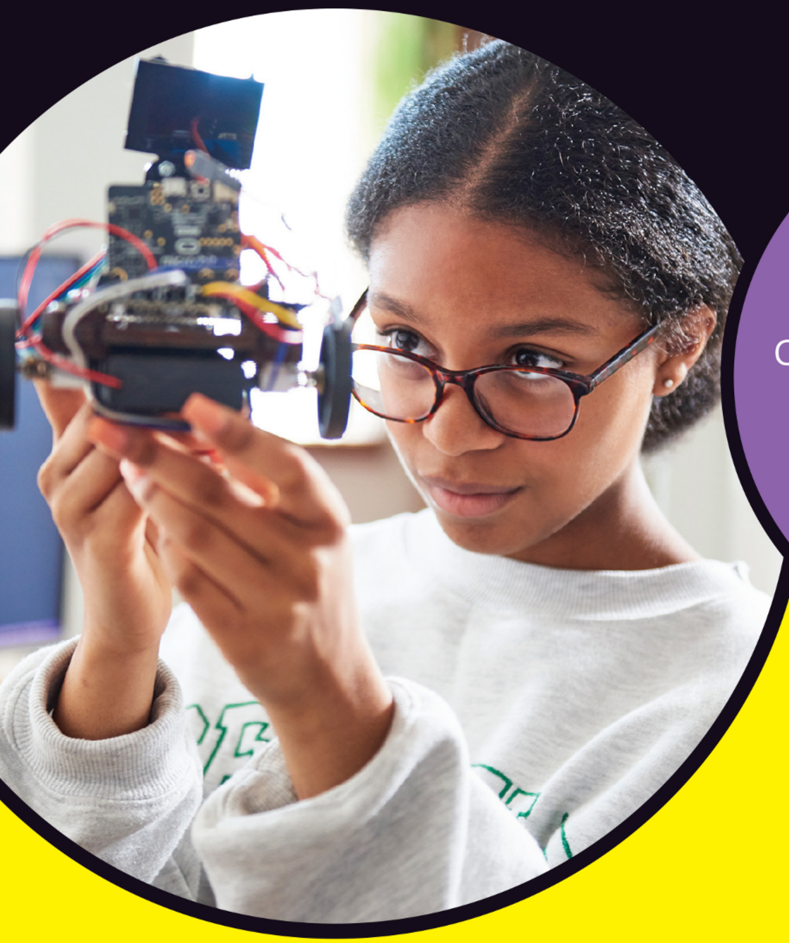
LEARNING MADE EASY

Teaching STEM for dummies

A Wiley Brand



Develop your approach to STEM education

Create life-long learners with inquiry-based teaching

Engage students with real-world projects

Andrew Zimmerman Jones

Quarter-century as a STEM educator and communicator

Teaching STEM

by Andrew Zimmerman Jones

for dummies®
A Wiley Brand

Teaching STEM For Dummies®

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Introduction

What would the world look like without global shipping logistics, telecommunications, world financial markets, the pharmaceutical industry, and streaming videos of unlikely pet friendships set to upbeat music? Some might argue that it would be a better world, but it wouldn't be *our* world. The modern world relies on scientific discoveries applied through technological feats of engineering implemented with immense levels of numerical precision. In other words, it relies on science, technology, engineering, and mathematics, otherwise known as STEM, working together.

A world that hangs together on those disciplines should also prioritize educational approaches and policies that teach them. Around the world, educators are discovering that their students are far more advanced than they are in some of these STEM areas, and woefully behind in others. Students who bypass the school's internet security with ease may go on to fail tests that cover basic math skills.

Engaging students with STEM lessons that motivate deep learning is an imperative to bridge these gaps. Teachers must meet the students where they are and lead them to where they need to be. Giving teachers the tools they need to accomplish this mission is the goal of this book. And so, *Teaching STEM For Dummies* takes on the mission of informing you about teaching STEM disciplines.

About This Book

This book serves as an accessible guide for teaching STEM subjects, primarily through classrooms or formal lessons. Here are a couple of things to watch out for in the book:

- **Source material is summarized.** Though the solutions offered throughout this book are based on the latest scholarship in the science of STEM learning, I focus on clearly summarizing research results and implications rather than quoting researchers directly or citing numerous individual sources. In cases where a single, definitive text on a subject exists, I provide information on that source and, if possible, a link to access it for free.

