most of traditional teaching is focused more closely on what students can achieve independently, but a constructivist teacher teaches to the upper zone by providing assistance to students’ performance through prompts, leading questions, hints and clues, or asking students to clarify their thoughts about the phenomenon being studied. Although this interaction can be interpreted as an “expert-novice” relationship, Vygotsky believed that all students could enhance their learning through social mediation with peers or an adult.

One instructional strategy based upon the idea of the ZPD is “scaffolding” (Wood, Bruner, & Ross, 1976), a metaphor to building construction. Scaffolding provides a level of support that enables the learner to accomplish a task normally beyond his or her current capabilities. In scaffolding situations, the teacher purposefully and intentionally designs a performance task just beyond the independent level. Providing guidance at first, the teacher then gradually decreases the assistance until the student can take more responsibility for completing the task. Vygotsky suggests that teachers provide problems and tasks just beyond the student’s present capabilities; through cooperative learning groups and modeling from adults, the student is scaffolded to high levels of thinking and performance.

To provide an example of scaffolding, I'll use the day I taught my daughter, Janice, to ride a two-wheeled bike. She was the only one in her 4th-grade class who wasn’t riding a bike without training wheels. That was enough of an incentive for Janice to ask me for help. We got the bike out of the garage and headed for the street. At first, she practiced balancing on the bike without the training wheels while I held the bike upright. Next, we moved on to short spurts where Janice pedaled and I ran alongside, holding the bike upright. With one hand on the back of the seat, I held the bike while she pedaled down the street. I can still recall her saying, “Daddy, don’t let me go!” Well, what she didn’t know, as I ran alongside the bike for what seemed an eternity, was that I was sporadically letting go of the bicycle seat, allowing Janice to ride on her own. “I’ve got you,” I said. “Just keep pedaling!” Nearly out of breath, she began to gain confidence in balancing without assistance. After a few spills and some scraped knees, she gained more confidence and achieved the goal of riding the bike on her own. I think I lost a few pounds that day running up and down the street!

In many ways, good constructivist teachers teach in the same way. They are consciously aware of the prompts and assistance they need to provide to have their students achieve at higher levels of academic performance. Constructivist and inquiry-based teachers do not make the task easier; rather, they provide the appropriate level of support and assistance for students to acquire the necessary knowledge and skills in science. Constructivist and inquiry-based teachers are also constantly aware of shifting the onus of responsibility from the teacher to the
student, enabling the student to become a more independent learner. Sometimes unknowingly, high school teachers use Vygotskian principles by implementing guided, semiguided, and independent approaches to providing tasks to students. The teacher begins by providing a mental challenge task to the student. With help from the teacher or a peer, the student is guided to the solution and begins to understand the nature of the concept. With the second problem, the student is provided a semiguided practice to gain confidence and control over the task. Presented with a third problem, the student functions independently at solving the task. The teacher models appropriate behaviors and assists students to work at levels that stretch their imagination, thinking, and abilities. As the communication exchanges between the student and the teacher continue, the student begins to construct and mediate understanding of the topic.

CONSTRUCTIVISM TODAY

Currently, many educators and cognitive psychologists carry the constructivist torch for innovation in teaching and learning for mathematics and science. They include David Ausubel, Jacqueline Brooks, Jerome Bruner, Catherine Fosnot, Linda Lambert, Joseph Novak, Phillip Sadler, Ernst Von Glaserfeld, Robert Yager, and many others. Science teachers interested in learning more about constructivism and its implications to inquiry-based learning are encouraged to do further reading on the topic by these authors (see Resource A).

Constructivism today is having an increasingly significant impact on educational reform and more frequently is viewed as a valid theory on how children and adolescents learn.

In summary, key points in constructivism include the following:

1. The senses are conduits to assimilating new knowledge.
2. The learner’s existing or presently held understandings determine what new situations are accepted or ignored.
3. The learner’s existing or presently held understandings determine how new situations are interpreted.
4. Knowledge is not transmitted from one individual to another. Communication is transmitted, but communication or incoming information is not knowledge. Knowledge is constructed in the mind by the learner attempting to make linkages between new and previously stored knowledge within the brain.
5. The learner uses linkages to construct new understandings.
6. The learner’s understanding is constantly undergoing construction and reconstruction.
7. Learning is both personally (reflection) and socially constructed (testing one’s model against peers).
HOW ADOLESCENTS LEARN

Two Models of Learning

Have you ever heard a teacher say, "Those kids' minds are just like a sponge soaking up knowledge?" Although some educators frequently describe an adolescent's learning from a behaviorist/objectivist perspective, constructivist teachers view things quite differently. Constructivists perceive learning as a process by which the student is a "theory builder." In constructivist philosophy, one believes that knowledge is not imparted, accumulated, absorbed, or transmitted from one individual to another. Rather, knowledge and meaning is constantly being assimilated and accommodated in the mind of cognizant beings through interpretations of their experiences and from the communication of language with others.

