CHAPTER 6

Applying the 5E Model to STEM Education

The acronym STEM (science, technology, engineering, and mathematics) emerged in the education community in the 1990s. Since then, use of STEM has continually expanded to encompass almost anything related to these areas. In education, STEM is quite popular and has a varied, if ambiguous, meaning. In the context of this book, one could easily ask the question, Can the BSCS 5E Instructional Model be applied to STEM education? Given the diversity in meanings, the reasonable answer is that it depends. I will reframe the question: If one is concerned about a STEM curriculum and classroom instruction, can the 5E Model be applied? Here the answer is yes. In fact, the positive response to the question seems particularly appropriate given the inclusion of engineering design in the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013) and mathematics in the *Common Core State Standards* (*CCSS*; NGAC and CCSSO 2010).

A SOCIETAL PERSPECTIVE FOR STEM EDUCATION

The 20th century was a period of significant scientific advances and technological innovations, both of which contributed to dramatic social progress. As the nation's economy advanced, the requirements for skilled workers increased, especially the need for intellectual skills, including those often associated with STEM fields.

By 21st-century standards, the intellectual skills required in the early 20th century were low. With time, the nation's policy makers and educators realized the economic value of creative ideas and efficient means for the production and delivery of goods and services. As the 20th century progressed, the number of individual jobs requiring manual labor and routine cognitive skills steadily decreased, while the jobs requiring intellectual abilities such as adapting ideas and solving nonroutine problems increased. In short, work became more analytical and technical. By the 20th century's end, entry-level requirements for the workforce increased to levels beyond a high school education. Taking this general observation to a more specific level, one would have to note the combined role of science, technology, engineering, and mathematics as a driving force of economic change and the steady shift in requirements for entry into the workforce, especially in developed countries. The changes just described suggest a fundamental place for science, technology, engineering, and mathematics in our economy, and by extension in our education programs.

A CLASSROOM EXAMPLE OF THE BSCS 5E INSTRUCTIONAL MODEL AND A STEM TOPIC

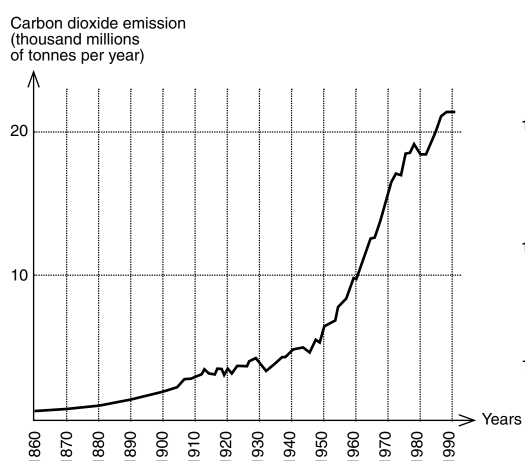
The following discussion is based on an adaptation of a released report from the 2006 Program for International Student Assessment (PISA). The title of the PISA unit was The Greenhouse Effect: Fact or Fiction? The unit can be reviewed in *Green at Fifteen: How Fifteen-Year-Olds Perform in Environmental Science and Geoscience in PISA 2006* (OECD 2009).

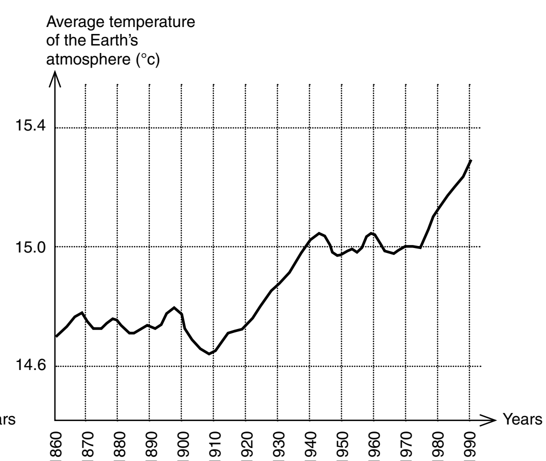
The original unit, cited above, was presented as an assessment that exemplified the PISA approach and the levels of proficiency for different items. In the following discussion, I have adapted this unit by adding a classroom and teaching context and arranging the activities to align with the 5E Instructional Model.

