CHAPTER 8

* Student Engagement
* Deeper standing
* Raise Achievement

Three Approaches to Integrated STEM

Q. How learning happen?
Q. What are learning barriers?

BEFORE YOU READ THIS CHAPTER, think about how you would characterize the kind of STEM integration of the Gears unit in Chapter 6. What in the unit enabled the students to see how the four STEM fields were joined together?

STEM education is an interdisciplinary approach to learning which removes the traditional barriers separating the four disciplines of science, technology, engineering, and mathematics, and integrates them into meaningful experiences for students.

—*Making STEM Real*, Hoachlander and Yanofsky (2011)

Q. Meaningful experience!!

What Does *Integration* Mean?

When you ask fourth graders about their day at school, most will respond with something like the following: "We did reading in the morning, then we had our reading groups, then we had recess and math before lunch." Students view these subjects as entirely separate because they are typically based on different standards and taught with curriculum materials that were developed without reference to each other. One of the great promises of STEM is in breaking down the isolation of science and mathematics—from each other and from the fabric of technology and design in the world outside of school. The idea of STEM teaching and learning is to

standard
curriculum
materials
Breaking
down
the
isolation
Outside world of school.

Q. What does integration really mean?
Q. Connections between concepts from different field.

increase student engagement, to deepen their understanding, to raise achievement, and to help them see the relevance in what they are learning (Hoachlander and Yanofsky 2011).

STEM education represents a fundamentally different approach to organizing the school curriculum. As such, it raises a number of practical questions. What does *integration* really mean? Is it sufficient for students to see the connections between concepts in different fields? Or does it mean assimilating concepts from two different fields so they become one? Should integration involve skills as well as concepts? How about connections to social studies? Language arts? Or to everyday life? These are important questions that we will address in this chapter. (+)

Q. Assimilating concepts from two different fields become one!!

Three Approaches

In the book *Meeting Standards Through Integrated Curriculum*, Drake and Burns (2004) begin by acknowledging that integrating the curricular areas is not a new idea, and reference a 1935 publication from the National Council of Teachers of English, which offered a range of definitions, from "casual attention to related materials in other subjects" to "the unification of all subjects and experiences." Drake and Burns further develop these ideas as three approaches to integration. Following is our own slightly modified scheme that we feel is especially suitable to describing different levels of STEM integration. In brief, they are: *multidisciplinary* or *thematic integration*, *interdisciplinary integration*, and *transdisciplinary integration*. * (+)

Integration

In the remainder of this chapter, we will illustrate how each of the approaches might be used to teach students about our solar system. Before we do that, however, we would like to emphasize three important points:

First, integration does not mean abandoning standards. It is still important that our students acquire all of the concepts and skills identified in standards documents; these are generally described within disciplinary areas.

Second, the real power of STEM lies in the integration of the subject areas so that students begin to see how the concepts and skills from different disciplines can work together to help them answer intriguing questions and solve meaningful problems.

Third, an integrated STEM curriculum shifts the teacher's focus from how to teach the concepts and skills within each discipline to how to help their students learn *to apply* STEM concepts and skills and relate what they are learning to the rest of their school day.

Multidisciplinary or Thematic Integration

The multidisciplinary, or thematic, approach connects the individual disciplines by organizing the curriculum around a common theme such as "Oceans," "Ecosystems," "Flight," or "Pirates." This approach is used to provide coherence to the curriculum so that the students have an opportunity to see that they can learn about something in many different ways. For example, a theme of "Pirates" might initially be suggested by an English teacher who is having her students read *Treasure Island* by Robert Lewis Stevenson. The science teacher might then have students learn about ships with a unit on buoyancy, and the social studies teacher assigns a chapter from a textbook on the real history of pirates. In math class students could learn what a gold doubloon would be worth in today's currency, and so on.

eas — across domain

kills - engaging context

Although this multidisciplinary or thematic integrated approach has the advantage of helping students connect ideas across domains and apply skills in an engaging context, it runs the risk of becoming an uncoordinated "potpourri" of subjects. By analogy, think of the junk drawer in your kitchen. It contains miscellaneous items that are put together for convenience but which you probably do not use as often as your drawer for the silverware, which also contains different items, but where items are organized by closely related functions.

mixture

ultidisciplinary approach ↓ ucational tool

For the multidisciplinary approach to serve as a rich, relevant, and effective educational tool, it is important for the multidisciplinary theme to capture students' interests and to enable students to meet the educational standards associated with each discipline.

