Encouraging girls in math and science

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IES Practice Guide

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U.S. DEPARTMENT OF EDUCATION

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Institute of Education Sciences

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Preamble from the Institute of Education Sciences

What is a practice guide?

The health care professions have embraced a mechanism for assembling and communicating evidence-based advice to practitioners about care for specific clinical conditions. Variously called practice guidelines, treatment protocols, critical pathways, best-practice guides, or simply practice guides, these documents are systematically developed recommendations about the course of care for frequently encountered problems, ranging from physical conditions such as foot ulcers to socioemotional issues such as navigating the demands of adolescence.[1]

Practice guides are similar to the products of typical expert consensus panels in that they reflect the views of those serving on the panel, as well as the social decision processes that come into play as the positions of individual panel members are forged into statements that all are willing to endorse. However, practice guides are generated under three constraints that do not typically apply to consensus panels. The first is that a practice guide consists of a list of discrete recommendations that are intended to be *actionable*. The second is that those recommendations taken together are intended to comprise a *coherent* approach to a multifaceted problem. The third, which is most important, is that each recommendation is explicitly connected to the *level of evidence* supporting it (e.g., strong, moderate, and low). The levels of evidence are usually constructed around the value of particular types of studies for drawing causal conclusions about what works. Thus one typically finds that the top level of evidence is drawn from a body of randomized controlled trials, the middle level from well-designed studies that do not involve randomization, and the bottom level from the opinions of respected authorities. Levels of evidence can also be constructed around the value of particular types of studies for other goals, such as the reliability and validity of assessments.

Practice guides can also be distinguished from systematic reviews or meta-analyses, which employ statistical methods to summarize the results of studies obtained from a rule-based search of the literature. Authors of practice guides seldom conduct the types of systematic literature searches that are the backbone of a meta-analysis, though they take advantage of such work when it is already published. Instead they use their expertise to identify the most important research with respect to their recommendations, augmented by a search of recent publications to assure that the research citations are up-to-date. Further, the characterization of the quality and direction of evidence underlying a recommendation in a practice guide relies less on a tight set of rules and statistical algorithms and more on the judgment of the authors than would be the case in a high-quality meta-analysis. Another distinction is that a practice guide, because it aims for a comprehensive and coherent approach, operates with more numerous and more contextualized statements of what works than does a typical meta-analysis.

Thus practice guides sit somewhere between consensus reports and meta-analyses in the degree to which systematic processes are used for locating relevant research and characterizing its meaning. Practice guides are more like consensus panel reports than meta-analyses in the breadth and complexity of the topic that is addressed. Practice guides are different from both consensus reports and meta-analyses in providing advice at the level of specific action steps along a pathway that represents a more-or-less coherent and comprehensive approach to a multifaceted problem.

Practice guides in education at the Institute of Education Sciences

The Institute of Education Sciences (IES) publishes practice guides in education to bring the best available evidence and expertise to bear on the types of systemic challenges that cannot be addressed by single interventions or approaches. Although IES has taken advantage of the history of practice guides in health care to provide models of how to proceed in education, education is different from health care in ways that may require that practice guides in education have somewhat different designs. Even within health care, where practice guides now number in the thousands,

[1] Field and Lohr (1990).

there is no single template in use. Rather, one finds descriptions of general design features that permit substantial variation in the realization of practice guides across subspecialties and panels of experts.[2] Accordingly, the templates for IES practice guides may vary across practice guides and change over time and with experience.

The steps involved in producing an IES-sponsored practice guide are first to select a topic, which is informed by formal surveys of practitioners and spontaneous requests from the field. Next, a panel chair is recruited who has a national reputation and up-to-date expertise in the topic. Third, the chair, working in collaboration with IES, selects a small number of panelists to co-author the practice guide. These are people the chair believes can work well together and have the requisite expertise to be a convincing source of recommendations. IES recommends that at least one of the panelists be a practitioner with considerable experience relevant to the topic being addressed. The chair and the panelists are provided a general template for a practice guide along the lines of the information provided in this preamble. They are also provided with examples of practice guides. The practice guide panel works under a short deadline of 6 to 9 months to produce a draft document. The expert panel interacts with and receives feedback from staff at IES during the development of the practice guide, but the panel members understand that they are the authors and thus responsible for the final product.

One unique feature of IES-sponsored practice guides is that they are subjected to rigorous external peer review through the same office that is responsible for independent review of other IES publications. A critical task of the peer reviewers of a practice guide is to determine whether the evidence cited in support of particular recommendations is up-to-date, and that studies of similar or better quality that point in a different direction have not been ignored. Peer reviewers also are asked to evaluate whether the evidence grades assigned to particular recommendations by the practice guide authors are appropriate. A practice guide is revised as necessary to meet the concerns of external peer reviews and to gain the approval of the standards and review staff at IES. The process of external peer review is carried out independently of the office and staff within IES that initiated the practice guide.