Prior Knowledge

Adolescents bring many levels of scientific understandings to our high school classrooms. This can be simultaneously necessary and problematic. On one hand, their prior knowledge, along with their models and theories, shapes how they interpret the natural world and new scientific information; on the other hand, prior knowledge, in the form of misconceptions, can mask the way information is interpreted and lead to unacceptable explanations (Roschelle, 1997).

David Ausubel (1968) once said, "The most important single factor influencing learning is what the learner already knows; ascertain this and teach him accordingly" (p. vi). But how, you might ask, can I get inside the heads of 28 high school students to assess their prior knowledge? Before beginning a lesson on evolution, sedimentary rocks, organic chemistry, or quantum physics, consider trying a few strategies to assess their pre-understandings. Students’ prior knowledge can be ascertained simply by asking, "What do you know about [a particular subject]?” Tell students to write down on a paper whatever they know about the subject you are about to introduce. They can make a list, write a short paragraph, construct a concept map, draw a picture, or use any method that is most convenient for them. After a few minutes, pair each student with a partner to share what each recorded. Tell them that they each get a minute to share what they wrote with their partner. Next, tell them to compare their statements and look for similarities and differences. After another 2 minutes, you can ask individual students to share their statements with the entire class while you record their comments on the board or overhead, making a list or a concept map. Review their presently held conceptions and, to yourself, make mental notes of any glaring misconceptions that need to be addressed later in the unit.

Usually, simply going around the room and listening to student conversations is a productive way to assess students’ prior understandings. As you visit each group of students, be especially attentive to inconsistencies in their thoughts and conversations.

Another strategy to assess students’ prior knowledge involves conducting misconception interviews. Pose a question or provide a task to three students at random a few days before starting a new unit. Have the students “think aloud” and verbalize their understandings as they perform the task. Again, listen attentively for any misconceptions or naive conceptions they raise during the interview. If misconceptions
arise during the interview, anticipate that other students may have similar conceptions. This will allow you to adjust and plan your lessons accordingly.

Other preassessment strategies include giving a simple pretest or using a case study discussion to elicit prior knowledge. Teachers also can give students small cards each containing a vocabulary word that will be used in an upcoming unit. Have students arrange the cards to make a concept map. Tell them to write linking words that connect one card to another.

Understanding the prior conceptions of every student in your class is nearly impossible, but by using these suggestions, teachers can anticipate many or most naive conceptions and start a lesson from the students’ point of view.

**Misconceptions**

Everyone has a set of beliefs, conceptions, and understandings. They are part of the models and theories we hold to make sense of the world around us. Duit and Treagust (1995) suggest that “at all ages students hold conceptions about many phenomena and concepts before they are presented in the science class. These conceptions stem from and are deeply rooted in daily experiences because they have proved to be helpful and valuable in daily life” (p. 47). These conceptions that students hold are sometimes grounded in scientific truth and other times are conceived through intuitive, yet incorrect, assumptions. Educators and cognitive psychologists often refer to these incorrect models as misconceptions, but because the conceptions are conceived from what the students believe to be reality, more appropriate terms may be naive conceptions, preconceptions, alternative conceptions, or intuitive conceptions.

Preconceptions play a major role in how students interpret new incoming information. Consider the case of an 11th-grade general physics class. Ms. Nolan is introducing the concept of pendulums and poses the question, “What affects the number of swings a pendulum will make in 30 seconds?” Let’s listen as Ms. Nolan works with two students, Christy and Kara.

**Ms. Nolan:** Ladies, what factors do you think affect the number of swings a pendulum makes?

**Christy:** I think it’s the weight at the end of the string.

**Kara:** Yeah, that sounds good. It’s the weight.

**Ms. Nolan:** What makes you think that?

**Kara:** Because when you swing on a swing, some people can go higher than others. So . . . (pause) . . . your weight can affect how high you swing.

**Christy:** I remember swinging my sister. She couldn’t go as high as I could because, I guess, I weigh more. That sounds right.