Engaging Students in a STEM Issue

The class is middle school, grade 8. This is the first day of the unit. On day 1 of the unit, the teacher, Mr. Kennedy, engages the students with a teachable moment. Mr. Kennedy enters the classroom and tells the students, "I have a puzzling situation. The other day I mentioned global warming and one student became very interested. That student, Andy, became so engaged that he went on the web and did a search of the topic and found two graphs that he thought showed a possible relationship between the average temperature of the Earth's atmosphere and the carbon dioxide (CO_2) emissions on the Earth. At this point in the lesson, Mr. Kennedy showed the students the graphs that Andy discovered (Figure 6.1).

Figure 6.1. Graphs Showing Possible Relationship Between the Average Temperature of Earth's Atmosphere and CO_2 Emissions on Earth





Source: OECD. 2009. *Green at fifteen?: How 15-year-olds perform in environmental science and geoscience in PISA 2006*. PISA, OECD Publishing. *http://dx.doi.org/10.1787/9789264063600-en.* Reprinted with permission.

Mr. Kennedy explained that Andy concluded from these two graphs that it is certain that the increase in the average temperature of the Earth's atmosphere is due to the increase in the carbon dioxide emission.

At this point, Mr. Kennedy divided the class into pairs and asked the groups to discuss what they concluded from the two graphs and Andy's position. Mr. Kennedy provided each group with the graphs. In this *engage* phase, the teacher created a teachable moment by suggesting that he was puzzled and wanted the students to review the two graphs that initiated Andy's interest and formed the basis for his conclusion. He did not define the terms *global warming* or *greenhouse effect*. Furthermore, he did not clarify the details of the two graphs.

The small-group discussion provided an opportunity for the teacher to assess the students' knowledge of the greenhouse effect, their understanding of the graphs, and their reasoning that connected the graphs to Andy's conclusion.

Exploring the STEM Issue

On day 2, Mr. Kennedy further explained the problem: Another student, Jean, disagreed with Andy's conclusion. She compared the two graphs and said that some parts of the graphs did not support his conclusion.

Mr. Kennedy asked the small groups to identify what evidence might have been the basis for Jean's claim and her disagreement with Andy's conclusion. The teacher asked Jean to give an example of the part of the graphs that did not support Andy's conclusion.

Different groups of students presented the following observations:

- In the period 1900–1910, CO_2 emissions increased and temperatures decreased.
- In the period 1980–1983, CO_2 emissions decreased and temperatures increased.
- In the 1800s, the temperature stayed about the same and CO_2 emissions increased.
- Between 1950 and 1980, CO_2 emissions increased but the temperature did not.
- Between 1940 and 1975, the temperature stayed about the same, but CO_2 emissions increased significantly.

In some other groups, the students made incomplete observations. For example, some groups only indicated dates and other groups did not indicate a period of time, only a date with an acceptable example. Finally, some groups identified the difference between the two graphs but did not refer to specific periods that supported Andy's conclusion. Mr. Kennedy asked the students to indicate the data from the graphs and their reasoning—that is, how and why the data support Andy's conclusion. As the teacher listened to the student discussions, he observed the following ideas. Some groups referred to the increase of both temperature and CO_2 emissions. Some even used the term *correlation* to describe the similarity in graphs. Some examples included these statements:

- Both graphs indicate increases—one of CO_2 emissions, the other of temperature.
- In 1910, both graphs increased.
- The higher the CO_2 emissions, the higher the temperature.

Explaining Components of a STEM Issue

The class begins with a representative of the student groups explaining what they observed about the two graphs and the possible conclusions by Andy and Jean.