Because practice guides depend on the expertise of their authors and their group decision-making, the content of a practice guide is not and should not be viewed as a set of recommendations that in every case depends on and flows inevitably from scientific research. It is not only possible but also likely that two teams of recognized experts working independently to produce a practice guide on the same topic would generate products that differ in important respects. Thus consumers of practice guides need to understand that they are, in effect, getting the advice of consultants. These consultants should, on average, provide substantially better advice than educators might obtain on their own because the authors are national authorities who have to achieve consensus among themselves, justify their recommendations in terms of supporting evidence, and undergo rigorous independent peer review of their product.

[2] American Psychological Association (2002).

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Disclosures of potential conflicts of interest

Practice guide panels are composed of individuals who are nationally recognized experts on the topics about which they are rendering recommendations. IES expects that such experts will be involved professionally in a variety of matters that relate to their work as a panel. Panel members are asked to disclose their professional involvements and to institute deliberative processes that encourage critical examination of the views of panel members as they relate to the content of the practice guide. The potential influence of panel members' professional engagements reported by each panel member is further muted by the requirement that they ground their recommendations in evidence that is documented in the practice guide. In addition, the practice guide is subjected to independent external peer review prior to publication, with particular focus on whether the evidence related to the recommendations in the practice guide has been appropriately presented.

The professional engagements reported by each panel member that appear most closely associated with the panel recommendations are noted below.

Dr. Aronson has developed interventions aimed at changing students' conceptions of intelligence in order to improve their academic achievement. He has also developed interventions to reduce stereotype threat. These interventions are not referenced in the practice guide.

Introduction

The goal of this practice guide is to formulate specific and coherent evidence-based recommendations that educators can use to encourage girls in the fields of math and science. The target audience is teachers and other school personnel with direct contact with students, such as coaches, counselors, and principals. The practice guide includes specific recommendations for educators and the *quality of evidence* that supports these recommendations.

We, the authors, are a small group with expertise on this topic. The range of evidence we considered in developing this document is vast, ranging from experiments, to trends in the National Assessment of Educational Progress (NAEP) data, to correlational and longitudinal studies. For questions about what works best, high-quality experimental and quasi-experimental studies, such as those meeting the criteria of the What Works Clearinghouse, have a privileged position. In all cases, we pay particular attention to findings that are replicated across studies.

Although we draw on evidence about the effectiveness of specific practices, we use this information to make broader points about improving practice. In this document, we have tried to take findings from research or practices recommended by experts and describe how the use of this recommendation might actually unfold in school settings. In other words, we aim to provide sufficient detail so that educators will have a clear sense of the steps necessary to make use of the recommendation.

A unique feature of practice guides is the explicit and clear delineation of the quality and quantity of evidence that supports each claim. To this end, we adapted a semi-structured hierarchy suggested by the Institute of Education Sciences. This classification system helps determine whether the quality and quantity of available evidence in support of a practice is of strong, moderate, or low quality. This system appears in table 1 below.

Strong refers to consistent and generalizable evidence that an approach or practice causes improved performance in math or science among girls or that an assessment is reliable and valid. *Moderate* refers either to evidence from (a) studies that allow strong causal conclusions but which cannot be generalized with assurance to the target population because, for example, the findings have not been sufficiently replicated, or (b) studies that are generalizable but have more causal ambiguity than offered by experimental designs, for example, statistical models of correlational data or group comparison designs where equivalence of the groups at pretest is uncertain. For assessments, *moderate* refers to high quality studies from a small number of samples that are not representative of the whole population. *Low* refers to expert opinion based on reasonable extrapolations from research and theory on other topics and/or evidence from studies that do not meet the standards for moderate or strong evidence.

For each recommendation, we include an appendix that provides more technical information about the studies and our decisions regarding level of evidence for the recommendation. To illustrate the types of studies reviewed, we describe one study in considerable detail for each recommendation. Our goal in doing this is to provide interested readers with more detail about the research designs, the intervention components, and how impact was measured. By including a particular study, we do not mean to suggest that it is the best study reviewed for the recommendation or necessarily an exemplary study in any way.