**Kara:** I think I remember talking about this in Mr. Farrell’s science class in the eighth grade.

**Ms. Nolan:** Now, make a hypothesis about how the weight, but let’s call it the mass—how the mass affects the number of swings the pendulum makes.
Kara: The more mass, the more swings the pendulum will make.
Ms. Nolan: All right, how could you design an investigation to test that hypothesis?
Christy: We would have to set up the pendulum and tie a paperclip to the end of the string. Then we could open up the paperclip to form an "S" hook and add different amounts of washers to the paperclip. We could start with one washer and keep adding a washer until we had five washers on the hook.
Ms. Nolan: Good! How far will you pull back the washers before releasing them?
Kara: I'd say we should pull the washers back halfway, to a 45-degree angle.
Ms. Nolan: Will you change the angle of release?
Kara: No, that will be the same for each trial.
Ms. Nolan: And how many trials will you do?
Christy: One?
Kara: No, I think we should do three and then take the average.
Christy: Yeah, three. Sounds good.
Ms. Nolan: Now what about the length of the string. Will that change?
Kara: No, that will remain the same for all the trials.
Ms. Nolan: Why is that?
Kara: We can have only one variable in the experiment.
Ms. Nolan: And what's that?
Christy: The number of washers.
Kara: Actually, it's the mass.
Ms. Nolan: Very good. Nice job! Now set up your experiment, and call me over when you have your data.
(Ten minutes later, Christy calls Ms. Nolan over to their table.)
Ms. Nolan: Well, what did you find out?
Christy: I think our calculations are wrong. We got the same number of swings for all three trials and with all the different washers.
Kara: We must have made a mistake somewhere. We got 12 swings for all the trials and washers. What did we do wrong?
Ms. Nolan: Did you time the number of swings the same for all the trials?
Kara: Yeah. We used 10 seconds for each time.
Christy: Something is wrong with our data.
Ms. Nolan: According to your data, the mass had no effect on the number of swings the pendulum made.
Kara: Is our hypothesis wrong?
Christy: No, something is wrong with our data. Let’s do it all over again.

Ms. Nolan: Well, before you do the experiment all over again, what else might affect the number of swings the pendulum makes?

Kara: I’m not sure.

Ms. Nolan: Could it be how far you pull back and release the washers?

Christy: That might be it, but I still think something is wrong with our data.

Ms. Nolan: Try to test the effect of the release point on the number of swings the pendulum makes. Design an investigation to test the release point, and call me back when you’re done. Be sure to write a hypothesis first before actually carrying out your procedure.

(Ten minutes later, Christy again calls Ms. Nolan over to their table.)

Christy: I don’t believe this. We keep getting the same number of swings each time.

Kara: We got 12 swings, the same as before.

Ms. Nolan: Wait a minute. Are you saying you changed the mass and it had no effect, then you changed the release point and that still had no effect?

Kara: Yup.

Christy: This is very confusing. I don’t know what’s going on. Something’s fishy!

Ms. Nolan: Okay, let’s make sense of this. You tried the mass and no effect. Then you tried the release point and it still had no effect. What else can you try?

Christy: I don’t know. Something is really fishy here.

Kara: What about the length of string? Can we try that?

Ms. Nolan: Okay, that’s a good idea. Go back to the drawing board and design a new investigation to see if the length of the string affects the number of swings the pendulum makes. What variable will you change?

Kara: The length of string.

Ms. Nolan: What will remain constant in your experiment?

Christy: The number of washers and the release point?

Ms. Nolan: Great! You got it!

(Ten minutes later, Christy calls Ms. Nolan over to their table.)

Kara: I think we got it. When we changed the length of string, it changed the number of swings the pendulum made. The shorter the string, the more swings. The longer the string, the fewer swings it made.

Christy: That’s weird. I thought it was going to be the mass, not the length of the string, that affected the number of swings.

Ms. Nolan: Where did you get your original idea?
Christy: I don't know. I guess it was from watching kids play on the playground swing. It just seemed normal to say that the mass would make a difference. So, our calculations weren't wrong. It really was the length of the string.

Ms. Nolan: Now, when you came into the lab this morning, what did you think affected the swing of the pendulum?

Christy: I thought it was the weight or mass.

Kara: Me too!

Ms. Nolan: What do you think now?

Christy: It's definitely the length of the string, not the mass.

Ms. Nolan: Did you give up on your "mass theory"?

Kara: I know I did.