- **Web addresses appear in monofont.** If you're reading a digital version of this book on a device connected to the internet, note that you can click the web address — like this one: `www.dummies.com` — to visit that website.

To make the content of this book more accessible, I've divided it into five parts.

- **Part 1: Getting Started with Teaching STEM.** This part of the book gives a broad overview of STEM education and teaching, including definitions, overviews of the content, and key concepts. I also cover the reason why teaching STEM is so important and the history of STEM education in the United States.
- **Part 2: Gathering the Building Blocks of STEM.** Throughout this part, I explore the four areas of STEM (science, technology, engineering, and mathematics), including many of the relevant national academic standards. I also discuss ways to integrate STEM subjects with each other and combine them with other subjects, such as English, social studies, and the arts.
- **Part 3: Employing Approaches to STEM Education.** In this part, I dive into the key elements of creating a STEM lesson and a STEM curriculum, including how to assess STEM education to figure out student progress. I also cover additional ways to enhance the STEM program for your students.
- **Part 4: Troubleshooting STEM Education.** This part focuses on a variety of cases that dive into the particular aspects of teaching STEM, including planning for classroom needs, finding opportunities for STEM instruction at home, and working with diverse student populations.
- **Part 5: The Part of Tens.** A classic feature of the *For Dummies* series is the Part of Tens chapters. In this part, you can get some ideas for quick and easy STEM lessons that you can do with little prep and resources that should be available to you free or for a low cost.

Foolish Assumptions

This book is for anyone who teaches STEM subjects to a younger or less experienced person. Though I often reference *teachers*, *students*, *classrooms*, and *schools* throughout this book, most of the information is also useful for homeschooling, tutoring, and non-traditional STEM teaching environments and situations.

I do make the following assumptions about you, the people who are reading this book:

- **You know the content that you're teaching** (though you need not be an expert). I don't spend much time explaining the actual STEM concepts, except for a bit in Part 2 at a high level. You can find other resources (including many in the *For Dummies* series) if you need a deeper understanding of a specific subject such as physics, biology, or 3D printing.
- **You have some background experience with the fundamentals of teaching,** such as classroom management strategies and preparing lesson plans, either through formal training or that you picked up along the way. If you need those fundamentals, then two great resources are *Instructional Design for Dummies* and *First Year Teaching For Dummies*.
- **Your goal is to teach STEM content broadly,** rather than to focus on teaching a specific skill within STEM. Someone teaching a STEM-related career certification course can benefit from this book, but I didn't write it specifically for those situations.

Guidance throughout this book is useful for educators at a range of levels, from administrators to individual teachers and even parents wanting to give more STEM opportunities to their kids.

Icons Used in This Book

Throughout this book, icons in the margins highlight certain types of valuable information that they call out for your attention. Here are the icons you encounter and a brief description of each.

TIP

The Tip icon marks tips and shortcuts that you can use to make planning lessons and teaching STEM easier.

REMEMBER

The Remember icon marks information that's especially important to know. To siphon off the most important information in each chapter, you can just skim through these icons.

TECHNICAL STUFF

The Technical Stuff icon marks information of a highly technical nature that you can normally skip over. (This one isn't often used in this book.)

WARNING

The Warning icon tells you to watch out! It marks important information that may save you headaches, particularly content that can easily cause problems when presented poorly.

Beyond the Book

In addition to the abundance of information and guidance related to teaching STEM that I provide in this book, you get access to even more help and information online at `dummies.com`. To check out this book's online Cheat Sheet, just go to `www.dummies.com` and search for *Teaching STEM For Dummies Cheat Sheet*.

Where to Go from Here

If you're looking to get a feel for STEM in general, then start at the beginning (Chapter 1) and work your way through from there. The *For Dummies* style is modular, so feel free to jump around in the book as needed. References within the text give an idea of where you might find useful information in another chapter.

If you are an experienced teacher looking to focus on understanding STEM content, you may want to dive straight into Part 2. If you are knowledgeable about STEM content but want tips on forming lessons, you might find that Part 3 is a good place to start. Of course, the Table of Contents and the Index are good places for finding specific topic.

1 Getting Started with Teaching STEM

IN THIS PART . . .

Get a high-level perspective on STEM education and how teaching its core disciplines (science, technology, engineering, and mathematics) differs from more traditional education approaches.

Explore key educational principles of STEM education and the benefits that can come from that approach.

Review the history of STEM-related education in the United States, including an overview of the modern academic frameworks for STEM areas.