Table 1. Institute of Education Sciences Levels of Evidence	
Strong	In general, characterization of the evidence for a recommendation as strong requires both studies with high internal validity (i.e., studies whose designs can support causal conclusions), as well as studies with high external validity (i.e., studies that in total include enough of the range of participants and settings on which the recommendation is focused to support the conclusion that the results can be generalized to those participants and settings). Strong evidence for this practice guide is operationalized as: • A systematic review of research that generally meets the standards of the What Works Clearinghouse (see http://ies.ed.gov/ncee/wwc/) and supports the effectiveness of a program, practice, or approach with no contradictory evidence of similar quality; OR • Several well-designed, randomized, controlled trials or well-designed quasi-experiments that generally meet the standards of the What Works Clearinghouse and support the effectiveness of a program, practice, or approach, with no contradictory evidence of similar quality; OR • One large, well-designed, randomized, controlled, multisite trial that meets the standards of the What Works Clearinghouse and supports the effectiveness of a program, practice, or approach, with no contradictory evidence of similar quality; OR • For assessments, evidence of reliability and validity that meets the Standards for Educational and Psychological Testing.[3]
Moderate	In general, characterization of the evidence for a recommendation as moderate requires studies with high internal validity but moderate external validity, or studies with high external validity but moderate internal validity. In other words, moderate evidence is derived from studies that support strong causal conclusions but where generalization is uncertain, or studies that support the generality of a relationship but where the causality is uncertain. Moderate evidence for this practice guide is operationalized as: • Experiments or quasi-experiments generally meeting the standards of the What Works Clearinghouse and supporting the effectiveness of a program, practice, or approach with small sample sizes and/or other conditions of implementation or analysis that limit generalizability, and no contrary evidence; OR • Comparison group studies that do not demonstrate equivalence of groups at pretest and therefore do not meet the standards of the What Works Clearinghouse but that (a) consistently show enhanced outcomes for participants experiencing a particular program, practice, or approach and (b) have no major flaws related to internal validity other than lack of demonstrated equivalence at pretest (e.g., only one teacher or one class per condition, unequal amounts of instructional time, highly biased outcome measures); OR • Correlational research with strong statistical controls for selection bias and for discerning influence of endogenous factors and no contrary evidence; OR • For assessments, evidence of reliability that meets the Standards for Educational and Psychological Testing[4] but with evidence of validity from samples not adequately representative of the population on which the recommendation is focused.
Low	In general, characterization of the evidence for a recommendation as low means that the recommendation is based on expert opinion derived from strong findings or theories in related areas and/or expert opinion buttressed by direct evidence that does not rise to the moderate or strong levels. Low evidence is operationalized as evidence not meeting the standards for the moderate or high levels.

[3] American Educational Research Association, American Psychological Association, and National Council on Measurement in Education (1999).
[4] Ibid.

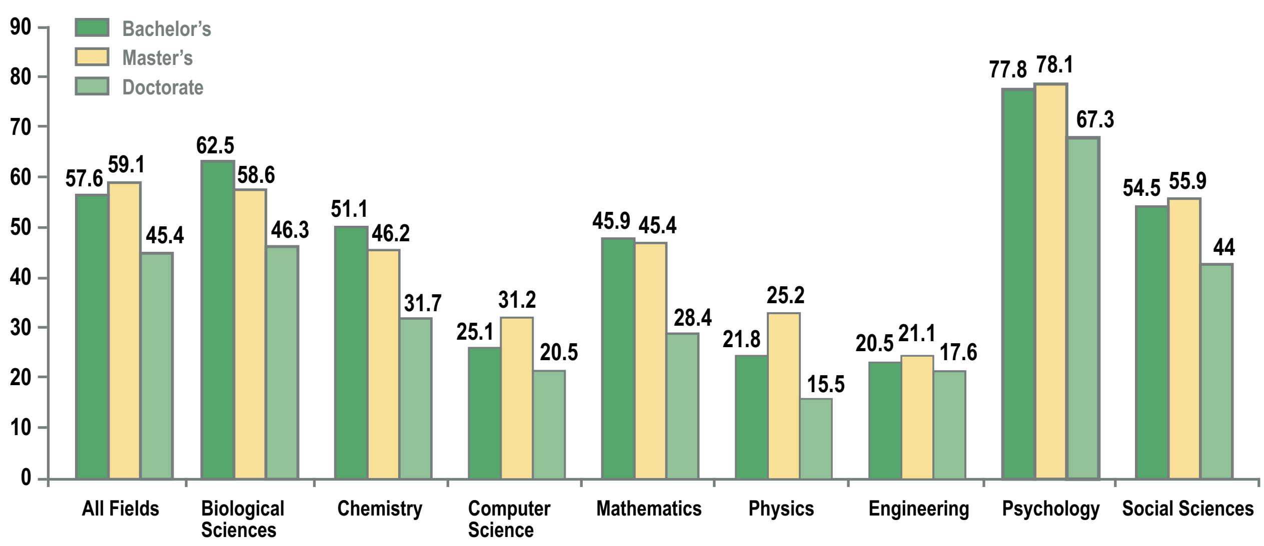
Encouraging girls in math and science

Overview

Although there is a general perception that men do better than women in math and science, researchers have found that the differences between women's and men's math- and science-related abilities and choices are much more subtle and complex than a simple "men are better than women in math and science."[5] In fact, experts disagree among themselves on the degree to which women and men differ in their math- and science-related abilities.[6] A quick review of the postsecondary paths pursued by women and men highlight the areas in math and science where women are not attaining degrees at the same rate as men.

