Chapter 1

Why STEM Should Become STEAM

It is by intuition that we discover and by logic we prove.

—Jules Henri Poincaré, French mathematician (1854–1912)

We have never discovered a culture on this planet, past or present, that doesn't have art in some form. Yet there have been a number of cultures—even some existing today—that do not have reading and writing. Why is that? One likely explanation is that the cognitive, physical, and emotional activities represented by the arts—dance, music, drama, and visual arts—are basic to the human experience and necessary for survival. If they weren't, why would they have been part of every civilization from the Cro-Magnon cave dwellers of 35,000 years ago to the urban citizens of the twenty-first century? (Please see Table 1.1.)

Table 1.1 Public often sees STEM and the arts as having opposite characteristics.

STEM	Arts
Objective	Subjective
Logical	Intuitive
Analytical	Sensual
Reproducible	Unique
Useful	Frivolous

Science, the scientific method, and mathematics, on the other hand, are more recent developments. Around 4,000 years ago, the Babylonians recorded the motions of the moon, planets, and stars on clay tablets. The ancient Egyptians and Chinese made significant advances in astronomy and mathematics. Variations of the scientific method—as we currently describe it—evolved during the Middle Ages in several cultures. Arts and sciences do not compete; they are complementary. The arts create a very subjective view of the world, while science creates an objective view of the world. A person's brain needs both views in order to make suitable decisions.

Few people will argue against studying the natural sciences and mathematics in the elementary and middle schools, and support remains strong for these subjects—including Advanced Placement courses—in high schools. We wish to make clear that we support initiatives that enhance K–12 STEM courses. Recent data show that although there are 3.6 unemployed workers for every job in the United States, there is only one unemployed STEM worker for two *unfilled* STEM jobs (Change the Equation, 2012). There are many STEM-area jobs going unfilled because we do not have the skilled workers for them. Clearly, we need to improve our teaching in the STEM areas.

However, our concern is that when budgets get tight, some people view music and other arts courses as a drain on the funds needed to preserve STEM—especially science and mathematics courses. They often see STEM and the arts as polar opposites. The STEM areas are thought of as objective, logical, analytical, reproducible, and useful. The arts, on the other hand, are supposed to be subjective, intuitive, sensual, unique, and frivolous. In the budgetary competition between the arts and STEM in U.S. schools, the arts have frequently lost.

Figure 1.1 summarizes a recent report by the U.S. Department of Education noting that fewer public elementary schools are offering visual arts, dance, and drama classes during the decade of 2000 to 2010, a decline many attribute to budget cuts and an increased focus on reading and mathematics (Parsad & Spiegelman, 2012). During the decade, the percentage of elementary schools with a visual arts class declined from 87 percent to 83 percent. Although the decline in the *percentage* of schools offering music is not that great, the *amount of time* devoted to music instruction dropped dramatically, typically from three to five periods a week to just one or two.

The drop in drama was larger, from 20 percent to only 4 percent in the 2009–2010 school year. Dance slid from 20 percent to just 3 percent in that same time period. Although dance and drama/theater dropped dramatically during the decade as stand-alone subjects in elementary schools, they

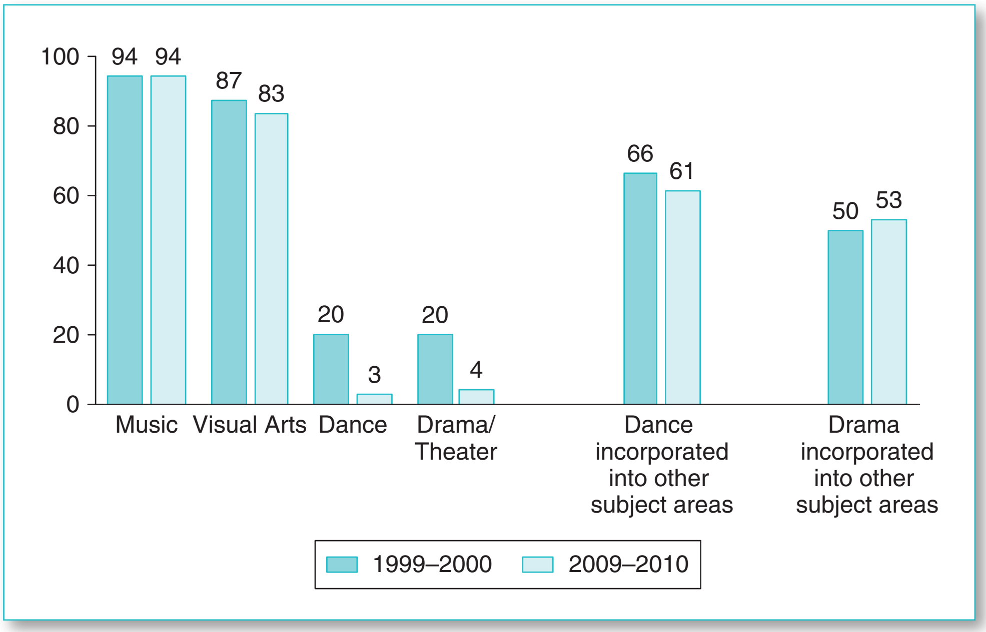


Figure 1.1 Percentage of public elementary schools with arts classes 1999–2000 and 2009–2010.

continued to be incorporated into other subject and curriculum areas. Music classes at the elementary and secondary schools remained steady, but there were noticeable declines in the nation's poorest schools. Just a decade ago, 100 percent of the poorest high schools had music classes, while today that number is down to 81 percent.

THE POWER OF THE ARTS

Many scientists, mathematicians, and engineers know that the arts are vital to their success, and they use skills borrowed from the arts as scientific tools. These include the ability to do the following:

- Draw on curiosity.
- Observe accurately.
- Perceive an object in a different form.
- Construct meaning and express one's observations accurately.
- Work effectively with others.
- Think spatially (How does an object appear when I rotate it in my head?).
- Perceive kinesthetically (How does it move?).

These skills are often not expressly taught as part of STEM courses, but they are at home in writing, drama, dance, painting, and music.