Example of a Multidisciplinary Approach

Imagine a teachers' meeting in which they have just decided to organize a grade-level thematic unit on the solar system.

Science Teacher: "The new science textbook does a nice job of describing what we know today about the solar system, but I'd like to get the kids more involved in learning the features of the different planets, such as the rings of Saturn and Jupiter's Great Red Spot, and how the planets move around the Sun."

PE Teacher: "I could have the students play the part of planets on the activity field. I would stand in the middle to be the Sun and have the kids playing the part of inner planets run in circles around me. It would be a good test to see if they remember from science class how fast the different planets are supposed to move."

Art Teacher: "I could have the students make models of the planets using colored clay and then make mobiles so the kids could take them home and hang them up."

Math Teacher: "I could have the students practice dividing by big numbers to see how the distance to the Moon compares to the distance to the Sun, planets, and stars."

English Teacher: "I can change my schedule so the students read a science fiction book at about the same time. In the story the students invent an antigravity paint, which they use to build a spaceship and fly to Mars."

Social Studies Teacher: "I plan to teach a unit on mythology. That would provide a good opportunity for the students to learn about the origin of the names of the planets and their association with Greek and Roman gods and goddesses."

As illustrated in this imaginary scenario, multidisciplinary integration has advantages over business as usual. Students experience a more coherent series of lessons and activities, requiring only small changes by their teachers, such as modifying their schedules, finding relevant media, or changing worksheets to reflect the common theme. This thematic curriculum plan for a unit on the solar system is illustrated in Figure 8.1.

Figure 8.1 illustrates that all of the activities are somehow connected to the solar system. However, the connections tend to be peripheral—they are related but do not focus on a common understanding among the teachers of the most important key concepts or essential skills that would help their students develop a deeper understanding of the solar system. Also, there are no obvious connections between the different disciplines, other than their common connection to the solar system.

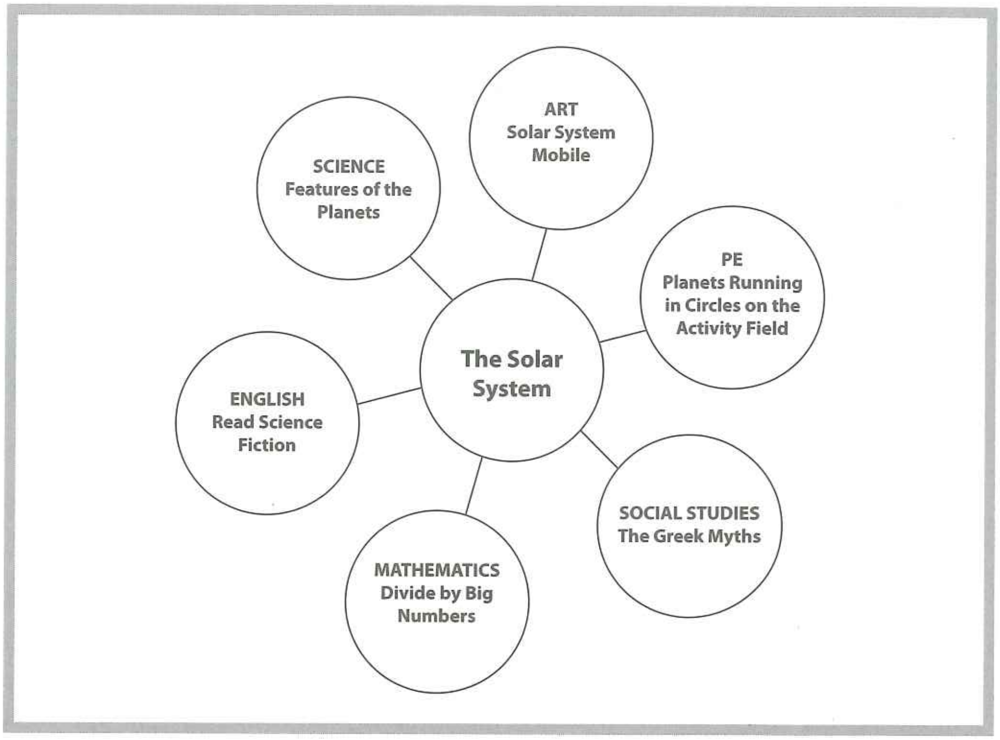

Figure 8.1 Multidisciplinary curriculum plan about the solar system.

common.