In 2004, women earned 58 percent of *all* bachelor's degrees, 78 percent of bachelor's degrees in psychology, 62 percent in biological sciences, 51 percent in chemistry, 46 percent in mathematics, 25 percent in computer sciences, 22 percent in physics, and 21 percent in engineering.[7] In general, women earn substantial proportions of the bachelor's degrees in math and the sciences, *except* in computer sciences, physics, and engineering. At the master's level, women earned 59 percent of all master's degrees. The pattern at the master's degree level is similar (see figure 1). At the doctoral level, however, gender imbalances become more prevalent, including in math and chemistry (see figure 1). Women earned 45 percent of all doctoral degrees, but they earn less than one-third of all doctoral degrees in chemistry, computer sciences, math, physics, and engineering.[8] In contrast, women earn 67 percent of the doctoral degrees in psychology and 44 percent in other social sciences.[9] This disproportionate representation in math and science graduate degrees is also reflected in math and science career pathways. While women make up nearly half of the U.S. workforce, they make up only 26 percent of the science and engineering workforce.[10] The question many are asking is why women are choosing not to pursue degrees

Figure 1. Percent of degrees awarded to women by major field



SOURCE: National Science Foundation, *Science and Engineering Degrees: 1966-2004.*

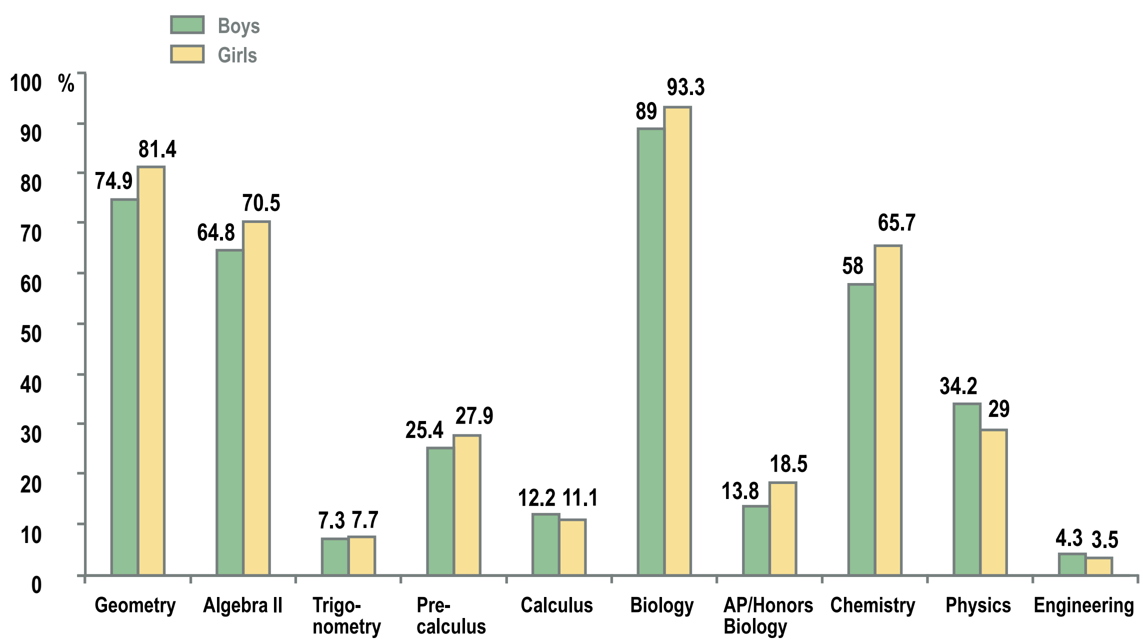
[5] See Hyde (2005), Spelke (2005), and Halpern (2000) for recent discussions of the literature.
[6] See Gallagher and Kaufman (2005) for a collection of chapters representing different researchers' views.
[7] National Science Foundation (2006d).
[8] Ibid.
[9] Ibid.
[10] National Science Foundation (2006c).

and careers in the physical sciences, engineering, or computer science. Several potential reasons for the gender disparity include previous coursework, ability, interests, and beliefs.