After listening to the students' explanations, Mr. Kennedy told the class that he would like them to listen while he introduced some scientific ideas that would help them with the activity. He proceeded to discuss the following ideas:

- Living things need energy to survive. The energy that sustains life on Earth comes from the Sun, which radiates energy into space. A tiny proportion of this energy reaches the Earth.
- The Earth's atmosphere acts like a protective blanket over the surface of our planet, preventing the variations in temperature that would exist in an airless world.
- Most of the radiated energy coming from the Sun passes through the Earth's atmosphere. The Earth absorbs some of this energy, and some is reflected back from the Earth's surface. Part of the reflected energy is absorbed by the atmosphere.
- As a result of absorbed energy, the average temperature above the Earth's surface is higher than it would be if there were no atmosphere. The Earth's atmosphere has the same effect as a greenhouse, hence the term *greenhouse effect*.
- Scientists report that the greenhouse effect has become more pronounced during the 20th century.
- Scientific evidence indicates that the average temperature of the Earth's atmosphere has increased. Increased carbon dioxide emission is often cited as the main source of the temperature rise in the 20th century.

After this introduction, Mr. Kennedy asks for students' questions. The students ask for more information on the greenhouse effect, how scientists know the atmospheric temperature is changing, why some light energy gets through the Earth's atmosphere but does not get out, and how much evidence scientists have about changes in the Earth's atmosphere.

Mr. Kennedy gives further explanations and examples in response to these questions. In this phase of the instructional sequence, the teacher first asked for students' explanations as indicators of what they had learned. The second part of this lesson was a direct introduction of concepts related to the greenhouse effect and the evidence supporting the concept. Finally, there was time for questions from the students.

Elaborating on STEM Knowledge and Practices

Mr. Kennedy begins the next class by telling the students that Andy persists in his conclusion that the average rise in temperature of the Earth's atmosphere is caused by the increase in carbon dioxide emissions. But Jean thinks his conclusion is premature. She says, "Before accepting this conclusion, you must be sure that other factors that could influence the greenhouse effect are constant."

The students are then assigned the task of preparing two statements. One statement should support Andy's conclusion and the other should support Jean's position. The students should use the original graphs, their own web searches, and other information in the preparation of their statements. The students will hand in the written statements and make a presentation to the class about their conclusions.

Evaluating STEM Knowledge and Practices

To evaluate students' learning, Mr. Kennedy designed the following rubric (see Table 6.1).

Table 6.1. Evaluation Rubric for Greenhouse Lesson

LEARNING OUTCOMES	EVALUATION	
Knowledge of greenhouse effect	Formative	Summative
Analyzing and interpreting data		
Using mathematics and computational thinking		
Constructing explanations		
Engaging in argument from evidence		
Obtaining, evaluating, and communicating information		
Systems thinking		

RECOMMENDATIONS

Applying the BSCS 5E Instructional Model to STEM education is possible; the example used in this chapter demonstrates that possibility. This section presents several recommendations that will help you use the 5E Model for STEM education.

Identify a Context for Your Unit of Instruction

I have found it particularly difficult to begin with a discipline (e.g., science) and then try to build an integrated instructional sequence that includes other disciplines (e.g., technology, engineering, mathematics). My recommendation is to begin with a local, regional, or global context that has personal meaning for your students. Although there may be others, contexts that lend themselves to STEM include the following:

- Health maintenance and disease prevention
- Energy efficiency
- Environmental quality
- Natural hazards
- Natural resource use

The example in the prior section used global climate change as the context.

Decide on Your Approach to Integration

A step beyond maintaining separate STEM disciplines requires the consideration and a decision to advance STEM education by integrating the disciplines. This decision can be made at the state level, but in the approach suggested here, the decision is best made at the district or school level.

Several approaches to curriculum integration have been published. I recommend reviewing the following resources: *Designs for Science Literacy* (AAAS 2001); *Meeting Standards Through Integrated Curriculum* (Prak and Burns 2004); *Making Sense of Integrated Science: A Guide for High Schools* (BSCS 2000); and *Interdisciplinary Curriculum*: *Design and Implementation* (Jacobs 1989).