Interdisciplinary Integration

In this approach to integration, teachers organize the curriculum around common learning across disciplines. They chunk together the common learning embedded in the disciplines to emphasize interdisciplinary skills and concepts. ?? The disciplines are identifiable, but they assume less importance than in the multidisciplinary approach. Therefore, the first step in designing this type of STEM curriculum is to choose a key concept or skill that is important for all students to learn and that is enriched by combining knowledge and skills from two or more disciplines.

Combining knowledge & skills from 2

Interdisciplinary integration should not be viewed as entirely distinct from thematic or multidisciplinary integration. Both approaches aim at providing a curriculum that is coherent from the viewpoint of the learner. Also, interdisciplinary integration can occur within a thematic curriculum plan, whenever the theme includes an important key concept that is taught from the viewpoint of two or more disciplines.

Interdisciplinary integration can also link entirely different disciplines, such as science and mathematics, or technology and social studies. In the multidisciplinary approach, the focus is on one main topic as in the example in Figure 8.1; in the case of the interdisciplinary approach, learning goals from two disciplines are "fused" to form a single key concept or skill—just as a chain consists of individual links but functions as a whole.

Two disciplines are fused.

Although taking this interdisciplinary approach further may at first sound daunting, an example or two will illustrate that it is not all that difficult to accomplish.

Example of an Interdisciplinary Approach

Suppose the science teacher from the multidisciplinary example begins with a different question—one that requires teaching a concept that is shared with a different discipline. What might that conversation look like?

Science Teacher: "The new science textbook does a nice job of describing what we know today about the solar system, but I'd like my kids to have a better concept of scale—like the huge range of sizes of the planets and how far apart they are in space. Can anyone help me with that?"

Mathematics Teacher: "If you mean understanding the scale of the solar system, I heard about an activity in which students use the same scale for the size of the planets as for the distance they are from the Sun. It's called 'The Earth as a Peppercorn' (Ottewell 1989) and it shows you just how much space there is in space! I've been having the students work on ratios, and I'd like to have the students figure out the sizes and distances in their model if I give them the scale factor."

In this approach, the teachers organize the curriculum around common learnings across the disciplines. They chunk together the common learnings embedded in the disciplines to emphasize the interdisciplinary skills and concepts. Remember, the disciplines are still identifiable, but they assume less importance than in the multidisciplinary approach. And in this case the key concept of scale helps the students understand the solar system at a much deeper level than would be possible from learning about surface features of the planets alone, while providing good practice in applying their abilities to use ratios. This conceptually integrated curriculum plan of the two disciplines is illustrated in Figure 8.2.

In the integrated plan, the link between science and mathematics is at a deep conceptual level. From the mathematics teachers' perspective, students are

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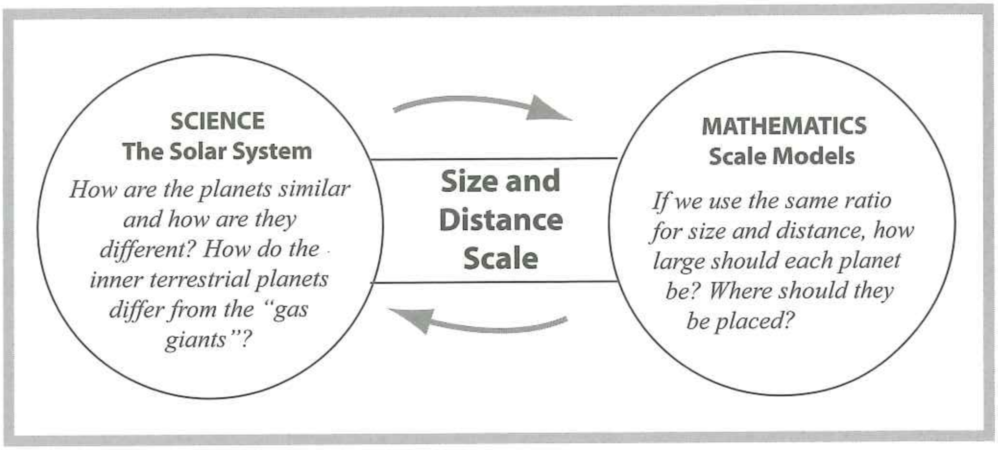

Figure 8.2 Interdisciplinary curriculum plan about the solar system.

using their growing understanding of ratios to figure out how to properly scale a model, given data about the real sizes and distances in the solar system. From the science teachers' perspective, actually creating the model helps the students grasp the vast size and distance differences in the solar system better than any textbook illustration could provide. It also helps the students discover—from their modeling experience—that there are two broad categories of planets: the small terrestrial planets, including Earth, that are close to the Sun, and the four huge gas giant planets, including Jupiter, Saturn, Uranus, and Neptune. If Pluto is added to the model, students can also see how different it is from any of the major planets, being much further from the Sun than the terrestrial planets and much smaller than the gas giants.