IN THIS CHAPTER

» Exploring STEM's meaning

» Teaching skills using STEM

» Motivating students to become lifelong learners

» Looking at new ways to teach

Chapter 1
The Nuts and Bolts of STEM Education

One of the most important jobs that anyone can have involves effectively educating the next generation. Although students need great teaching in all areas, this book emphasizes the teaching of *STEM*, the areas of science, technology, engineering, and mathematics. These four areas represent some of the more complex subjects that students encounter in K-12 (kindergarten through 12th grade in the U.S.) education. And teaching STEM has unique challenges, but the rewards that students receive — for example, satisfaction from accomplishing a worthwhile task and solving a real-world problem — from quality STEM instruction are tremendous.

STEM education is more than just a bundle of subjects, though. When done right, this education is also a student-centered approach to learning that emphasizes authentic, real-world problem-solving tasks that deeply engage the students.

In this chapter, I start by diving into the meaning of STEM education and then explore why teaching STEM enables teachers to get at important skills that traditional approaches often overlook. You find out how STEM lessons can help to motivate learning among students. Also, you discover how STEM approaches redefine the traditional classroom experience.

Thinking about the Meaning of STEM

What do you think of when you think of a STEM class? Do you picture a classroom with math equations written neatly on a dry-erase whiteboard? A clean and orderly science lab with beakers and test tubes? Students building a bridge out of craft sticks, straws, pipe cleaners, and cardboard? A cluttered workshop with a half-built robot? High-tech drones flying through an obstacle course?

TIP

Depending on their backgrounds, any two people can have starkly different images of what it means to teach STEM. Any time you discuss STEM with others, take some time to make sure that they are aware of their preconceptions. You want to be talking about the same thing.

Core STEM subjects

At the heart of STEM are four core subject areas that make up the acronym. Here are definitions that I use as a jumping-off point.

- **Science:** Systemic approach to studying the structure and behavior of the natural and physical world, through a mix of observation and experimentation.
- **Technology:** Study of making modifications to objects or structures in the natural world toward a human-driven goal.
- **Engineering:** Systemic and iterative approach to designing objects, processes, and systems toward a human-driven goal, emphasizing design under given constraints.
- **Mathematics:** Study of numbers, shapes, and patterns, as well as the abstract and concrete relationships between these concepts and their quantities.

Though schools have included mathematics and science for as long as anyone can remember, only in more recent years have schools demonstrated an explicit drive to loop in engineering and technology, even starting in early elementary school grades.

REMEMBER

Within the STEM paradigm, these four subject areas are not independent silos, isolated from each other and united only by a clever acronym. The point of using the acronym *STEM* is to highlight the underlying connections between these four areas. Some of the connections are obvious — such as the key role mathematics plays in both engineering and science — but some connections are far more subtle (for example, structural similarities between scientific experimentation and engineering design processes).

ACRONYM ORIGINS

The acronym STEM came from those rascals at the U.S. National Science Foundation (NSF), but when they began referring to the concept in the 1990s, they actually used the acronym SMET. In a way, this acronym made more sense because science and mathematics were more well-established as educational subjects, and the goal was to point out the need for greater emphasis on engineering and technology.

Around 2001, American biologist Judith A. Ramaley, assistant director of education and human resources of the NSF, decided to reorder the words to form the acronym STEM. This acronym caught on more broadly and took hold in the ensuing movement to expand teaching in these areas.

Is it a coincidence that a biologist changed the acronym to match the part of a plant? Probably. Regardless, everyone should be very grateful, because talking about STEM just feels better than talking about SMET.

I unpack each of these areas a bit more in Chapter 2 and dive into the related academic standards in Chapter 3. A far more intensive look within each category, and how they integrate together, comes in Part 2.

What different people mean when they say STEM

The four core areas of STEM cover a wide range of human activity, so when people apply the term *STEM*, they might be using it in different ways. Some people have an expansive definition of STEM (encompassing everything that includes any hint of these subjects), while others have a more restricted one (referring to only hands-on projects in a standalone STEM class that is designed to touch on *all* of these domains). In general, throughout this book, I take a pretty expansive definition of STEM. In other words, a mathematics class is a STEM class and benefits from incorporating recognized STEM educational practices into it — including finding ways to incorporate other STEM elements.

To be a little more specific, some people use related terms that may help to clarify or expand on the traditional (and potentially vague) acronym of STEM and related educational areas.

These related terms include the following.