An examination of course-taking patterns shows that girls are taking math and science courses in high school. On the 2005 National Assessment of Educational Progress (NAEP) High School Transcript Study, girls who graduated from high school, on average, earned slightly more credits in mathematics and science (7.3) than boys earned (7.1). Boys, however, earned slightly more credits in computer-related courses (1.1) than girls earned (0.8).[11] Figure 2 shows the percentages of female and male high school graduates in 2000 that completed math and science courses. Although a greater percentage of boys completed physics (34 percent) and calculus (12 percent) than girls (physics, 29 percent; calculus, 11 percent), girls were more likely to complete biology (girls, 93 percent; boys, 89 percent), advanced placement (AP) or honors biology (girls, 19 percent; boys, 14 percent), and chemistry (girls, 66 percent; boys, 58 percent) than boys were. Although some gender differences are present in high school math and science course enrollments, similarities between the genders is also common. This gender parity in course-taking patterns may be less surprising than it appears, given that high school graduation requirements typically include multiple science courses, as well as mathematics.

A second reason for the observed differences in college and occupational choices may be that males and females have variant math and science abilities, as measured by standardized tests. Although girls generally do as well as, or better than, boys on homework assignments and course grades in math and science classes,[12] boys tend to outscore girls when tested on

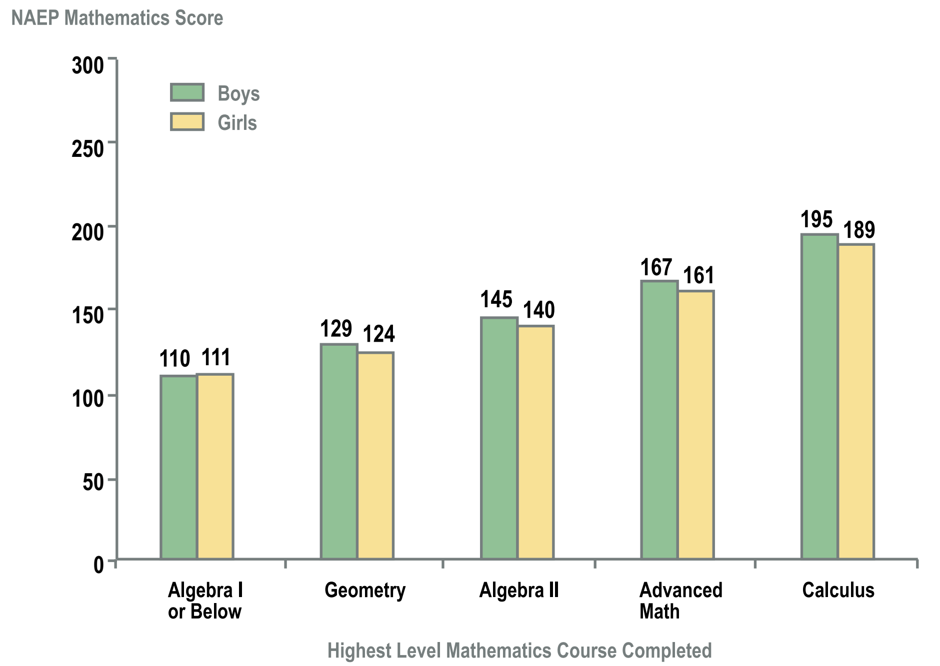
Figure 2. Percent of public high school graduates who completed various mathematics and science courses in high school, by gender: 2000



SOURCE: U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics. *Trends in Educational Equity of Girls & Women: 2004.*

[11] Shettle, Roey, Mordica, et al. (2007).
[12] College Board (2006, August 29); Shettle, Roey, Mordica, et al. (2007).

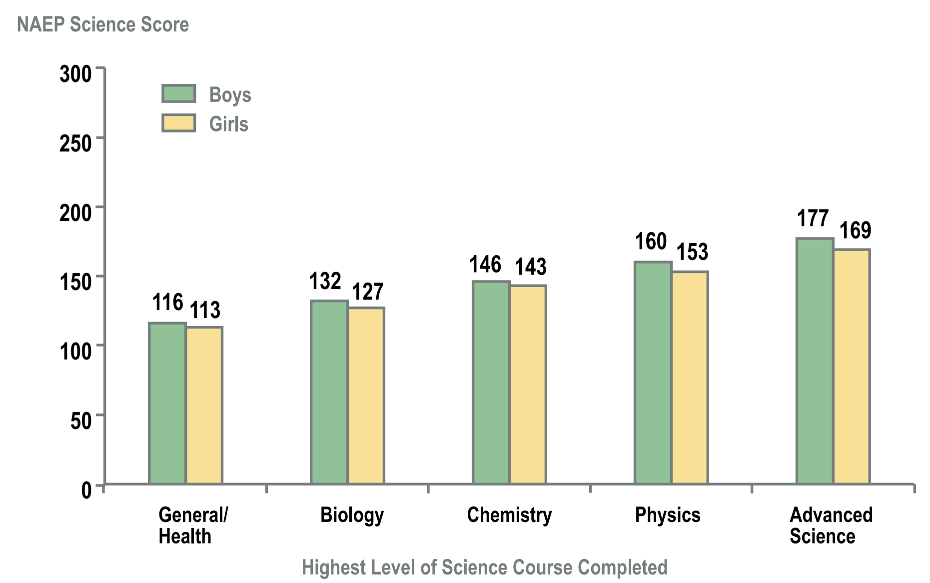
Figure 3. NAEP mathematics scores by highest course completed and gender: 2005



NOTE: Advanced mathematics courses, other than calculus, are courses generally taken after Algebra II (e.g., AP statistics and precalculus).