Q. How to scale a model?

Interdisciplinary Integration of More Than Two Disciplines

The interdisciplinary curriculum plan about the solar system described here is a good starting point for a more comprehensive curriculum. To see how such a plan can be expanded to include more disciplines, imagine how the faculty meeting described previously might proceed after the mathematics and science teachers agree to work together.

Science Teacher: "I was wondering if I might also get some help from social studies since I know that you are teaching about world history during the sixteenth and seventeenth centuries. The textbook we are using in science tells the story of how Galileo's use of the telescope helped people realize that Copernicus was right—that the Earth circles the Sun like the other planets. But it would be better if they could learn more about why this was such a controversial idea at the time."

Social Studies Teacher: "Actually, I can do better than that. I am teaching a unit about people who have been persecuted for their ideas. One of the people that our students will learn about was Giordano Bruno, who was burned at the stake in the year 1600 for expressing the idea that the Sun is a star and that there is an infinite number of habitable planets in space. That was just ten years before Galileo published his famous book, *The Sidereal Messenger*, about his observations of the Moon and Jupiter."

Science Teacher: "Thank you, that's perfect! Galileo's use of the telescope to show that the Moon had mountains and valleys like Earth, and that Jupiter had its own moons, changed people's understanding of the solar system forever. It would certainly be great if the kids could look through a telescope themselves and see what Galileo saw."

Career and Technical Education (CTE) Teacher: "I can help with that. We can buy some inexpensive kits with the materials for making small telescopes like Galileo's. Since each kit includes just two lenses and a sliding tube, it's hard to hold it steady to get a good look at the Moon or Jupiter. But making mountings for the telescope will be a great engineering project for the kids. I have some scrap wood, and I can show them pictures of different kinds of telescope mountings to get them started."

Mathematics Teacher: "And I can help the students calculate the magnifying power of their telescopes. Magnifying power is just the ratio of the focal lengths of the two lenses. I can have the students measure the focal length of the two lenses by turning off the lights and holding each lens near the wall to focus a picture of things outdoors. The distance between the lens and the wall when the picture is sharp and clear is the focal length. It's another good application of ratios."

This interdisciplinary unit is illustrated in Figure 8.3.

On the right side of Figure 8.3, between the science and mathematics circles, is a key concept about the sizes and distances of solar system bodies. That concept enriches the students' understanding of the solar system as it meets the educational goals of both the science and mathematics teachers.

At the top of the diagram is the key concept of how technology has increased our understanding of the solar system. This key concept helps students under-