Christy: We both did.

Ms. Nolan: Now, let me ask you one more question. In the beginning of the lab, if I told you that the mass did not affect the swing of the pendulum, but it was the length of the string, would you believe me?

Kara: I don't think so.

Ms. Nolan: Why not?

Christy: We had to do it ourselves. We had to actually test it to change our minds.

Ms. Nolan: Great job today!

The case of the swinging pendulum reminds us that rote learning does not usually facilitate change in conceptual understandings, especially when the misconception is deeply held. Did you notice that Kara read about pendulums in the eighth grade? Keep in mind that misconceptions can be stubborn. In this case, Christy and Kara held, probably for 15 years, the naive conception that the mass affected the number of swings. The authority of a teacher is not often strong enough to change students' previously held conceptions and make accommodations in their cognitive structures. Combining a constructivist approach using both hands-on and minds-on strategies does have that strength.

Conceptual Change Theory

Now let's reflect on what we read about cognitive learning theory and apply it to the case of the pendulums. According to Piaget, people form networks or schemas within the brain to store information. Both Kara's and Christy's prior experience on the playground helped them to believe that mass affects the swing of the pendulum. All incoming information is now translated through the student's schema. When a new situation arises that is inconsistent with a child's present schema (such as the data from the mass experiment), the student may either disregard the new information because it doesn't fit with the presently held notion or he or she may change or give up the previously held notion and accept a new notion based on new evidence.
Driscoll (1994) points out that questioning one’s beliefs and prior conceptions can be threatening to students and lead to defensive moves. In this case, Ms. Nolan was very careful not to ridicule their previously held models, but instead effectively posed questions and prompts to lead Christy and Kara to a new level of understanding.

When a child accepts a new model, it is probably more useful, makes more sense, or is more plausible than the previously held model. Keep in mind that children, adolescents, and even adults often are reluctant to give up their presently held models and misconceptions despite what their teachers or friends tell them. As you read before, misconceptions are stubborn and sometimes very resistant to change. Conceptual change is an integral part of cognitive development. Gunstone and Mitchell (1998) tell us, “When considered in terms of an individual learner . . . it is the learner who must recognize his/her conceptions, evaluate those conceptions, [and] decide whether to reconstruct the conceptions” (p. 134).

High school students often test their theories and models through the interactions with their peers, one of the most influential aspects of their life. When their observations and experiences continue to match their presently held theories and those of their peers, the experiences are assimilated and the model is reinforced. When their observations and experiences do not match their presently held theories, either the experience can be discounted because it doesn’t align with their understanding or the model can be accommodated, by a conceptual change, to include this new experience. Adolescents then continue to test their ideas, beliefs, and models through ongoing observations. Assimilation is the filtering and integration of stimuli, concepts, and external elements within the context of existing knowledge and schema, whereas accommodation is the modification and adjustment of cognitive structures to new situations. Assimilation and accommodation influencing and working together result in equilibrium.

Posner, Strike, Hewson, and Gertzog (1982) suggest that students will undergo a conceptual change when the following conditions exist:

1. They must become dissatisfied with their existing conceptions.
2. The scientific conception must be intelligible.
3. The scientific conception must be plausible.
4. The scientific conception must be useful in a variety of new situations.

The history of science is a story with theories and models that are continually tested, refined, and changed over time. Youngson (1998) tells us that getting it wrong is often the way science advances. According to Youngson, “we are prisoners of our own experience” (p. 2). Consider Ptolemy, who placed Earth in the center of the solar system, or Lamarck, who proposed a theory of evolution based on the length of the giraffe’s long neck. Do you remember the hoopla and fiasco about cold fusion? Yet probably no other theory has changed as much as that of the structure of the atom. In words that have been attributed to Thomas Huxley, “The great tragedy of science is slaying a beautiful hypothesis by an ugly fact.”

Making Sense of Language

If we were to think that knowledge is imparted solely through language between teacher and students, why do teachers often find themselves teaching a concept one
day and discovering the next day that the students just did not “get it”? If my teaching philosophy was based upon assumptive learning, I might assume that learning occurs because the students are listening to me, the teacher. But just because students are listening to me does not mean that they are always making sense of the words coming out of my mouth. Words are a sensory input that the learner must act upon.