In addition, the National Academy of Engineering and the National Research Council (NRC) released *STEM Integration in K–12 Education* (NRC 2014). I also note that some of this discussion is adapted from my book *The Case for STEM Education: Challenges and Opportunities* (Bybee 2013).

Different perspectives of STEM education can be described. Here are several variations to consider for the integration of STEM:

- *Coordinate:* Two subjects taught in separate courses are coordinated so content in one subject synchronizes with what is needed in another subject. For example, students in mathematics learn algebraic functions when they need that knowledge in engineering.
- *Complement:* While teaching the main content of one subject, the content of another subject is introduced to complement the primary subject. For example,

while designing an energy-efficient car in a technology class, science concepts of frictional resistance (drag), loss of kinetic energy, and mass are introduced to improve the car's design and efficiency.

- *Correlate:* Two subjects with similar themes, content, or processes are taught so students understand the similarities and differences. For example, you could teach scientific practices and engineering design in separate science and technology courses.
- *Connections:* The teachers use one discipline to connect other disciplines. For example, they could use technology as the connection between science and mathematics.
- *Combine:* This approach combines two or more STEM disciplines using projects, themes, procedures, or other organizing foci. For example, one could establish a new course on science and technology that uses student projects to show the relationship between science and technology.

Because of the dominance of the traditional disciplines in state, district, and school standards, curricula, and assessments, you likely will need to provide a rationale with supporting recommendations for integrating the STEM disciplines. This is especially the case when you move beyond integration through coordination, complements, correlation, or connections. Combining subjects or designing courses that transcend the separate STEM disciplines will require elaborate and detailed justifications.

There are a few arguments for curricular integration. First, the situations of life and living are all integrated. The decisions that citizens face are not nicely contained within disciplines such as science or mathematics. Life situations typically require the knowledge, abilities, and skills of multiple disciplines. Second, individuals learn best when the context within which they are learning has personal meaning—that is, learning is enhanced when it is related to something people recognize or know, or in which they have a personal interest. Third, there is an efficiency that comes with combining the knowledge and skills of different disciplines, and there is limited time in school days and years. If lessons, courses, and school programs can attain learning outcomes of both content and processes of different disciplines such as engineering and mathematics, that benefits both teachers and students.

Table 6.2. Applying the BSCS 5E Instructional Model to a STEM Topic

THE BSCS 5E INSTRUCTIONAL MODEL	WHAT THE TEACHER DOES	WHAT THE STUDENT DOES
Engagement: This phase of the instructional model initiates the learning task. The activity should make connections between past and present learning experiences, surface any misconceptions, and anticipate students' thinking on the learning outcomes of current activities. The student should become mentally engaged in the concept, practices, or skill to be explored.		
Exploration: This phase of the teaching model provides students with a common base of experiences within which they identify and develop current concepts, practices, and skills. During this phase, students may use cooperative learning to explore their environment or manipulate materials.		
Explanation: This phase of the instructional model focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities for them to verbalize their conceptual understanding or demonstrate their skills or behaviors. This phase also provides opportunities for teachers to introduce a formal label or definition for a concept, practice, skill, or behavior.		
Elaboration: This phase of the teaching model challenges and extends students' conceptual understanding and allows further opportunity for students to practice desired skills and behaviors. Cooperative learning is appropriate for this stage. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills.		
Evaluation: This phase of the teaching model encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate students' progress toward achieving the performance expectation.		

Developing an Instructional Sequence for a STEM Topic

Table 6.2 on page 82 briefly describes criteria for each phase of the 5E model. After you have identified an appropriate STEM topic, use the table to sketch an instructional sequence. I strongly recommend using backward design as it was presented in Chapter 5.

CONCLUSION

The acronym STEM is widely used in education. Although STEM has caught the interest of policy makers and many educators, the meaning remains elusive. In the 21st century, citizens need to have essential knowledge and skills associated with science, technology, engineering, and mathematics. This chapter provided a rationale for STEM education and directed the reader's attention to STEM as it may be applied in the context of curriculum and instruction. Thus, an application of the 5E Model gains specific meaning for classroom teachers.

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