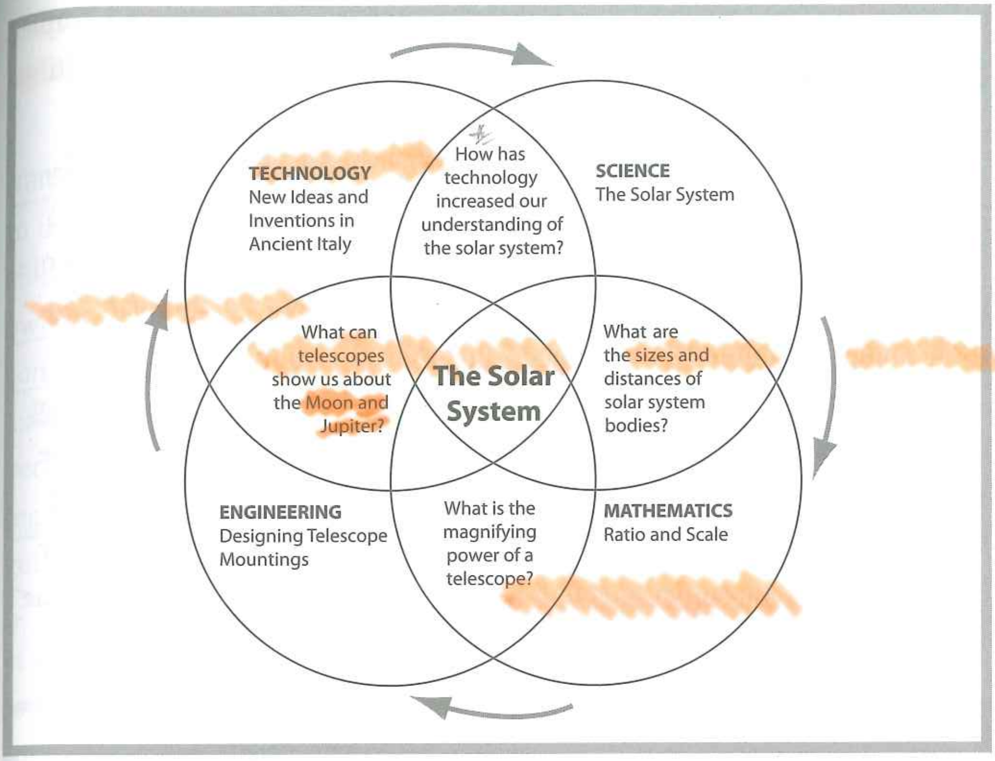

Figure 8.3 Interdisciplinary curriculum plan about the solar system.

stand where our knowledge of the solar system comes from. It also meets the science teachers' goal of helping students understand the role of technological inventions in advancing scientific understanding and the social studies teachers' goal of helping students understand how new ideas are introduced into society, sometimes at great peril to independent thinkers.

The left side of the diagram identifies what telescopes reveal about the Moon and Jupiter as a key concept. Galileo's observations that the Moon looked like an actual place, somewhat like the Earth, and was not a perfect sphere were very important in helping people think of the planets as worlds. Likewise his observations of Jupiter showed that it was like a mini–solar system, with four tiny moons going around it, suggesting that Copernicus was right and that Earth is not the center of the universe, but it circles the Sun along with the other planets. This part of the plan would not be nearly as rich without the help of the CTE teacher, whose skills helping students design and build simple structures helped students see the Moon and Jupiter as Galileo did, but with slightly improved optics and a steadier mounting.

The unit does not have to stop there. The English teacher could have students read excerpts from Galileo's original text, including the passage and drawing that Galileo published soon after he saw the Moon through a telescope for the first time (Figure 8.4). The students could then write about their own observations and impressions and make their own drawings.

It is important to point out that interdisciplinary STEM teaching does not have to be accomplished by a team of teachers. Although teamwork has the advantage of bringing together teachers with complementary expertise and helps students see the subject from different points of view, a single teacher can accomplish conceptual integration by intentionally bringing together the

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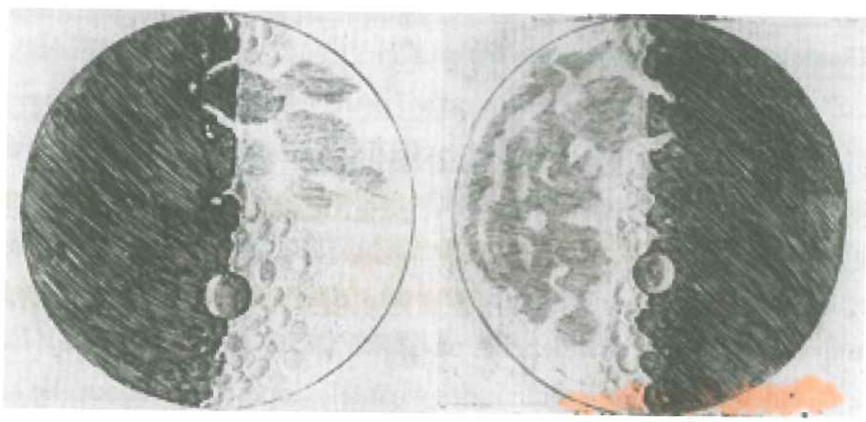

"From these observations I have been led to the opinion and conviction that the surface of the moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it (and the other heavenly bodies) to be, but is uneven, rough, and full of cavities and prominences, being not unlike the face of the earth, relieved by chains of mountains and deep valleys."

(Drake 1957, 31–35, translation of *The Starry Messenger* by Galileo Galilei, 1610)

Figure 8.4 The first telescopic observations of the Moon.

learning objectives of two different disciplines with a focus on a single key concept.

Transdisciplinary ⇒ Teachers organize curriculum

Transdisciplinary Integration

In the transdisciplinary approach to integration, teachers organize curriculum around student questions and concerns. This is where we ask students to take ownership of the learning and apply their knowledge and skills in a real-world context. In the transdisciplinary approach, the relevance of the students' learning and their ability to use their knowledge in a real-world application becomes the focal point. The essential question is the driver, the STEM learning objectives are the road map, and the students' previous experiences are the guideposts.