Consider the case of a biology class just beginning a unit on the parts of the cell. On the first day of the unit, Mrs. Bell introduces the various cell organelles by writing their names and functions on the board. As students are copying notes, she is spelling out words and phrases such as mitochondria, ribosome, endoplasmic reticulum, Golgi bodies, and nuclear membrane. The words are part of the sender’s (the teacher’s) everyday language and experience, but not part of the receivers’ (the students’). In this case, the terms make perfect sense to the teacher but may not mean anything at this point to the students. Thus, language is an important aspect of learning in a constructivist approach. The student needs a language connection, based upon his or her previous experience, to make sense of what is currently being said. We can see in the organelle lesson that the teacher had the cognitive structure (schema) to make sense of these terms. In the case of students without the cognitive structure to make sense of these terms, the words enter the brain through the ear, look for connections, and, finding none, get filtered out. Students are left with puzzled looks on their faces.

**THE 5E LEARNING CYCLE**

There are several implications to the constructivist learning model. The 5E Learning Cycle is one of them. Like constructivism, the 5E Learning Cycle is not new. It was originally proposed for elementary school science programs in the early 1960s by J. Myron Atkin and Robert Karplus (1962) and further documented by Lawson, Abraham, and Renner (1989), Beisenherz and Dantoni (1996), Marek and Cavallo (1997), Bybee (1997), Abraham (1997), and Colburn and Clough (1997). In the last 10 years, however, it has become a popular model for high school teachers too. Many articles in *The American Biology Teacher* refer to the learning cycle approach as an effective lesson format. In addition, the Biological Sciences Curriculum Study (BSCS), a premier curriculum developer in the area of biology, uses the 5E format for its instructional model. Unlike traditional three-step lesson plans in science that begin with introducing new vocabulary, then providing a step-by-step lab to verify the information presented, and finally finishing with an end-of-chapter problem or test, the 5E Learning Cycle model (see Figure 3.1) is a constructivist teaching strategy that includes five stages consistent with cognitive theories on how learning occurs:

- **Engagement**
- **Exploration**
- **Explanation**
- **Elaboration or Extension**
- **Evaluation**
During the **Engagement** stage, the teacher sets the stage for learning. This is accomplished by stating the purpose of the lesson. Often, the teacher introduces the topic of the lesson and states the expectations for learning by explaining what students should know and be able to do by the end of the lesson or unit. The Engagement phase is also a means of getting the students' attention and focus. By using attention-grabbing demonstrations and discrepant events (Liem, 1987), the teacher creates ways to "hook" students into learning. Discrepant events generate interest and curiosity that set the stage for inquiring about a particular phenomenon. Discrepant events serve to create cognitive dissonance—or, in Piaget's words, disequilibrium—because the observation of such events does not readily assimilate into the student's presently held understanding. Because the observations made from discrepant events are counterintuitive to the students' prior experience, the students quickly activate questions.

From a constructivist perspective, the Engagement phase also provides an opportunity for the teacher to activate learning, assess prior knowledge, and have students share their prior experiences about the topic. During the Engagement stage, the teacher can note possible naive conceptions or misconceptions stated by the students. These misconceptions can be addressed during and after the students have an opportunity to work through the Exploration and Explanation stages. It should be noted that it is nearly impossible for any teacher to fully ascertain all the misconceptions held by all the students. The learning cycle, specifically the Engagement stage, does, however, provide the teacher with a means of assessing students' current beliefs and understandings.

The **Exploration** stage is an excellent place to engage high school students in inquiry-based labs or teacher-initiated inquiries. During the Exploration stage, students raise questions, develop hypotheses to test, and work without direct instruction from the teacher. They go about collecting evidence and data, recording and organizing information, sharing observations, and working in cooperative groups. The Exploration stage allows students to build on a common experience as they carry out their investigations. This common experience or exploration is
essential because students will enter the classroom with different levels of experience and knowledge about the topic being studied. The Exploration stage allows all students to experience hands-on learning and helps “level the playing field” within a culturally diverse classroom. The Exploration stage also provides opportunities for students with diverse experiences to share their different understandings and broaden the perspective of the entire class.

During the teacher-directed Explanation stage, the teacher facilitates data- and evidence-processing techniques for the individual groups or entire class (depending on the nature of the investigation) from the information collected during the exploration. Information is discussed, and the teacher often explains the scientific concepts associated with the exploration by providing a common language for the class to use. This common (or scientific) language helps students articulate their thinking and describe their investigations and experiences in scientific terms. The teacher can continue to introduce details, vocabulary terms, and definitions to the lesson as students assimilate their understanding against the “scientific” explanation. This can be accomplished by using direct instruction/lecturing, audiovisual resources, online sources, and computer software programs. Here, the teacher uses the students’ prior experiences to explain the concepts and attempts to address misconceptions uncovered during the Engagement or Exploration stages. The Explanation stage is sometimes called the “Concept Development” stage because evidence and newly developed concepts are assimilated into the cognitive structure of the student. During the Explanation stage, students may work to assimilate or accommodate new information as they make sense of their understanding, “constructing” new meaning from their experience and conceptual change.