- **STEM subject:** A subject or class such as science, mathematics, algebra, biology, or computer science, which falls squarely within one of the four categories.
- **Integrated STEM:** At least two STEM areas combined together, possibly in combination with another area such as art, literature, or social studies.
- **STEAM:** Acronym for Science, Technology, Engineering, Art, and Mathematics, with an emphasis on highlighting the role of creativity.
- **STEAMM:** Acronym for Science, Technology, Engineering, Art, Mathematics, and Music, which is like STEAM but also highlights the musical arts.
- **STEMM:** Acronym for Science, Technology, Engineering, Mathematics, and Medicine, focusing on the medical sciences and service fields as a separate discipline.
- **Career and Technical Education (CTE):** Related to teaching skilled trades and career preparation, particularly those areas with specific technical requirements. At one time, schools referred to these areas as *vocational arts* or *shop class*.
- **The Maker Movement:** Cultural and educational movement that emphasizes construction, design, and invention, with a large overlap with the Do-It-Yourself (DIY) culture.

People can feel passionate about their particular acronym or phrasing, and since the goal with all of this is to make sure that students are engaged and learning, I generally find that getting into an argument over exactly what wording you're using isn't worthwhile. See the sidebar, "STEM, STEAM, and Creativity," for more thoughts about the use of various acronyms.

REMEMBER

I mainly use the STEM acronym throughout this book. And I don't intend to exclude the importance of artistic and other aspects to the problem-solving and critical-thinking processes.

Helping Students Acquire Necessary Skills

One way to think about education involves wanting kids, by the time they get out of high school (or college, if that's their path), to be the kind of people that you'd be happy to have as a neighbor or coworker. . .or both! Heck, you might even have them as an in-law!

Toward this goal, society evolved an educational system in which students participate in a little over a decade of education. During this time, teachers (and parents) strive to impart the civic and intellectual skills that will achieve this end — that of producing people who are well-adapted to both the job market and civic life.

But which skills do educators actually focus on? And how does STEM help impart those skills?

Academic skills

Most people naturally think of classes as focusing on teaching academic skills. Classes in school are named for the academic subjects, after all. STEM education is firmly rooted in teaching the academic disciplines, and teaching them with a high level of rigor, so nothing about teaching STEM means moving away from that. However, it may mean thinking about those academic disciplines and assessing those academic skills in less-traditional ways.

Sometimes, very bright kids just don't fit the mold of traditional students. Some very smart kids who can explain things well in discussions freeze up when taking tests. Or kids may test well but have grades that reflect an inability to turn in homework rather than a lack of knowledge.

Here's how the STEM approach steps in to help out all students.

REMEMBER

- **It focuses on learning *and* doing:** One of the major goals of a STEM approach to education is to embed crucial academic skills in authentic, real-world problem-solving tasks. The learning and the doing of the task are mixed together, so it's very hard for any student to just coast on through without participating.
- **It advances skills to a higher level:** The academic skills themselves move beyond just the memorization of facts. *How* you know or do things is just as important as *what* you know or do. More details on this concept in Chapter 2.
- **It benefits kids across the ability spectrum:** Students who traditionally do well academically are successful in applying their knowledge in the real world. Students who haven't traditionally thrived academically have a new path, with practical activities giving context for previously esoteric knowledge.

Collaboration and employability skills

One other major element of STEM instruction is that it often moves away from a traditional individual approach (in which each student is working on their own task) to a structure that was once the bane of all overachievers — the *group project*.

Most people that I know have a negative view of group projects, and that's largely because the people they work with on the projects (the group) have let them down so many times. Historically, teaching collaboration and teamwork skills haven't been a strong component of classroom instruction.

Early education focuses on basic social skills such as getting along, but actually working productively in a group involves more than just not shoving your partner. These group collaboration skills rarely have been a point of explicit emphasis in traditional classroom instruction once you pass into upper elementary school.

REMEMBER

This lack of focus on collaborative skills makes sense in an environment in which science education looks primarily at acquiring knowledge and memorizing facts. When you need to know if each kid has memorized the facts, mixing a bunch of them to work together muddies the water, because you don't know for sure who contributed what. But when the process is just as important as the facts (like in the STEM approach), space opens up for different groups to explore different approaches and find those that work.

STEM, STEAM, AND CREATIVITY

The STEAM acronym has become increasingly popular in recent years. Solving a problem or designing something is inherently a creative act. When given an open-ended problem, groups of people approach it from wildly divergent paths.