The Real Purpose of Schooling

We should remember that the real purpose of schooling is to prepare students for their life *after* high school, whatever their choice may be. Too often, we look at schools as mainly college preparatory institutions. But we should keep the following statistics in mind:

> ***The real purpose of schooling is to prepare students for their life* after *high school.***

- Almost 25 percent of students enrolled in U.S. high schools drop out *before* graduating (Chapman, Laird, Ifill, & KewelRamani, 2011). What will they do? Will what they learned in high school help them succeed?
- U.S. Department of Education surveys show that in 2009, only about 70 percent of high school graduates went on to college (U.S. Department of Education, 2011). That means that about 30 percent go into the workforce or some other field of endeavor. Are they adequately prepared?
- A growing number of students drop out of college in their first or second year. What will they do next?

We will discuss more about high school instruction in Chapter 6. Our point now is that, although we encourage all students to get as much formal education as possible, providing all high school students with exposure to arts-related activities may give those who do not go on to college the incentive to pursue opportunities in the arts or arts-related fields. Numerous well-known artists in all fields never went to college but became famous for their artistic work nonetheless. A few examples are Ansel Adams (photographer), Ben Affleck (actor), Edward Albee (playwright), Irving Berlin (songwriter), James Cameron (director), Tom Cruise (actor), Bil Keane (cartoonist), and Claude Monet (painter).

The Arts Are Basic to the Human Experience

As we learn more about the brain, we continue to find clues as to why the human activities required for the arts are so fundamental to brain function (see Figure 1.2).

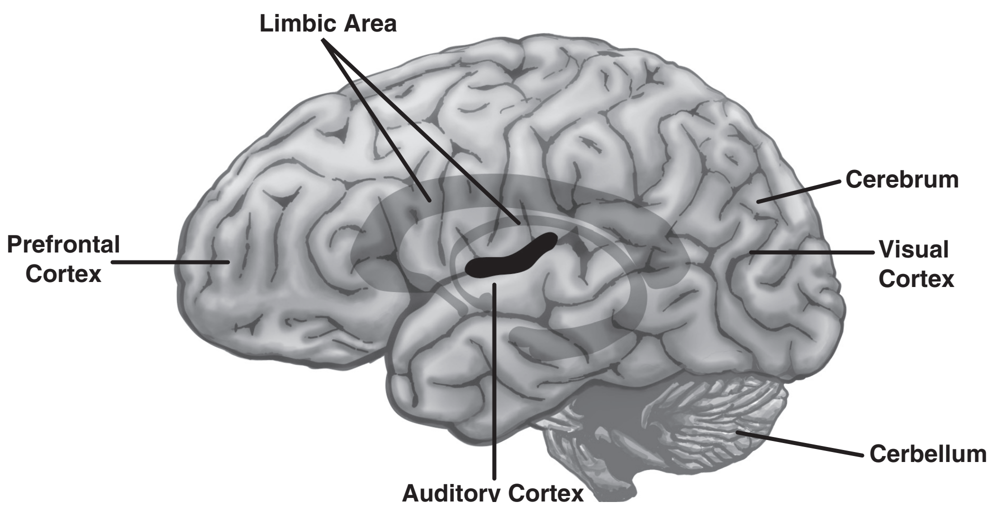


Figure 1.2 Diagram with parts of the brain mentioned in this section labeled.

- *Music:* It seems that certain structures in the auditory cortex respond only to musical tones.
- *Dance:* A portion of the cerebrum and most of the cerebellum are devoted to initiating and coordinating all kinds of learned movement, from intense running to the delicate sway of the arms.
- *Drama:* Specialized areas of the cerebrum focus on spoken language acquisition and call on the limbic system (the emotional control center) to provide the emotional component.
- *Visual Arts:* The internal visual processing system can recall reality or create fantasy with the same ease.

Meanwhile, the prefrontal cortex of the frontal lobe—the brain's executive control area—coordinates all this information to help the individual make appropriate decisions.

These cerebral talents did not develop by accident. They are the result of interactions over thousands of years between humans and their environment, and the continued existence of these talents must indicate they contribute in some substantial way to our survival. In those cultures that do not have reading and writing, the arts are the media through which that culture's history, language, mores, and values are transmitted to the younger generations and perpetuated. They also transmit more basic information necessary for the culture's survival, such as how and what to hunt for food and how to defend the village from predators.

Consequently, the arts are an important force behind group survival. For example, due to its fractured landscape, about 1,000 of the roughly 6,500 languages on this planet are spoken in just one place—New Guinea! Each language is totally unrelated to any other known language in New Guinea (or elsewhere) and is spoken by a tribe of just a few thousand people living within a 10-mile radius. Even more astonishing is that, despite their isolation, each tribe has its own music, visual arts, and dance (Diamond, 1992). These arts-related activities give the tribe its identity and its individuals a sense of belonging.

Our brain has developed elaborate neural networks to process both language and music as forms of communication.

In modern cultures, the arts are thought of rarely as survival skills, but rather as frills—the aesthetic product of a wealthy society with lots of time to spare. In fact, people pay high-ticket prices to see the arts performed professionally, leading to the belief that the arts are highly valued. This cultural support is often seen in high schools, which have their choruses, their bands, their drama classes, and an occasional dance troupe. Yet seldom do public elementary and middle schools enjoy this continuous support, precisely when the young brain is most adept at refining the skills needed to develop artistic talent (several private school initiatives have been the exception, most notably the Montessori schools and the Waldorf schools). Furthermore, when school budgets become tight, elementary and middle level art and music programs are among the first to be reduced or eliminated. Now, pressure to improve reading and mathematics achievement is prompting elementary schools to trade instruction in the arts for more classroom time in preparation for high-stakes testing. Apparently, state testing programs believe it is much more important for a student to know the letters that make up words and sentences but not the notes of the scale that produce a melody. Yet our brain has developed elaborate neural networks to process both language and music as forms of communication. Why would that be if both were not biologically important (Sylwester, 2007)?

This trade-off does not make sense in light of the emerging research on how the arts assist in developing the young brain. We will first explore the arguments for teaching the arts—whether they be taught as separate courses or infused with other subjects, or both—and then suggest how including the arts can help students be more successful in learning the concepts associated with the STEM subjects.

Why Teach the Arts?

The basic arguments we make here are these:

- The arts play an important role in human development, enhancing the growth of cognitive, emotional, and psychomotor pathways in the brain.
- Schools have an obligation to expose children to the arts at the earliest possible time and to consider the arts as a fundamental—not an optional—curriculum area.
- Learning the arts provides a higher quality of human experience throughout a person's lifetime.
- The arts evoke emotions, and we know that emotions enhance learning and increase retention.