During the Elaboration or Extension stage, the teacher helps reinforce the concept by extending and applying the evidence to new and real-world situations outside the classroom. This stage also facilitates the construction of valid generalizations by the students, who also may modify their presently held understandings of the phenomena being studied. During the Elaboration stage, teachers can provide follow-up, student-initiated inquiries and expand upon the teacher-initiated inquiry from the Exploration stage.

During the Evaluation stage, the teacher brings closure to the lesson or unit by helping students summarize the relationship between the variables studied in the lesson and posing higher-order questions that help them to make judgments, analyses, and evaluations about their work. Connections among the concepts just studied and other topics can be illustrated by using a concept map. Here, the teacher can compare the prior knowledge that was identified during the Engagement stage with the newly formed understanding gained from the lesson.

On the assessment side, the teacher will provide a means for students to assess their learning and make connections from prior understandings to new situations that encourage the application of concepts and problem-solving skills. Assessment strategies may include monitoring charts or checklists, portfolios, rubrics, and student self-evaluations. Later, in Chapter 8, we will address these assessment strategies.

The Biological Science Curriculum Study (BSCS) provides an excellent summary of the 5E Learning Cycle by indicating descriptors for the students as well as the teachers regarding consistency with the model. (See Figures 3.2 and 3.3.)
### Figure 3.2  What the Student Does

<table>
<thead>
<tr>
<th>Stage of the Instruction Model</th>
<th>What the Student Does . . .</th>
<th>What Is Consistent With the 5E Model</th>
<th>What Is Inconsistent With the 5E Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engage</td>
<td></td>
<td>Asks questions, such as: Why did this happen? What do I already know about this? Shows interest in the topic</td>
<td>Asks for the &quot;right&quot; answer Offers the &quot;right&quot; answer Insists on answers or explanations Seeks one solution</td>
</tr>
<tr>
<td>Explore</td>
<td></td>
<td>Thinks freely, but within the limits of the activity Tests predictions and hypotheses Forms new predictions and hypotheses Tries alternatives and discusses them with others Records observations and ideas Suspends judgment</td>
<td>Lets other do the thinking and exploring (passive involvement) Works quietly with little or no interaction with others (only appropriate when exploring ideas or feelings) &quot;Plays around&quot; indiscriminately with no goal in mind Stops with one solution</td>
</tr>
<tr>
<td>Explain</td>
<td></td>
<td>Explains possible solutions or answers to others Listens critically to others' explanations Questions one another's explanations Listens to and tries to comprehend explanations the teacher offers Refers to previous activities Uses recorded observations in explanations</td>
<td>Proposes explanations from &quot;thin air&quot; with no relationship to previous experiences Brings up irrelevant experiences and examples Accepts explanations without justification Does not attend to other plausible explanations</td>
</tr>
<tr>
<td>Elaborate</td>
<td></td>
<td>Applies new labels, definitions, explanations, and skills in new but similar situations Uses previous information to ask questions, propose solutions, make decisions, and design experiments Draws reasonable conclusions from evidence Records observations and explanations Checks for understanding among peers</td>
<td>&quot;Plays around&quot; with no goal in mind Ignores previous information or evidence Draws conclusions from &quot;thin air&quot; Uses only those labels that the teacher provided</td>
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<tr>
<td>Evaluate</td>
<td></td>
<td>Answers open-ended questions by using observations, evidence, and previously accepted explanations Demonstrates an understanding or knowledge of the concept or skill Evaluates his or her own progress and knowledge Asks related questions that would encourage future investigations</td>
<td>Draws conclusions without using evidence or previously accepted explanations Offers only yes or no answers and memorized definitions or explanations Fails to express satisfactory explanations in his or her own words Introduces new, irrelevant topics</td>
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</table>