SOURCE: U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, High School Transcript Study (HSTS), 2005.

Figure 4. NAEP science scores by highest course completed and gender: 2005



NOTE: Advanced science courses are courses that contain advanced context (like AP Biology, IB Chemistry, AP Physics, etc.) or are considered second-year courses (Chemistry II, Advanced Biology, etc.).

SOURCE: U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, High School Transcript Study (HSTS), 2005.

the same content in high-pressure situations, such as standardized tests with time limits. These tests are typically not linked to instructed curriculum, and so can be understood to be measures of more general abilities in math and science.[13] For example, on the 2005 NAEP math and science assessments, girls scored lower than boys when controlling for highest course completed at all levels, except the lowest level (see figures 3 and 4).[14] Performance differences on timed standardized tests do not necessarily mean that girls are not as capable as boys in math or science. Researchers have found, for instance, that SAT math scores underpredict young women's performance in college math courses.[15] This suggests that it is not ability, per se, that hinders girls and women from pursuing careers in math and science. If not ability, then what?

Areas where consistent gender differences have emerged are children's and adolescents' beliefs about their abilities in math and science, their interest in math and science, and their perceptions of the importance of math and science for their futures. In general, researchers have found that girls and women have less confidence in their math abilities than males do and that from early adolescence, girls show less interest

in math or science careers.[16] This gender difference is interesting, and somewhat puzzling, given that males and females generally enroll in similar courses and display similar abilities (at least as measured by course grades). In other words, girls, particularly as they move out of elementary school and into middle and high school and beyond, often underestimate their abilities in mathematics and science. However, it is important to note that not all girls have less confidence and interest in mathematics and science, and that girls, as well as boys, who have a strong self-concept regarding their abilities in math or science are more likely to choose and perform well in elective math and science courses and to select math- and science-related college majors and careers.[17] This is noteworthy because it suggests that improving girls' beliefs about their abilities could alter their choices and performance. Theory and empirical research suggest that children's beliefs about their abilities are central to determining their interest and performance in different subjects, the classes they choose to take, the after-school activities they pursue, and, ultimately, the career choices they make.[18]

What can teachers do to encourage girls to choose career paths in math- and science-related fields? One major way to encourage girls to choose careers in math and science is to foster the development of strong beliefs about their abilities in these subjects–beliefs that more accurately reflect their abilities – and more accurate beliefs about the participation of women in math- and science-related careers (see table 2). Our first two recommendations, therefore, focus on strategies that teachers can use to strengthen girls' beliefs regarding their abilities in math and science: (1) Teach students that academic abilities are expandable and improvable (Level of Evidence: Moderate); and (2) Provide prescriptive, informational feedback (Level of Evidence: Moderate). Our third recommendation addresses girls' beliefs about both their own abilities and the participation of women in math- and science-related careers: (3) Expose girls to female role models who have succeeded in math and science (Level of Evidence: Low).

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[13] See Halpern, Benbow, Geary, et al. (2007) for a more thorough discussion of this point.
[14] Shettle, Roey, Mordica, et al. (2007).
[15] Wainer and Steinberg (1992).
[16] Andre, Whigham, Hendrickson, et al. (1999); Herbert and Stipek, (2005); Jacobs, Lanza, Osgood, et al. (2002); Simpkins and Davis-Kean (2005); Wigfield, Eccles, Mac Iver, et al. (1991).
[17] Simpkins and Davis-Kean (2005); Updegraff and Eccles (1996).
[18] Pajares (2006).