> ***The arts develop . . . creativity, problem solving, critical thinking, communications, self-direction, initiative, and collaboration.***

The skills that the arts develop include creativity, problem solving, critical thinking, communications, self-direction, initiative, and collaboration. All these skills—which align with what many educators now refer to as "twenty-first century skills"—will be needed by every student in order to survive successfully as an adult in an increasingly complex and technologically driven world.

The Olympics Once Honored the Arts

Walter Winans' first Olympic medal in the 1912 Summer Olympics in Stockholm was the silver medal for sharpshooting (Stromberg, 2012). When he took the winner's podium a second time, it was to receive a gold medal awarded for a small bronze statue of a horse pulling a chariot. Winans had won the first ever Olympic gold medal for sculpture. How did this happen? Baron Pierre de Coubertin, the founder of the modern Olympic Games in 1894, was well aware that the ancient Olympic Games in Greece included contests of art, and they were equal in prestige to the sports competitions. By 1912, he was able to convince the Olympic committee to include medal awards for works submitted in the areas of music, painting, architecture, literature, and sculpture. The only condition was that the work had to be inspired by the concept of sport.

The awards continued for nearly four decades, but were discontinued after the 1948 games. Ironically, the Baron's idea still lingers. For the 2012 Summer Olympics in London, artists were invited to send sculptures and graphic works on the theme "Sport and the Olympic values of excellence, friendship, and respect." No medals were awarded, but the winners received cash prizes, and their work was displayed in London during the games.

Even today, the arts are important to the Olympic Games. Just think of how the arts are needed in designing the winners' medals, the venues, the logo, the torches, the cauldron, and the athletes' outfits; in designing and making the costumes and directing the choreography for the opening and closing ceremonies; and in writing and selecting the music for the ceremonies and gymnastic competitions. The Olympic Games still place value on the arts; shouldn't our schools do the same? Figure 1.3 shows the major reasons why we should ensure that the arts remain available for all students at all grade levels.

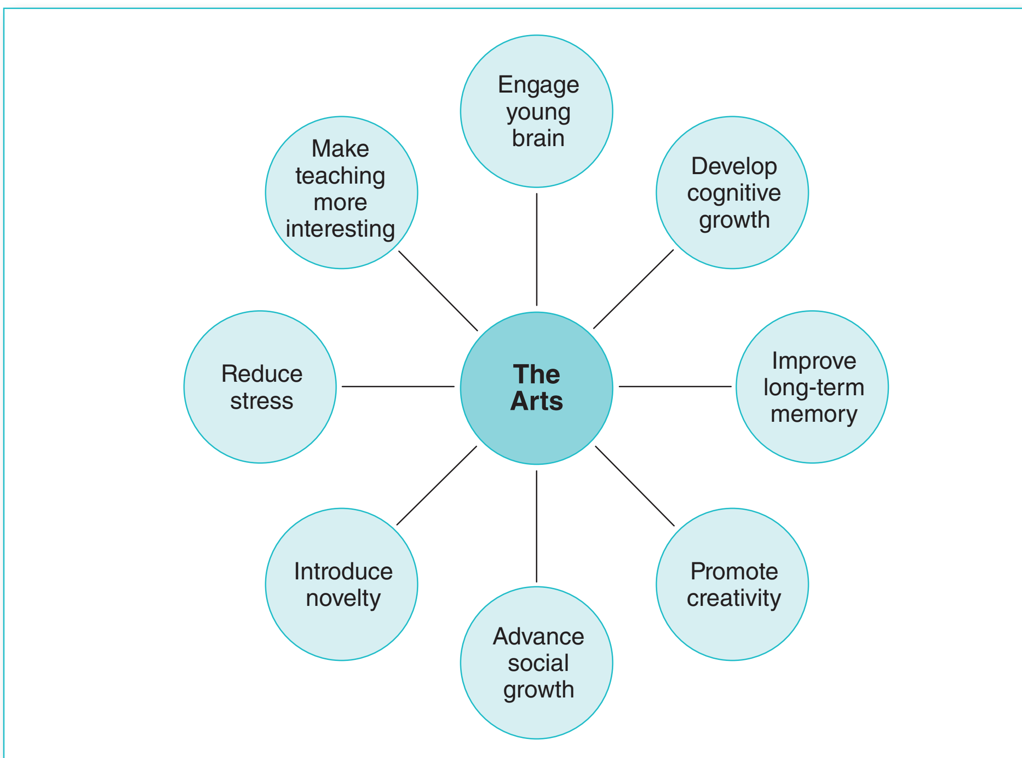


Figure 1.3 The diagram illustrates the reasons why the arts should remain available for all students at all grade levels.

The Arts Engage the Young Brain

During a child's early years, there is an explosive growth of cell branches and connections within the brain. Much of what young children do as play—singing, drawing, dancing—are natural forms of art. These activities engage all the senses and help wire the brain and create the neural networks needed for successful learning. When children enter school, these art activities need to be continued and enhanced. Cognitive and visual-spatial areas are developed as the child learns songs and rhymes and creates drawings and finger paintings. Dancing and movements during play develop those gross motor skills necessary for survival.

Music can also help young students remember information, such as learning the alphabet through song. Color is also a powerful way to help with remembering information, such as the states of the union and their capitals or the planets in our solar system. The sum of these activities enhances emotional well-being.

The arts also contribute to the education of young children by helping them realize the incredible breadth of human experience around the globe. They begin to recognize the different ways humans express sentiments and convey meaning, and they start to develop subtle and complex forms of thinking (Eisner, 2002b).

The Arts Develop Cognitive Growth

> ***The arts . . . are a collection of skills and thought processes that transcend all areas of human engagement.***

Although the arts are often thought of as separate subjects, like chemistry or algebra, they really are a collection of skills and thought processes that transcend all areas of human engagement. When taught well, the arts develop cognitive competencies that benefit learners in every aspect of their education and prepare them for the demands of the twenty-first century. Elliot Eisner (2002a) of Stanford University identifies these eight competencies:

- *The perception of relationships.* Creating a work in music, words, or any other art discipline helps students recognize how parts of a work influence each other and interact. For example, this is the kind of skill that enables an executive to appreciate the way a particular system affects every other subsystem in an organization. This skill also helps a biologist recognize how shifts in one part of an ecosystem can affect several other parts of that system or even other systems as well.