As a result, I don't think the "Art" needs to be added in to STEM for you to know that designing and artistic creativity are part of the process. Creativity should be a natural part of the engineering design process (see Chapter 6). So, calling the educational approach STEAM is mostly about messaging.

Could a problem arise when using the STEAM acronym? My only reservation to this term stems from seeing a "STEAM project" that is little more than an art project about a vaguely science-adjacent concept. You could do a dozen such projects and feel like you've accomplished a lot of STEAM, even if you have perhaps touched only slightly on the deep learning of STEM concepts.

For more about integrating the arts and STEM together, see Chapter 8.

You can find out more about these skills in Chapter 2, and then about how to teach (and assess) them throughout Part 3.

Embracing the Challenge (and Promise) of STEM Education

In addition to teaching skills, STEM education meets students where they are and reinforces certain core educational values that will benefit them throughout their lifetimes. I cover these and more benefits of STEM education in greater depth in Chapter 2.

Establish a culture of learning

One sign of a successful, STEM-centered classroom is that students are continually looking for questions to ask, ideas to explore, and things to learn about. You don't want them to passively receive information but instead recognize knowledge as something that they can actively seek out.

Throughout the book, I return to this idea of creating a culture of learning (particularly in Chapters 9 and 13), but here are three key elements you can think about incorporating into your teaching approach immediately:

- **Encourage intellectual risk-taking.** You might reward students who go out of their way to present an idea that seems out-of-the-box in some way. Instead of quickly dismissing such thinking to get on with the required lesson, validate such unorthodox ideas. You can maybe even spend some time discussing their implications and how you might be able to test or explore them (before returning to the lesson).
- **Always create a central focus on student questions.** For example, maintain a physical space, such as a guiding questions board, where students can pose questions. Some questions will be resolved quickly, but others might linger and provide motivation for future lessons.
- **Empower students to look for multiple answers.** Give them an opportunity to brainstorm and come up with as many possible answers before moving on to the stage of resolving whether any specific answer works.

WARNING

Often, teachers find themselves unintentionally thwarting these key elements through applying too much emphasis on getting the facts into the students' brains as quickly and efficiently as possible. And it's understandable, largely due to structural elements of the school day. Teachers have a lot of material to get through, often moving along at a set pace to meet defined learning objectives throughout the year. The neuroscience of learning (see Chapter 9) tells us that taking more time on the initial learning actually helps solidify the information more firmly in the learner's mind.

Encouraging questions is worth the risk

Though I love the saying, "There's no such thing as a stupid question," the reason it gets used so often is that people — both kids and adults — are constantly terrified that they're asking stupid questions. It can be incredibly difficult to ask a question in front of a group of people, especially when you sort of suspect that most of them actually know the answer and that you're revealing your ignorance.

TIP

One goal of a classroom should absolutely be that students feel intellectually safe. It is crucial that students not only feel comfortable displaying their knowledge, but also (and perhaps more importantly) demonstrating, acknowledging, and explaining their ignorance.

WARNING

Of course, this doesn't mean that a student should get by with being rude in the guise of asking questions. You don't have to tolerate an inherently offensive question like "Why is Andrew such an idiot?" just because you're trying to establish a question-asking culture.

Helping kids become question machines

I once heard a famous cosmologist (and also a parent) make the joke that, at some point, the answer to the question of "Why?" is "Go to bed." Kids, by nature, ask questions as a means of engaging with the unknown parts of the world — that is, until they are taught that asking those questions isn't acceptable.

As a teacher, you have no control over the messages kids are getting from their families, their friends, or the media they consume . . . but you can control how you're presenting things in your classroom.

Make sure that questions aren't just allowed but *encouraged*. Almost any lesson that you're doing can contain a couple of minutes in which you solicit a list of questions related to the subject. I cover some specifics on how to approach encouraging questions in Chapter 9.

TIP

Students who discover that asking questions is valuable don't just stop asking questions when the bell rings. After you establish that culture of learning, it increases student engagement in all areas. Students will also be inclined to ask questions about world and historical events, or about literature they're reading.

Turning students into answer seekers

It might seem like all of these new student-generated questions can only compound the frustration. How are you going to get through all the material you need to cover? But wait! Though they are comfortable asking you those questions, they aren't actually dependent upon you to give them the answers. In fact, answering all the questions is no longer your job! Your job has now become giving them the tools, resources, and space to figure out the answers on their own.