Table 2. Recommendations and corresponding Levels of Evidence to support each	
Recommendation	**Level of Evidence**
1. Teachers should explicitly teach students that academic abilities are expandable and improvable in order to enhance girls' beliefs about their abilities. Students who view their cognitive abilities as fixed from birth or unchangeable are more likely to experience decreased confidence and performance when faced with difficulties or setbacks. Students who are more confident about their abilities in math and science are more likely to choose elective math and science courses in high school and more likely to select math and science-related college majors and careers.	Moderate
2. Teachers should provide students with prescriptive, informational feedback regarding their performance. Prescriptive, informational feedback focuses on strategies, effort, and the process of learning (e.g., identifying gains in children's use of particular strategies or specific errors in problem solving). Such feedback enhances students' beliefs about their abilities, typically improves persistence, and improves performance on tasks.	Moderate
3. Teachers should expose girls to female role models who have achieved in math or science in order to promote positive beliefs regarding women's abilities in math and science. Even in elementary school, girls are aware of the stereotype that men are better in math and science than women are. Exposing girls to female role models (e.g., through biographies, guest speakers, or tutoring by older female students) can invalidate these stereotypes.	Low
4. Teachers can foster girls' long-term interest in math and science by choosing activities connecting math and science activities to careers in ways that do not reinforce existing gender stereotypes and choosing activities that spark initial curiosity about math and science content. Teachers can provide ongoing access to resources for students who continue to express interest in a topic after the class has moved on to other areas.	Moderate
5. Teachers should provide opportunities for students to engage in spatial skills training. Spatial skills training is associated with performance in mathematics and science.	Low

Girls are more likely to choose courses and careers in math and science if their interest in these fields is sparked and cultivated throughout the school years.[19] Our fourth recommendation focuses on the importance of fostering long-term interest (Level of Evidence: Moderate) and provides concrete strategies that teachers might use to promote greater interest in math and science.

A final way to encourage girls in math and science is to help them build the spatial skills that are crucial to success in many math- and science-related fields, such as physics, engineering, architecture, geometry, topology, chemistry, and biology. Research suggests that spatial skills, on which boys have typically outperformed girls, can be improved through specific types of training. Thus, our final recommendation is that teachers provide students, especially girls, with specific training in spatial skills (Level of Evidence: Low).

Scope of the practice guide

This practice guide provides five recommendations for encouraging girls in math and science. These recommendations together form a coherent statement: To encourage girls in math and science, we need to begin first with their beliefs about their abilities in these areas, second with sparking and maintaining greater interest in these topics, and finally with building associated skills. Our specific recommendations cover these three domains in a representative but not exhaustive way. In particular, we have chosen to focus on specific recommendations that have the strongest research backing available. In addition, we limit our focus to recommendations that teachers can carry out in the classroom and that do not require systemic change within a school district. We remind the reader that students' choices to pursue careers in math and science reflect multiple influences that accumulate over time. We have identified practices that elementary, middle, and high school teachers can implement during instruction that we believe would increase the likelihood that girls and women will not prematurely decide that careers in math and science are not for them.

[19] Wigfield, Eccles, Schiefele, et al. (2006).

Checklist for carrying out the recommendations

Recommendation 1: Teach students that academic abilities are expandable and improvable.

- ☐ Teach students that working hard to learn new knowledge leads to improved performance.
- ☐ Remind students that the mind grows stronger with use and that over time and with continued effort, understanding the material will get easier.

Recommendation 2: Provide prescriptive, informational feedback.

- ☐ Provide students with feedback that focuses on strategies used during learning, as opposed to simply telling them whether they got an answer correct. This strategy encourages students to correct misunderstandings and learn from their mistakes.
- ☐ Provide students with positive feedback about the effort they expended on solving a difficult problem or completing other work related to their performance.
- ☐ Avoid using general praise, such as "good job," when providing feedback to individual students or an entire class.
- ☐ Make sure that there are multiple opportunities for students to receive feedback on their performance.

Recommendation 3: Expose girls and young women to female role models who have succeeded in math and science.

- ☐ Invite older girls and women who have succeeded in math- or science-related courses and professions to be guest speakers or tutors in your class.
- ☐ Assign biographical readings about women scientists, mathematicians, and engineers, as part of students' assignments.
- ☐ Call attention to current events highlighting the achievements of women in math or science.
- ☐ When talking about potential careers, make students aware of the numbers of women who receive advanced degrees in math- and science-related disciplines.
- ☐ Provide girls and young women with information about mentoring programs designed to support students who are interested in mathematics and science.
- ☐ Encourage parents to take an active role in providing opportunities for girls to be exposed to women working in the fields of math and science.

Recommendation 4: Create a classroom environment that sparks initial curiosity and fosters long-term interest in math and science.

- ☐ Embed mathematics word problems and science activities in contexts that are interesting to both boys and girls.
- ☐ Provide students with access to rich, engaging relevant informational and narrative texts as they participate in classroom science investigations.
- ☐ Capitalize on novelty to spark initial interest. That is, use project-based learning, group work, innovative tasks, and technology to stir interest in a topic.
- ☐ Encourage middle and high school students to examine their beliefs about which careers are typically female-oriented and which are typically male-oriented. Encourage these students to learn more about careers that are interesting to them but that they believe employ more members of the opposite gender.
- ☐ Connect mathematics and science activities to careers in ways that do not reinforce existing gender stereotypes of these careers.