- *An attention to nuance.* The arts teach students that small differences can have large effects. Great amounts of visual reasoning go into decisions about nuance, form, and color to make an art work satisfying. In writing, similarly, great attention to detail in use of language is needed to employ allusion, innuendo, and metaphor. Think how helpful this skill is, for example, to a scientist who is trying to explain a difficult abstract concept to nonscientists.
- *The perspective that problems can have multiple solutions, and questions can have multiple answers.* Good things can be done in different ways. Schools too often emphasize learning focused on a single correct answer. In business and in life, most difficult problems require looking at multiple options with differing priorities and recognizing that each potential solution may have both positive and negative consequences.
- *The ability to shift goals in process.* Work in the arts helps students recognize and pursue goals that were not thought of at the beginning. Too often in schools the relationship of means to ends is oversimplified. Arts help us see that ends can shift in process.
- *The permission to make decisions in the absence of a rule.* Arithmetic has rules and measurable results, but many other things lack that kind of rule-governed specificity. In the absence of rules, it is personal judgment that allows one to assess what feels right and to decide when a task is well done.
- *The use of imagination as the source of content.* Arts enhance the ability to visualize situations and use the mind's eye to determine the appropriateness of a planned action.
- *The acceptance of operating within constraints.* No system, whether linguistic, numerical, visual, or auditory, covers every purpose. Arts give students a chance to use the constraints of a medium to invent ways to exploit those constraints productively.
- *The ability to see the world from an aesthetic perspective.* Arts help students frame the world in fresh ways—like seeing the Golden Gate Bridge from a design or poetic angle.

In the time since Eisner enumerated these competencies, neuroscientists have been developing theories about ways in which art develops cognition.

One common element of the current theories is that each art form involves different brain networks, as shown in Figure 1.4 (Posner, Rothbart, Sheese, & Kieras, 2008). Visual arts are processed mainly in the occipital lobe (the rear part of the brain) and in the temporal lobes (just behind the ears). Linguistic arts (e.g., prose writing and poetry) involve Broca's and Wernicke's areas (the dotted-line ovals)—which are the primary language areas of the brain. Movement arts are processed through the motor cortex, a thin strip across the top of the brain, indicated by the dotted lines. Music is processed by the auditory cortex, located in the temporal lobes.

Using techniques with children that record the brain's electric signals (called electroencephalography or EEG), the researchers discovered that arts training required the children to focus and that this concentrated attention improved cognition. Thus, children who begin participating in arts training at an early age get the benefit of improving their cognitive growth while their brain is still developing. In addition, the arts often involve powerful emotions, and such emotions enhance cognitive processing and long-term memory.

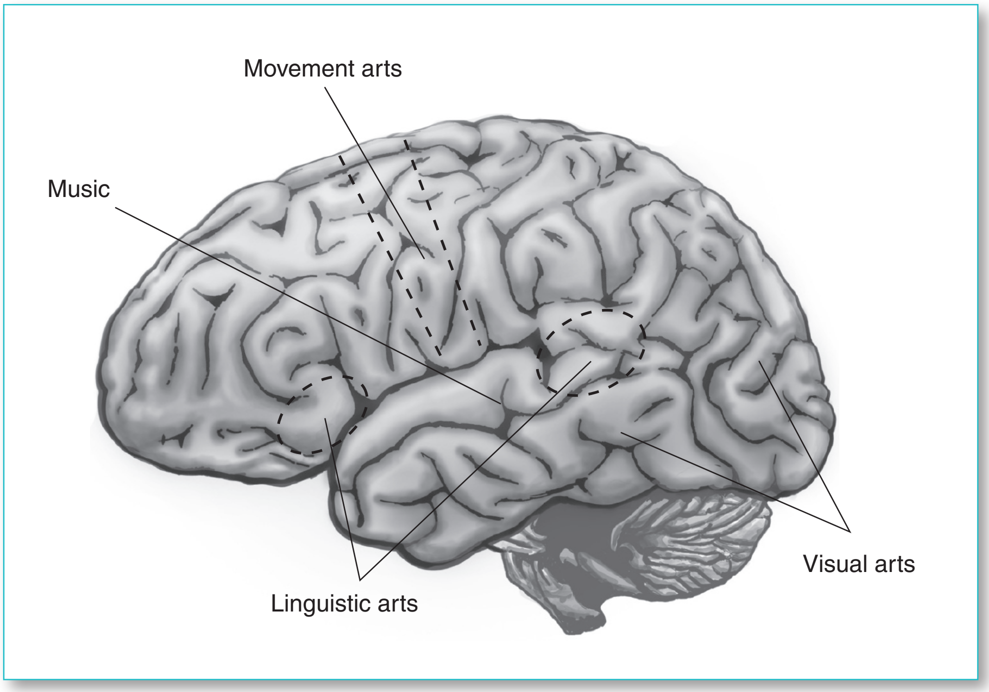


Figure 1.4 The different brain networks.

Source: Adapted from Posner et al. (2008).

At-Risk Students

The impact of arts education can begin as early as preschool. Two studies carried out by the same researchers examined the effects of arts enrichment on school readiness with at-risk preschool students (Brown, Benedett, & Armistead, 2010). The first study looked at achievement within an arts enrichment preschool that served low-income children. These students practiced school readiness skills through early learning of music, creative movement, and visual arts classes. Students who attended the preschool for two years demonstrated higher achievement than those who attended for one year, suggesting that brain maturation alone did not account for the gains in achievement. During the two years that the students attended the program, they were assessed four times. Assessment results continually showed that the students improved in school readiness skills. Furthermore, there were no significant effects of race, ethnicity, or developmental level on the growth of their achievement.

The second study compared students attending the arts enrichment preschool to those attending a nearby alternative school on a measure of receptive vocabulary—one that has been found to predict school success. At the end of just one year of attendance, students in the arts program showed greater receptive vocabulary than those at the comparison preschool.

> ***[There is a] strong association between participation in the arts and a wide variety of positive outcomes.***

Perhaps the most impressive study of how arts involvement helped the achievement of at-risk students is the one supported by the National Endowment for the Arts (Catterall, 2012). For the purposes of this study, "at-risk" was defined as those students in the bottom 25 percent of the socioeconomic scale, as measured by their parents' level of education, their employment, and family income. This large study used information from four separate databases, which followed students for a number of years. Three of the databases tracked the students' activities in high school as well as their achievements in early adulthood.