### Figure 3.3  What the Teacher Does

<table>
<thead>
<tr>
<th>Stage of the Instruction Model</th>
<th>What the Student Does . . .</th>
<th>That Is Consistent With the 5E Model</th>
<th>That Is Inconsistent With the 5E Model</th>
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<tbody>
<tr>
<td>Engage</td>
<td></td>
<td>Creates interest</td>
<td>Explains concepts</td>
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<td>Generates curiosity</td>
<td>Provides definitions and answers</td>
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<td>Raises questions</td>
<td>States conclusions</td>
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<td>Elicits responses that uncover what</td>
<td>Provides closure</td>
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<td>the students know or think about the</td>
<td>Lectures</td>
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<td>concept/topic</td>
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<td>Explore</td>
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<td>Encourages the students to work together</td>
<td>Provides answers</td>
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<td>without direct instruction from the</td>
<td>Tells or explains how to work through</td>
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<td>teacher</td>
<td>the problem</td>
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<td>Observes and listens to the students</td>
<td>Provides closure</td>
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<td>as they interact</td>
<td>Tells the students that they are wrong</td>
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<td>Asks probing questions to redirect</td>
<td>Gives information or facts that solve</td>
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<td>the students' investigations when</td>
<td>the problem</td>
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<td>necessary</td>
<td>Leads the students step-by-step to a</td>
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<td>Provides time for students to puzzle</td>
<td>solution</td>
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<td>through problems</td>
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<td>Acts as a consultant for students</td>
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<td>Explain</td>
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<td>Encourages the students to explain</td>
<td>Accepts explanations that have no</td>
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<td>concepts and definitions in their own</td>
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<td>words</td>
<td>Neglects to solicit the students'</td>
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<td>Asks for justification (evidence) and</td>
<td>explanations</td>
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<td>clarification from students</td>
<td>Introduces unrelated concepts or skills</td>
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<td>Formally provides definitions,</td>
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<td>explanations, and new labels</td>
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<td>Uses students' previous experiences as</td>
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<td>the basis for explaining concepts</td>
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<tr>
<td>Elaborate</td>
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<td>Expects the students to use formal</td>
<td>Provides definitive answers</td>
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<td>labels, definitions, and explanations</td>
<td>Tells the students that they are</td>
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<td>Encourages the students to apply or</td>
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<td>extend the concepts and skills in new</td>
<td>Leads students step-by-step to a</td>
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<td>situations</td>
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<td>Reminds the students of alternative</td>
<td>Explains how to work through the</td>
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<td>explanations</td>
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<td>Refers the students to existing data</td>
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<td>and evidence and asks: What do you</td>
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<td>already know? Why do you think . . .?</td>
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<td>Evaluate</td>
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<td>Observes the students as they apply</td>
<td>Tests vocabulary words, terms, and</td>
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<td>new concepts and skills</td>
<td>isolated facts</td>
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<td>Assesses students' knowledge and/or</td>
<td>Introduces new ideas or concepts</td>
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<td>skills</td>
<td>Creates ambiguity</td>
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<td>Looks for evidence that the students</td>
<td>Promotes open-ended discussion</td>
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<td>have changed their thinking or</td>
<td>unrelated to the concept or skill</td>
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<td></td>
<td>behaviors</td>
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<td>Allows students to assess their own</td>
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<td>learning and group-process skills</td>
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<td>Asks open-ended questions, such as:</td>
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<td>Why do you think . . .? What evidence</td>
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<td>do you have? What do you know about x?</td>
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<td>How would you explain x?</td>
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CHALLENGES TO CREATING A CONSTRUCTIVIST CLASSROOM CULTURE

An obvious question arises at this point: If constructivism has so many valid attributes to enhance student learning, why aren’t more teachers implementing constructivist strategies like the 5E Learning Cycle in their classrooms? The answer to the question may begin with the term constructivist strategies.

Constructivism should be viewed not as a set of teaching strategies, but rather as a theory about how learning occurs. To become a constructivist teacher, one needs to focus on developing and sustaining a culture of constructivism within the classroom rather than implementing a set of loosely coupled strategies or practices. According to Windschitl (1999), “before teachers and administrators adopt such practices, they should understand that constructivism cannot make its appearance in the classroom as a set of isolated instructional methods grafted on to otherwise traditional teaching techniques. Rather, it is a culture—a set of beliefs, norms, and practices that constitute the fabric of school life” (p. 752). Developing a constructivist classroom culture is an arduous process. It means taking on new challenges and unfamiliar norms. This new role does not occur overnight. Becoming an inquiry-based teacher takes years of sustained perseverance and reflection.