* Learn & apply
* Real-world application
* STEM = learning objectives

The transdisciplinary approach is grounded in constructivist theory (Fortus et al. 2005), which has been shown to improve student achievement in higher-level cognitive tasks, such as scientific processes and mathematical problem solving (Satchwell and Loepp 2002).

* Constructive

In the transdisciplinary approach, teachers bring together the twenty-first-century skills, knowledge, and attitudes with real-world application and problem-solving strategies. Layering on real-world, problem/project-based strategies provides a deeper and more relevant learning experience. These real-world problems are not well defined and do not have only one right answer.

* Real-world application
* Problem-solving
* Project-based

Example of the Transdisciplinary Approach

To envision how a transdisciplinary unit might be developed about the solar system, let's go back to the grade-level teacher meeting and imagine the conversation that could lead to a transdisciplinary experience for students.

* Transdisciplinary experience for students

Science Teacher: "The students have enjoyed the solar system unit, especially the chance to build a telescope and look through it to see Jupiter and its moons. But they still aren't as involved as I'd like them to be. I wish

I could put them in a rocket ship and fly them to the planets so they could really see what it is like to be there and have to deal with life on an alien world."

Art Teacher: "How about asking them to imagine being a weather reporter on another world? Maybe they could see what the weather is like on the other planets and give updates for local, national, and international weather for Mars or Saturn."

Science Teacher: "That's a great idea! They could work in groups, and each group could be assigned to give a weather report from a different planet. But first they would need to find out how people on Earth create weather forecasts. I guess the driving question would be: 'How would a meteorologist forecast the weather on Planet X?' That will get them thinking about how people predict the weather here on Earth and to imagine what it would be like to survive on another planet."

Career and Technical Education (CTE) Teacher: "It would also help the students find out about a lot of different careers—meteorologists and all sorts of jobs in the television industry. Perhaps I can contact some guest speakers from the university, the weather service, and even the local TV stations. Maybe we can take them on a tour of a TV studio, where they can find out about how many different kinds of jobs are needed to produce a television show."

Mathematics Teacher: "They're going to need some math if they want to send weather reports from another world. What if someone in the studio asks them a question? How much time will it take for the radio transmission to reach them and for them to send back an answer? That could be a challenge because the distances between the planets are always changing, but I know of a computer model of the solar system that the kids could use to figure that out for different dates and times. It would be a great introduction to mathematical modeling."

Art Teacher: "I could have the kids make studio sets for their weather forecasts. They could figure out what they'd need to do to make their sets as authentic as possible."

English Teacher: "I can help the students write their scripts. I'd start by contacting the local TV station so they could see what a real TV script looks like for the weather reporter. Technical writing is another career they might not have thought of."

Science Teacher: "Thanks, everyone! This will really get the kids engaged. I've always wanted my students to think of the planets as real worlds—just as Galileo did when he first looked at the Moon through a telescope and saw mountains and valleys. By working together we can also help them learn about the real world of weather prediction and television careers right here on Earth."

Equally important as the planning that goes into a transdisciplinary unit is the practice of listening to the students' ideas and allowing them to collaborate in deciding what comes next. This approach, in which the teacher sets the goal and invites the students to help figure out how to achieve it, is well supported by research (Drake and Burns 2004). In this case, the goal was embedded in the essential question: "How would a meteorologist forecast the weather on Planet X?" Each teacher stated the goal a little differently, so as to help the students acquire concepts and skills in their discipline, but in each case the students had some freedom to lead the exploration and express their own creative ideas. The structure of the unit is illustrated in Figure 8.5.

"students idea"
"Listen students"

Figure 8.5 illustrates the essential question that drives the unit as a whole and each of the discipline-based learning objectives. The enduring understandings are those ideas that you want the students to recall five or even ten years after the unit. From the students' point of view, the focus is on the project they are completing. From the teachers' point of view, the focus is on embedding