Researchers found a remarkably strong association between participation in the arts and a wide variety of positive outcomes. For instance, students who had rich experiences in the arts during high school showed higher overall grade point averages (GPAs) than did students who did not have those experiences. They even had slightly higher-than-average GPAs in mathematics. Furthermore, the higher grades paid off because the high school students heavily involved in arts-related activities had higher rates of enrollment in competitive colleges—71 percent compared to 48 percent enrollment for their peers who avoided the arts. Not surprisingly, those students in the top 25 percent of the socioeconomic scale also benefited from arts-rich experiences. They had significantly higher GPAs and enrollment rates in colleges than their low- or no-arts peers.

Researchers in this study came to the following noteworthy conclusions:

- Socially and economically disadvantaged children and teenagers who have high levels of arts engagement or arts learning show more positive outcomes in a variety of school-related areas than their low-arts-engaged peers.
- At-risk teenagers or young adults with a history of intensive arts experiences show achievement levels closer to—and in some cases exceeding—the levels shown by the general population in these studies.
- Most of the positive relationships between arts involvement and academic outcomes apply only to at-risk populations (i.e., low socioeconomic status or SES). But positive relationships between arts and civic engagement are noted in the high-SES groups as well.

Of course, these results do not necessarily establish cause and effect. It is possible that the same factors that lead some students toward the arts also make them more likely to excel in other subject areas as well. However, it is also possible that engagement with the arts provides the motivation, stimulation, and satisfaction that have an impact far beyond the arts' classroom.

These findings strongly suggest that an arts enrichment curriculum component may have a positive impact on early brain development and organization, resulting in better educational outcomes for children at risk.

Music

Remember the hype a few years back about music and its ability to raise intelligence—the so-called Mozart effect? What the media failed to report is that the modest boost in test scores for those students who listened to Mozart during the test dissipated after several hours. Nonetheless, the effect raised an interesting question among neuroscientists: In what ways, if any, does music influence the developing brain? Actually, for years researchers have been reporting positive associations between musical experience and cognitive growth in nonmusical areas among young children. But it is important to note that any long-term impact of music on cognitive growth comes from *taking* music lessons over time, which is distinct from the short-term effect of *listening* to music (Schellenberg, 2003). One example of such studies involved more than one hundred second-grade students (Piro & Ortiz, 2009). About half the group studied piano formally in school for three consecutive years. The other half served as the control group and had no exposure to music lessons during that time, either in school or privately. After assessing both groups, the music lesson group had significantly better vocabulary and verbal sequencing scores than did the control group.

Music instruction also appears to help reading by increasing verbal memory—the ability to hold words in temporary memory to complete a thought as one is reading. One study showed that adult musicians had enlarged areas of the brain that are responsible for processing auditory information (Chan, Ho, & Cheung, 1998). Participants in the study with musical training could remember 17 percent more verbal information that those without musical training. The results of a similar study with 90 six- to fifteen-year-old-boys supported these findings (Ho, Cheung, & Chan, 2003). Boys with musical training had significantly better verbal learning and retention abilities. Furthermore, the longer the duration of music training, the better their verbal memory. A follow-up study concluded that the effect was *causal*—that is, the music training caused anatomical changes in the brains of children who were engaged in making music.

Active engagement with music also appears to improve print awareness and writing skills. In one study, children from economically disadvantaged homes participated in instruction that focused on the concepts of print, singing activities, and writing. Participants in the experimental group showed enhanced print concepts and prewriting skills (Standley & Hughes, 1997). Another study replicated this work a few years later with a larger sample of 50 children, and the results again showed significant gains for those students in the music-enhanced instruction in writing skills and print awareness compared to the control group (Register, 2001).

Numerous studies in recent years have shown a strong connection between music and mathematics. For example, one study found that students who had studied a musical instrument prior to fourth grade had higher mathematics scores than those who did not (Haley, 2001). Another study showed that middle school and high school students who were placed in groups with high, moderate, and no music instruction differed in their mathematics achievement (Whitehead, 2001). Those students in the high involvement group showed the greatest gains in mathematics scores.

> ***Research evidence shows a positive connection between music instruction and academic progress.***

Music may also have an impact on the young brain by enhancing overall intelligence, as measured by IQ scores. One significant study randomly assigned a large group of children to four different groups—two of which received standard keyboard and voice lessons for a year (Schellenberg, 2004). Of the two control groups, one received instruction in drama, and the other group had no such lessons. All four groups had the expected increases in their IQ scores that are associated with the growth of children at this age. However, the music groups had larger increases in their IQ scores. Participants in the control groups had average increases of 4.3 points, while those in the music groups had increases of 7 points. Furthermore, the two music groups had larger increases than the control groups on all but two of the twelve subtests. In a large study of more than 4,700 elementary and middle school students across four regions of the United States, researchers found a strong relationship between the academic achievement of third and fourth graders (as measured by their test scores) and their participation in high-quality, in-school music programs (Johnson & Memmott, 2006).

Research evidence shows a positive connection between music instruction and academic progress. However, it should be noted that as supportive as these studies on music instruction and achievement may be, we noted earlier that other factors also contribute to this positive effect. For example, factors such as parents who are musicians or who enthusiastically support their child's interest in music, as well as a stable home environment that is conducive to music study, may have an impact on their child's academic progress. Exactly how much of an impact is still not clear.

The Arts Improve Long-Term Memory

Integrating the arts into other content areas, such as STEM, has been shown in numerous studies to improve long-term retention of content. A review of findings conducted by researchers at Johns Hopkins University found that arts integration significantly improved retention of learning through eight effects (Rinne, Gregory, Yarmolinskaya, & Hardiman, 2011). These effects were (1) rehearsing the information and skills, (2) elaborating that adds meaning to the learning, (3) students generating more information, (4) physically acting out the material, (5) students talking about their learning (oral production), (6) the amount of effort that students are contributing to establishing meaning, (7) the degree of emotional arousal over the learning, and (8) representing the learning in pictures.

These findings add to the growing body of solid research from cognitive science and neuroscience about the value that arts-related activities have in helping students remember what they learn. Too often, we hear STEM teachers tell us that their students do not recall much of what they learned in their classes several months earlier. This is an indication that the information never was encoded into long-term memory. Instead, it was retained in the temporary working memory just long enough to take the test, and then it just faded away. We cannot recall what our brain does not possess.