There are several challenges in transforming from the behaviorist-objectivist practices to a culture of constructivism. By examining these issues, we also question our own beliefs and values about good teaching and learning. Our journey to a constructivist culture begins with taking a risk to challenge our classroom norms and teaching paradigm.

1. Familiarity With Pedagogy: Despite its popularity in the research and journals, coupled with an increasing number of teachers embracing constructivist principles, many high school science teachers are still not familiar with the concept of constructivism. Most science teachers are well equipped in providing hands-on and problem-solving activities to students, but a lack of a philosophical foundation in learning theory often prevails. Looking back to their preservice education courses, many teachers cite the lack of constructivist role models, especially in college-level science content courses. Too often, teachers face lecture-centered college instructors in the science content areas who teach in a traditional, didactic format where learning is seen as externally motivated rather than internally motivated. This supports the notion that “teachers teach as they have been taught.”

2. High-Stakes Assessments: Often the end-of-the-year, multiple-choice examination does not accurately assess achievement of all the goals of a constructivist teacher. With the increased emphasis on statewide standardized tests and the pressure teachers face to have their students perform at high levels of achievement, it is no wonder we hear the phase “teaching to the test.” Constructivist educators constantly struggle with the balance between providing specific learning opportunities that best respond to the students’ prior experiences and present understandings and the reality that high-stakes standardized assessments are not going away. For constructivist teachers to align their instructional goals with assessment goals, they need the flexibility to have students demonstrate their competencies using forms of assessment other than paper-and-pencil, objective-type examinations. Project-based
goals, critical thinking, cooperative learning, and problem-solving skills are not normally assessed on standardized tests. Thus, a shift toward the use of journals, portfolios, performance tasks with rubrics, and self-assessments becomes essential.

3. Curriculum and Standards: With the compliance to new state and national standards, the "one-size-fits-all" approach to curriculum does not always complement a constructivist culture. That does not mean that constructivist teachers do not have high standards for their students, but having standards, without flexibility, for differentiating individual instruction is not always compatible with a constructivist philosophy. Given the pressures of standardized instruction, many schools and teachers do not have the luxury of reducing the curricula load despite the call from some educational reform experts that "less is more." Constructivist teachers face the challenge of finding ways to do fewer topics in greater depth while still meeting national or state standards.

4. Daily Schedule: As teachers provide the opportunity for students to problem solve and design their own investigations, the daily schedule of 45-minute periods soon becomes constraining. For teachers to implement constructivist and inquiry-based strategies, block scheduling becomes a viable alternative for extended instructional time and opportunities for teachers across disciplines to integrate their curricula and develop team teaching partnerships. A block schedule may also give time for a team of teachers to redesign the curriculum and environment into theme-based and project-based units of study. Block scheduling also can provide common planning time for cross-content teachers to engage in discourse and reflection.

5. Textbooks: Textbooks are the greatest single source of information from printed materials used in high schools today. Look in any high school or college science classroom and you will probably find a single textbook being used. Because textbooks are written for a national audience, publishers fear swaying too far from the "middle of the road" from what schools expect in a textbook. With the exception of some authors like the BSCS and Paul Hewitt, writers of high school science textbooks preteach vocabulary and introduce concepts before students have an opportunity to explore a new phenomenon. To move toward a constructivist culture, teachers and administrators should consider a multitext approach while using primary sources of relevant information.

6. Professional Development: Although many agree that professional development is a continuous, lifelong process, too often teachers experience professional development as fragmented, one-shot workshops or in-services that center on the transmission of either content knowledge or classroom management skills presented from the speaker to the audience. In creating a constructivist and inquiry-based culture, according to the NRC (1996), "the conventional view of professional development for teachers needs to shift from technical training for specific skills to opportunities for intellectual professional growth" (p. 58). Such opportunities may include understanding the theoretical foundations for constructivism along with teaching strategies consisting of scaffolding, modeling, cooperative learning, and implementing performance assessments. The NRC goes on to say that "when teachers have the time and opportunity to describe their own views about learning and teaching, and to compare, contrast, and revise their views, they come to understand the nature of exemplary science teaching" (NRC, 1996, p. 67).
To cultivate a constructivist culture, teachers need to develop a new vision about teaching and learning founded on research-based knowledge and then work to change their practices to achieve their vision (Gallagher, 1993). Because visions are often met through collaboration, you need to realize that you cannot fulfill your vision effectively doing it alone. Transforming classroom norms and altering past practices requires a support system sustained over time.