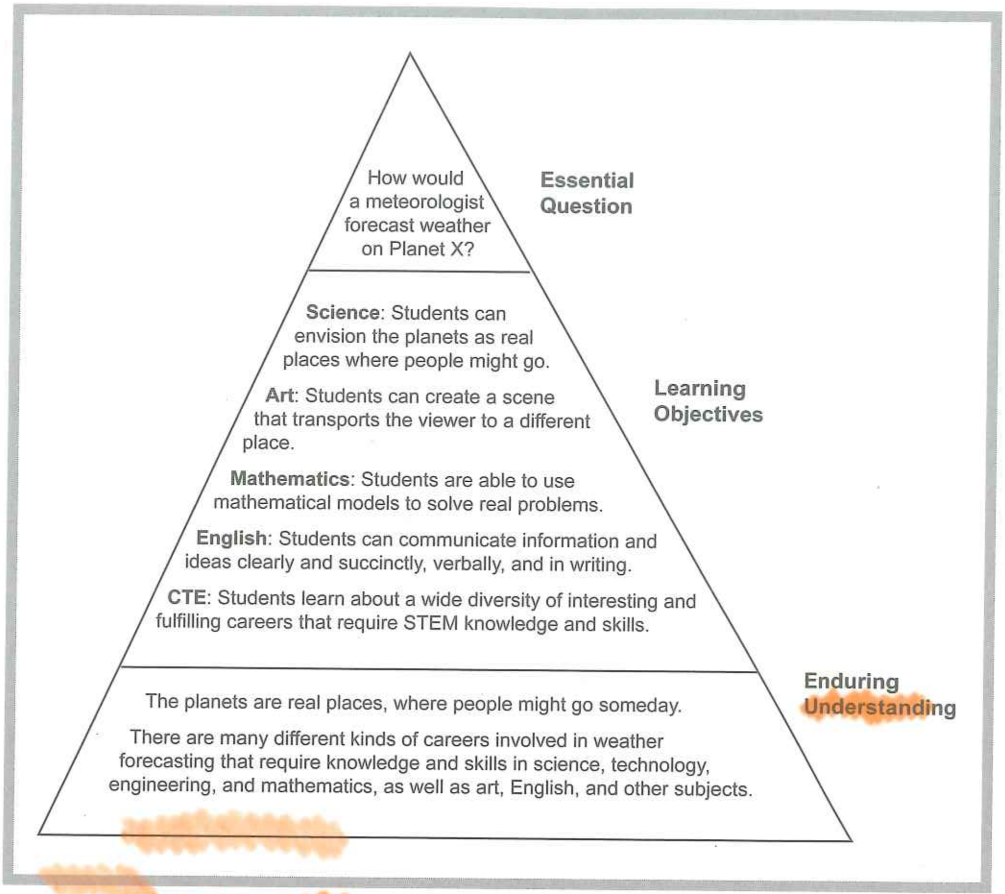

Figure 8.5 Transdisciplinary curriculum plan about the solar system.

the learning objectives so that students gain concepts and skills as they complete the project. The boundaries between the disciplines dissolve as students become more deeply immersed in the project.

Bear in mind that for the students to successfully complete a project of this type, it is necessary for them to have gained some level of knowledge and skill in the different disciplines first, probably in a more traditional learning context. Therefore, this type of integration is not something that is done every week or month and may be something that you organize and have the students do every quarter as a culmination of the learning that has been taking place.

Summary of the Three STEM Approaches

The three approaches introduced in this chapter can be used at any level of education, from elementary through graduate school. They can be planned and presented by a team of teachers or by a single teacher. And they can be enriched further by integrating authentic assessment tasks and by applying the principles of backward design (Wiggins and McTighe 2004). As illustrated in Figure 8.6, the approaches are not distinct, but rather fall along a continuum from less integrated to more integrated.

All of these ways of organizing the curriculum have value. None of these approaches are "wrong," and the difference among them is the matter of degree, rather than a difference in kind. And although integrated STEM teaching is recommended by the authors of this book, it is by no means the only way to teach.