The Arts Promote Creativity

Several definitions of creativity exist, but most seem to include the notion that creativity is, as the saying goes, thinking outside the box. It includes the ability to use divergent thinking to probe deeply and to find alternative solutions to a problem that were not previously considered. Although creativity comes naturally to some individuals, there is growing realization that creativity *can* be taught. It means, however, putting limits on the common instructional approach in today's classrooms that revolves predominantly around convergent thinking—that is, finding the one correct solution to a problem—and where memorization prevails over deep understanding. Schools should be dedicated more to helping students *think* rather than just *know.*

Neuroscientists who are exploring the nature of creativity suggest that creative thinking involves communication among brain regions that do not normally interact with each other during noncreative thinking. Most creative activities involve the brain's frontal lobe; although researchers agree that there is not one single brain area responsible for creativity (Heilman, Nadeau, & Beversdorf, 2003). Brain wave (EEG) and brain-scanning studies reveal that more brain areas are stimulated when performing creative activities than during conventional activities—especially in areas involved in working memory, cognition, and emotion (Chávez-Eakle, Graff-Guerrero, García-Reyna, Vaugier, & Cruz-Fuentes, 2007; Fink, Benedek, Grabner, Staudt, & Neubauer, 2007).

A key revelation regarding the nature of creativity comes from studies using functional magnetic resonance imaging (fMRI) that explored regions of the brain associated with inhibition. One study compared the brain activity of professional jazz pianists as they played the music they memorized to their brain activity as they played spontaneous improvisational jazz (Limb & Braun, 2008). The fMRIs taken during the improvisation revealed that the areas of the brain responsible for inhibition and self-regulation were much less activated than during the memorized performance, but activity increased in the brain areas associated with individuality and self-expression. Apparently, turning off the brain areas that control inhibition and self-regulation leads to less focused attention and spontaneous and creative behavior. Charles Limb, the lead researcher, describes this fascinating study in a video clip available at www.ted.com/talks/charles_limb_your_brain_on_improv.html.

Further evidence of this effect came from a study of six-year-olds (Koutsoupidou & Hargreaves, 2009). Some of these participants had opportunities for musical improvisation during their music lessons. With others, their music lessons involved more traditional instruction. All students were then assessed with Webster's Measure of Creative Thinking in Music on originality, extensiveness, flexibility, and syntax. Those who were involved with improvisation activities scored significantly higher on the development of creative thinking than those with traditional instruction. Thus, to enhance general creativity in students, the music lessons themselves must involve creative activities. In other words, the best way to be creative is to be creative!

Participation in the arts can foster spontaneity and self-expression, moderate the limiting effects of inhibition, and lead to creative results.

Participation in the arts can foster spontaneity and self-expression, moderate the limiting effects of inhibition, and lead to creative results. It can develop the attentional control for the persistence needed to overcome the fear, frustration, and failure that can accompany creative endeavors. Artistic activities also enhance imaging skills and introspection because they often require one to create and manipulate mental images of a task before doing it and to self-evaluate the quality of one's own performance.

So if creativity is not an innate characteristic that is genetically preset and fixed, how can we teach it? Numerous studies in recent years have focused on this very question, and the results may surprise you. We will discuss those fascinating findings in Chapter 2.

The Arts Advance Social Growth

We live in an age of technology that has transformed the classroom and the nature of instruction. With iPads, laptops, and smartphones, we can be in instantaneous and constant contact with each other. Students walk around tapping their text messages, scrolling on their touch screens, and wearing earphones from morning to night. The average teenager deals with an astounding 3,700 texts a month (Dokoupil, 2012). That is an average of more than 120 messages each day—double the 2007 figure. However, little snippets of online connections through e-mail, Twitter, or Facebook do not substitute for live face-to-face conversation. We have termed this interconnectedness *social media.* But is it? Psychologist Sherry Turkle at MIT contends that this technology is not only changing what we do but who we are (Turkle, 2011). We spend so much time with the technology that there is little time for the experience of developing rich and demanding human relationships. Turkle suggests that we are becoming accustomed to being "alone together," in each other's presence but in our own bubble, connecting electronically but not personally. Perhaps a more appropriate name for "social media" is "antisocial media." We have even observed young people texting each other while seated at the same table!

The recent results of studies in China focusing on the effects of excessive Internet usage on the young brain are disturbing. One study of middle and high school students compared fifty-nine Internet-addicted students with forty-three non-addicted students using an IQ test (Park et al., 2011). The Internet-addicted group had significantly lower scores in comprehension than those of the non-addicted group. Another study found that Internet-addicted adolescents had a lower density of gray matter in the areas of the brain responsible for decision making when compared to non-addicted controls (Zhou et al., 2011). Both studies suggest that Internet addiction may adversely affect the cognitive functioning of adolescents. Furthermore, a long-term study of surveys from about 10,000 children from 2005 to 2009 revealed hardly any increase in parent or teacher attempts to control excessive Internet use (Valcke, De Wever, Van Keer, & Schellens, 2011).

No one questions that the Internet provides valuable opportunities for commerce, political expression, distance learning, and countless sources of information for classroom use. But, regardless of their value, these are impersonal contacts. Humans are innately social animals. We even have regions of the brain that are most active during social interactions and which generate social emotions (Chen, 2009). (Curiously, the great apes, elephants, and other gregarious animals also possess these specialized brain regions.) Having cerebral neurons dedicated to processing social interactions suggests how important social relationships are to human development and behavior. Yet modern technology may be short-circuiting this development by diverting our social interactions to the electronics rather than to face-to-face conversations.

Turkle further suggests that we are becoming more comfortable with technology than with one another. We seem to prefer the illusion of companionship through online connections without the demands of relationships. Here is where experiences in the arts may help. Many activities in the arts require collaboration through group planning, problem solving, and performance. They foster discussion, debate, and teamwork. In the early 1870s, French sculptor Frédéric Bartholdi designed the Statue of Liberty but eventually needed the engineering genius of Gustav Eiffel to design the interior framework to support the statue and its raised arm. The arts may be a major contribution in the STEM curriculum toward counterbalancing the antisocial, anti-collaborative nature of today's technology.