REMEMBER

Being the source of answers to all student questions short-circuits the goal. You don't want to teach them that they can easily get answers to questions from an authority figure. You want to teach them how to figure out strategies to find the answers. Asking the question sets the student's mind on high alert to look for a path to the answers. If the student is mentally alert when engaging with the subject to ask questions, then that means they're also going to be looking for the answers to those questions.

Motivate students with engaging lessons

When you put the students' hands to work, you get their brains for free! And STEM lessons are great at giving students something to do with their hands, and then dragging the brain along for the ride.

TIP

Developing STEM lessons, particularly on the first try, might take some extra preparation compared to other types of lessons. For one thing, you often have to gather materials, or plan for the availability of necessary technology. But after you get the project (lesson) going, the students should really begin diving into it and taking ownership. This student engagement gives you the freedom to focus on the students who need help while other groups are able to progress on their own.

Throwing Out the Old Rulebook

You likely have a memory of a fairly traditional classroom experience, and one of my goals throughout this book is to challenge the assumption that the way you learned was the best way to learn. Or, at the very least, to challenge the idea that it was the *only* way to learn.

Despite all the changes that have taken place in classrooms over the years, if you walk into a traditional classroom in most of America today, you won't recognize a huge number of fundamental differences from fifty years ago. Yes, there are a few. Kids have computers and fewer books. Teachers are more likely to arrange desks in groups than orderly rows. Dry-erase whiteboards have replaced chalkboards, and overhead projectors are now digital.

But it's often still a teacher at the front of the class lecturing students. The big change in delivery comes from the occasional video.

Some of the changes noted are improvements, to be sure, but they also don't inherently transform education. A student half-listening to a lecture isn't significantly worse than a student half-listening to a video.

As you read through this book, I challenge you to think about what a classroom learning environment would be like if the students were actively engaged in the lessons. Is there a way to modify the approach to education that centers on the student, by elevating them as the owner of their learning?

My hope is that, by reading this book, you see that STEM provides a foundation for throwing out the old rulebook and building exactly the sort of engaging classroom that we need to educate future generations of lifelong learners.

IN THIS CHAPTER

- » Understanding the elements of STEM
- » Embracing STEM education principles
- » Exploring benefits gained from STEM

Chapter 2
What STEM Is (and Why It Matters)

Shortly after I became a district STEM coordinator, one of the teachers said to me, "I really love STEM, but I hate math." To her, STEM clearly meant something that didn't include mathematics (or, at the least, didn't include a traditional math class). Similarly, I've heard people ask questions like, "Is this lesson science or STEM?" So, some people draw distinctions that I wouldn't, because (as I say in Chapter 1) I use the term *STEM* expansively, and to me, every single science lesson and math lesson could be a STEM lesson, even in a standalone science or math class.

In this chapter, you find a broad overview of the meaning of STEM from a variety of perspectives. You find out about the core principles of STEM education that differentiate it from more traditional academic approaches. And you discover the most significant benefits that students can gain from engaging directly with STEM education.

Describing Core STEM Concepts

If you spend any time talking with people about STEM education, you may realize that different people use this acronym in different ways. Suppose you talk to three people; each could be thinking about just one of the following aspects of STEM:

- A collection of separate, individual math and science classes
- A standalone integrated STEM class
- A certification program for a STEM-related profession

From my perspective (and I'm the one writing the book), none of these three hypothetical people are wrong in their use of STEM to name the aspect that they're describing. But they could become confused if they're engaged in conversation with each other because they're thinking of slightly different interpretations (of the term *STEM*) and will certainly face different challenges when dealing with the various aspects of STEM.

TIP

The easiest thing to recognize about STEM is that it's an acronym standing for Science, Technology, Engineering, and Mathematics. Some of these component subjects have always been included in a school curriculum, and others may seem a bit more exotic — and intimidating to teach.

As intimidating as each area is to teach on its own, you also encounter the complication that the boundaries between the component subjects of STEM can be fuzzy. Doesn't engineering depend in part on understanding scientific principles? Doesn't mathematics play a key role in computer programming and scientific experiments? Isn't technology used heavily in science? If you're asking these questions, you're right to do so!

REMEMBER

No clear dividing lines exist between these four subject areas. They constantly touch upon and influence each other. One of the major goals of this book — and the STEM movement in general — is to try to increasingly think of how to teach these concepts together as one single unified whole, without introducing artificial barriers between them.

In the following sections, I explore each component STEM subject in turn and set a foundation for the deeper dive into each of them that you can find in Part 2 of this book.