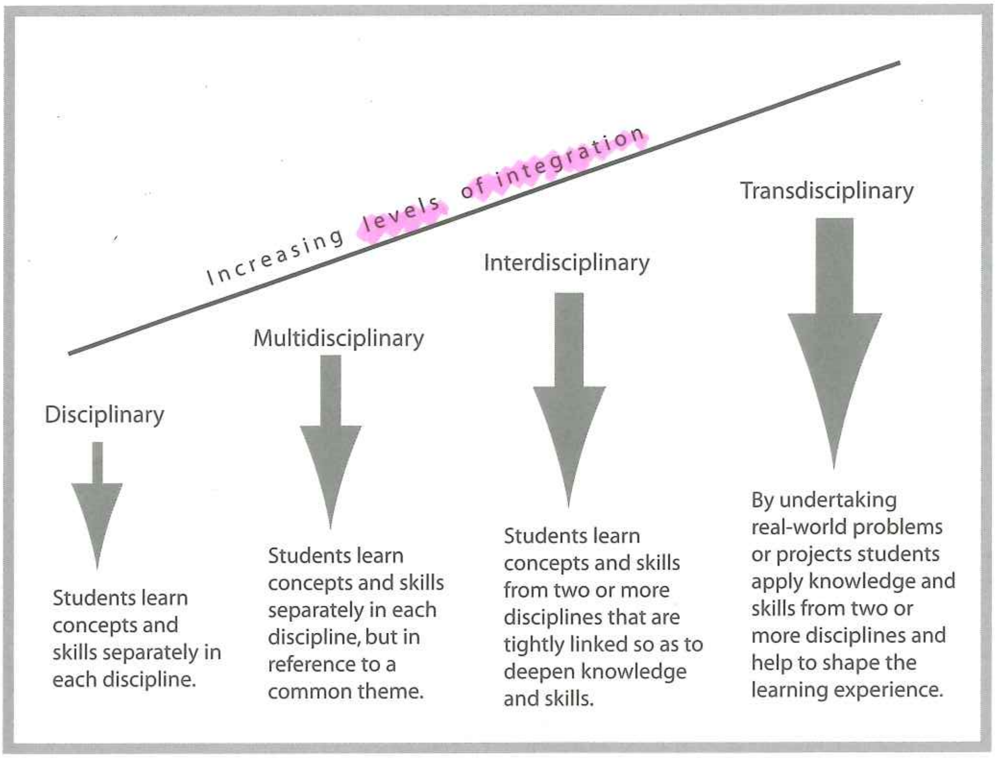

Figure 8.6 A continuum of STEM approaches to curriculum integration.

In fact, a mixture of methods is probably best. Additional differences among the three integrated approaches are shown in Figure 8.7.

Figure 8.7 Three approaches to designing integrated STEM curriculum units.

	Multidisciplinary	Interdisciplinary	Transdisciplinary
Organizing Center	Standards of the disciplines are organized around a theme.	Interdisciplinary skills and concepts are embedded in the disciplinary standards.	Problem/project based, in a real-life context, with student-driven questions.
Development of the Content	Knowledge and skills are best learned through the structure of each discipline.	Knowledge and skills are interconnected and interdependent.	Knowledge and skills are partly determined by the teacher and partly by the students.
Role of the Disciplines	Distinct skills and concepts of disciplines are taught independent of the other disciplines. Procedures of disciplines are considered most important.	Interdisciplinary skill, practices, and concepts are woven throughout. Procedures combine qualities of different disciplines.	Discipline boundaries are de-emphasized as students work on a real-life problem or project. Procedures are at least partially determined by the students in response to goals set by the teacher.
Role of Teacher	Lead instruction and facilitate student learning in each discipline.	Lead instruction and facilitate student learning across disciplines.	Set goals, facilitate student learning across disciplines, and invite students to help shape the learning experience.
Learning Goals	Discipline-specific concepts and skills.	Concepts and skills that bridge between the disciplines.	Concepts and skills that bridge between the disciplines, real-world contexts, and students' interests and concerns.
Degree of Integration	Low	Moderate	Extensive
Assessment	Discipline-based concepts and skills assessed in the usual/customary way.	Interdisciplinary concepts and skills assessed by combining methods from different disciplines.	Concepts and skills assessed by combining methods from different disciplines, and involving students in evaluating their own work.

Concluding Thoughts

Before concluding this chapter, we would like to raise the question of how explicit teachers should be when using these integrative approaches. It is common for teachers who are using a thematic approach to explain the theme to students, parents, and the entire school community. Some faculties call attention to a theme not only in academic classes, but also with art displays in the hallways, plays and concerts, and even menus for school lunches. However, it is less common that teachers call attention to interdisciplinary integration, perhaps because the concepts are so closely entwined.

In our view it is valuable for the students to know whenever disciplines are being combined—such as understanding the value of mathematics in science or of technology in history—because it helps students see how what they learn in different domains applies to key concepts. If students are to eventually see these connections for themselves, it is important for them to experience an integrated curriculum before they reach high school, where courses in the different disciplines are separated by such barriers as course names and credits.

We have for so long been focused on a silo approach to meet the standards and pass the test that moving along this continuum may take considerable effort. However, as you read the next few chapters, we believe you will become more experienced with designing STEM curricula. You will also gain ideas for making in-depth connections among the disciplines and hopefully begin to think about how you can begin this STEM integration journey.

Reflection

- Recall the three approaches to integrated STEM. Have you done any of these in your own teaching? If so, which approaches have you used?
- Which of the three approaches do you think would be most helpful for a specific purpose in your curriculum? (Keep in mind that all three approaches are helpful, but in different contexts or for different purposes.)

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