The Arts Introduce Novelty

Teachers remark that capturing students' attention these days is not an easy task. Yet attention is necessary for most learning to occur (Heimann, Tjus, & Strid, 2010). Neuroscientists have been exploring the nature of attention for decades and now seem to agree that it is a complex process involving three separate, integrated neural systems (Figure 1.5). One system is the *alerting* (sometimes called arousal) system that monitors the environment for any unusual (novel) activity or emotion. A teacher who begins lessons the same way every day does not represent unusual activity (and probably neutral emotions) and thus will often not be successful in activating the alerting system. The students' brains are thinking, "Same old, same old . . ." But when the alerting system does detect a novel event, the second system, called the *orienting* system, causes the individual to face toward the source of the alert—in this case, the teacher. Now the brain must make a decision what to do, and that is the job of the third system or the *executive control* area located in the frontal lobe.

When a teacher starts the class by saying, "We're going to do something different today" or "I have a surprise for you," the students realize that

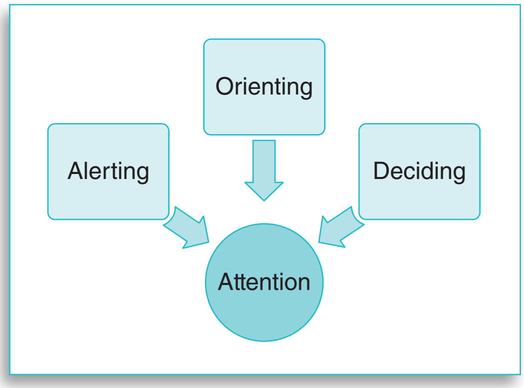


Figure 1.5 These three neural systems are used to get an individual's attention.

something unexpected is about to happen, and their attention rises dramatically. By integrating arts-related activities, teachers offer plenty of opportunities for novelty. Asking the students to draw their answers, put them to song, or act them out is sure to raise the students' interest and participation.

We recognize that some STEM teachers may be resistant to introducing music, dance, and role-playing into their classrooms. Some may think it silly or maybe inappropriate. However, remember that using novelty does *not* mean the teacher needs to be a stand-up comic or the classroom a three-ring circus. It simply means using a varied teaching approach that involves more student activity along with lesson components and emotional stimuli that the students did not expect. Appropriately used, novelty—especially those involving arts-related activities—can add new interest and fun to learning the STEM concepts.

The Arts Reduce Stress

Creating an artistic product can be a pleasurable experience that stimulates the brain's reward system and sends a rush of a chemical called dopamine across neurons. This dopamine torrent gives us a feeling of euphoria and lowers our stress levels. A study in Japan divided 57 healthy college students (27 males and 30 females) into four groups, each of which participated in thirty-minute sessions of one of the following creative activities or a control activity: playing the piano, molding a piece of clay, writing calligraphy, and remaining silent (the control group) (Toyoshima, Fukui, & Kuda, 2011). Before and after each session, the researchers measured the blood levels of the stress hormone cortisol and administered an anxiety inventory to each participant. The post-session cortisol levels were markedly decreased for piano playing, clay molding, and writing calligraphy, indicating a reduction in stress due to participation in these creative activities. Interestingly, the effect of piano playing was significantly greater than clay molding and writing calligraphy. In addition, the post-session scores on the anxiety inventory decreased significantly in all groups except for the control group, indicating a reduction in anxiety induced by engaging in creative activities. In other words, creative activities are valuable mental health tools for reducing anxiety is schools, which are often very stressful environments.

All of these research findings alone should justify teaching the arts for the arts' sake, and one should not have to suggest that we teach the arts only because they enhance the learning of other academic subjects, such as STEM. Nonetheless, it may be necessary to document any spillover effects that learning the arts can have on learning other subjects. That is because of the risk that the arts will fall by the wayside as schools are held more accountable for improving achievement in language arts and mathematics.

> ***Arts education is [not] only for those students who want to be artists.***

It is encouraging that more states have recently promoted the arts in their curriculum through policies, such as including the arts as part of high school graduation requirements, standards, and assessments. Although the extent of commitment varies, some states have developed more extensive programs in the arts for schools and created partnerships with state arts councils and local arts organizations. We must be cautious, however, not to accept the notion that arts education is only for those students who want to be artists. To do so would imply that we should teach history only to those students who want to be historians and science only to those who want to be physicists, chemists, or biologists.

The Arts Make Teaching More Interesting for STEM Teachers

A 2011 poll found that only 44 percent of teachers were "very satisfied" with their job (MetLife, 2012). This was the lowest level in the annual poll's 28-year history. Teachers reported that they feel too tied to the curriculum and have little leeway for creative planning and instruction. As they get frustrated, their motivation begins to wane. If they get bored, the students are bored.

More beginning science and mathematics teachers leave the profession after their first year than teachers in other subject areas. A University of Pennsylvania study showed that the first-year dropout rate was 18.2 percent for science teachers, 14.5 percent for mathematics teachers, and 12.3 percent for all other subjects (Ingersoll, Merrill, & May, 2012). Integrating arts-related activities can liven up the curriculum content, make the lesson more successful and interesting to both teachers and students, and introduce much-needed creative thinking into the teaching-learning process. When teachers see success in their classrooms as a result of their efforts, they are more likely to stay.

THE ARTS AND STEM DO HAVE DIFFERENCES

We recognize, of course, that in our zeal to integrate arts and STEM, we need to acknowledge that there are differences between the arts and STEM. For instance, the criteria for deciding what makes good art are quite different from the criteria for deciding what makes good science or good engineering. Another difference is in the generation of ideas and product. Any new idea that a scientist has, say making brackish pond water suitable for drinking, has most likely been thought about and tried by another scientist somewhere else, or would be at some future time. The real world is the ultimate determiner of whether that new idea will work. But think of an artist creating a product, say Leonardo da Vinci painting his *Mona Lisa,* or John Philip Sousa composing "Stars and Stripes Forever," or John Milton writing *Paradise Lost.* If they did not produce those artistic products, nobody else could have. Thus, the idea for an artistic product (such as a painting, song, or poem) is far more linked to the individual artist than a scientific idea is to an individual scientist. Sure, some scientific discoveries are associated with their discoverers, such as Albert Einstein with $E = mc^2$, and James Watson, Rosalind Franklin, and Francis Crick with the DNA helix. However, the point is that other scientists would probably have made these discoveries later because these were areas of intense scientific interest and investigation.

Some critics of STEAM argue that the arts and STEM subjects are very different ways of looking at the world. Although the areas share some communality, the critics are wary that students may not understand the critical differences. This is a legitimate concern. However, we believe that teachers who are aware of how arts and STEM learning intersect and support each other can competently demonstrate to students the important differences in these two domains of human activity. Furthermore, the integration strategies we suggest in the ensuing chapters make these differences clear.

STEM Learning Needs the Arts

Indeed, the arts can enlighten STEM in many ways. Robert Root-Bernstein (1997) offered some vivid examples:

- The elegant shape of Buckminster Fuller's geodesic domes can describe soccer balls and architectural buildings, as well as the structure of viruses and some recently discovered complex and enormous molecules.
- NASA employs artists to design visual displays that present satellite data as accurate, yet understandable to nonscientists.
- A biochemist looks at the fiber folds in her weaving cloth and recognizes another way of explaining protein folding.
- Computer engineers code messages to the frequencies of a specific song to prevent interception or blocking of the message, unless the decoder knows the song.
- Genetic researchers convert complex data into musical notation to facilitate analysis of the data, as, for example, decoding the sequence of genes in a chromosome.

Of course, the two people who probably personify STEAM are the Renaissance figures Leonardo da Vinci and Michelangelo Buonarroti. Although these fierce competitors were known more as painters and sculptors, they were also renowned as inventors, engineers, and scientists. For example, da Vinci conceptualized the helicopter and battle tank and made important discoveries in anatomy, hydrodynamics, and optics. Michelangelo also worked as an architect and engineer, designing the large dome of St. Peter's Basilica in Rome. These men saw no boundaries between the arts and sciences. Their work is inspiring, so let's take a closer look at how arts training can directly relate to the goals of STEM education.

Skills for Learning STEM and the Arts

As we mentioned in the Introduction, the STEM initiative is a logical extension of the framework recently proposed by the National Research Council (NRC) that was designed to address perceived weaknesses in K–12 science education in the United States (NRC, 2012). This proposal will likely become the basis for the next generation of core standards in science. The NRC framework consists of three dimensions: (1) scientific and engineering practices, (2) crosscutting concepts, and (3) disciplinary core ideas. This last dimension identifies specific content for the physical, life, earth, and space sciences, as well as for engineering, technology, and the applications of science. So let's set that one aside and focus on the first two dimensions, which deal with learning certain skills and broad concepts. Our premise here—based on recent research findings—is that students who have been exposed to arts-related instruction will have an advantage in acquiring these STEM-related skills and concepts over students who have not.

To support our premise, Table 1.2 lists in the left column the practices and concepts from the first two dimensions of the NRC framework. Alongside in the right column, we have listed some of the cognitive, emotional, and physical skills that students can acquire as a result of participating in arts-related instruction. As the arrow in the table indicates, the interaction works in both directions. Just as arts-related skills can enhance the learning of STEM concepts, so can the introduction of STEM concepts into standalone arts courses help those students understand the nature, development, and application of artistic skills.

Playing the piano, writing a poem, acting out a role, performing a dance, or creating a painting sharpens observations, hones details, stimulates multiple brain networks, and puts things into context. These are the same tools needed by a good scientist, mathematician, or engineer. The study of the arts not only allows students to develop skills that will improve the quality of their lives but also sustains the same creative base from which scientists and engineers seek to develop their innovations and breakthroughs of the future. In Chapters 4, 5, and 6, we explore in greater detail how integrating arts-related skills supports STEM learning at various grade levels.

Table 1.2 Practices and concepts from the K–12 National Research Council framework and skills often acquired in arts-related instruction.

First Two Dimensions of National Research Council Framework ⟷	**Skills Acquired in Arts-Related Instruction**
Scientific and Engineering Practices:	*Instrumental and Vocal Music, Art, and Dance Instruction:*
1. Asking questions and defining problems	1. Exploring the various ways to create art and make an informed decision
2. Developing and using models	2. Researching and appreciating the work of other artists, such as an analysis of a Beethoven sonata
3. Planning and carrying out investigations	3. Making color choices for a mural based on other works, as well as applying understanding of color and color variations.
4. Analyzing and interpreting data	4. Researching a written work, such as *Romeo and Juliet,* and creating a ballet interpreting the work
5. Using mathematics and computational thinking	5. Creating a series of pottery measuring cups, calculating the amount of clay, and the amount of kiln-shrinkage to have exact proportions
6. Constructing explanations and designing solutions	6. Writing a script based on a current events issue
7. Engaging in argument from evidence	7. Having a team create a comic strip in a roundtable format, based on a current political situation
8. Obtaining, evaluating, and communicating information	8. Creating a puppet show based on the "greenhouse theories."

(Continued)

Table 1.2 (Continued)

Crosscutting Concepts:	
1. Patterns	1. Discussing and performing rhythmic and melodic musical patterns
2. Cause and effect; mechanism and explanation	2. Experimenting with different media in creating a work of art on paper: watercolor vs. acrylics vs. chalk vs. pencil
3. Scale, proportion, and quantity	3. Creating a sculpture
4. Systems and system models	4. Analyzing the orchestration of a symphony both by visual review of the score and listening cues
5. Energy and matter: Flows, cycles, and conservation	5. Choreographing a piece depicting reclamation of western Pennsylvania steel mill buildings and land
6. Structure and function	6. Creating a set for a stage production
7. Stability and change	7. Analyzing and listening to the history of jazz in America

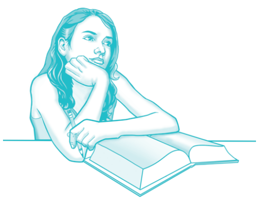
Source: Adapted from National Research Council (2012).

WHAT'S COMING?

In this chapter, we have looked at *why* we believe it is advantageous to integrate arts-related skills into STEM instruction and to use STEM concepts to enhance learning in the arts. In the next chapter, we explore what researchers in neuroscience and cognitive psychology are discovering about the brain and learning as it relates to the arts, STEM, and creativity. It will address theories about how we think, examines how mind-set has such a powerful influence over student achievement and teacher success, and delves into the nature of creativity. Be prepared for some fascinating revelations.

Chapter 1—Why STEM Should Become STEAM

Major Points to Ponder



Jot down key points, ideas, strategies, and resources that you want to consider later.