Recommendation 5: Provide spatial skills training.

- ☐ Recognize that children may not automatically recognize when spatial strategies can be used to solve problems and that girls are less likely to use spatial strategies than boys. Teach students to mentally image and draw spatial displays in response to mathematics and science problems.
- ☐ Require students to answer mathematics and science problems using both verbal responses and spatial displays.
- ☐ Provide opportunities for specific training in spatial skills such as mental rotation of images, spatial perspective, and embedded figures.

Recommendation 1: Teach students that academic abilities are expandable and improvable.

To enhance girls' beliefs about their abilities, we recommend that teachers understand and communicate this understanding to students: Math and science abilities—like all abilities—can be improved through consistent effort and learning. Research shows that even students with considerable ability who view their cognitive abilities as fixed or unchangeable are more likely to experience greater discouragement, lower performance, and, ultimately, reduce their effort when they encounter difficulties or setbacks. Such responses may be more likely in the context of math, given stereotypes about girls' innate mathematics abilities.[20] In contrast, students who tend to view their abilities as expandable tend to keep trying in the face of frustration in order to increase their performance. To help girls and young women resist negative reactions to the difficulty of math and science work, it can be very helpful for them to learn that their math and science abilities can improve over time with continuous effort and engagement.

Level of evidence: Moderate

The panel judges the level of evidence supporting this recommendation to be *moderate*, based on the two small experimental studies that examined the effect of this practice for improving K–12 students' performance on math,[21] one experimental study that examined the effect of this strategy for improving college students' general academic performance,[22] and supporting correlational research demonstrating the relation between students' beliefs about the stability and malleability of intellectual abilities and their performance.[23]

Brief summary of evidence to support the recommendation

What students believe about the nature of intelligence and ability affects their achievement.[24] Some students believe that people, in general, are born with a fixed amount of intelligence, such that some people are born smart and others less smart and that little can be done to change this. Similarly, some students believe that their abilities were determined at birth and cannot be changed. An alternative way to think about intelligence or ability is that it is not fixed but can be improved through hard work and effort. Research shows that children who view intelligence as a fixed trait or believe that their own abilities cannot be changed tend to pursue "performance goals." That is, they tend to be more concerned with demonstrating their intelligence and prefer to complete tasks that will show that they are "smart." In contrast, students who believe that intelligence or ability can be improved with effort are more likely to pursue learning goals.[25] That is, they tend to be more concerned with learning new material and are more likely to seek to master difficult material, even if doing so does not make them look "smart" (e.g., they might not be able to solve problems initially). When tasks become more challenging, students who believe that abilities or intelligence cannot be changed are more likely to become anxious, downgrade their assessment of their ability, and give up. However, students who believe that abilities can be improved through effort and hard work are more likely to respond to challenge with increased effort. In the long run, the students who are able to persist in their attempts to master difficult material perform better than the students who doubt their ability and give up.[26]

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[20] See Dweck (2006) for a recent discussion focused on girls' beliefs about intelligence.
[21] Good, Aronson, and Inzlicht (2003); Blackwell, Trzesniewski, and Dweck (2007).
[22] Aronson, Fried, and Good (2002).
[23] Weiner (1986); Graham (1991); see Dweck (1999) for an overview of research in this area.
[24] Grant and Dweck (2003).
[25] Dweck (1999); Dweck and Leggett (1988).
[26] Utman (1997).

These different orientations toward learning may have long-term implications. For example, if a child's goal is to look smart, she may shy away from challenging tasks with potential for failure in favor of easier tasks with higher potential for success. In addition, if a child believes that intelligence or abilities are fixed, then she is likely to attribute failure to lack of ability, and her belief in her own abilities may eventually decline. Thus, failures or challenges can have a negative impact on children who view intelligence or abilities as a fixed trait. In contrast, research shows that when students are taught that intelligence and abilities can be increased with hard work, their test scores and their grades improve.[27]

Finally, why is it important to foster girls' belief in the malleability of intellectual abilities? As discussed in the overview, girls tend to lack confidence in their math and science abilities even when they do well in their math and science courses. Teaching girls that knowledge and intellectual skills increase, for example, when students learn how to solve problems that they previously could not do explicitly provides girls with a way to interpret failure that does not discourage them from persevering to master new material in class.

How to carry out the recommendation

To help modify students' beliefs about their intelligence or abilities, teachers can:

- Expose students to and discuss the neuroscience research that shows that brains grow new synaptic connections when new material is learned and practiced, thus making the brain more complex and "smarter"—that working hard to learn new knowledge leads to improved intelligence. Sports analogies can buttress this learning: practicing academic skills, like solving math problems, improves performance much like practicing free throws improves basketball performance or practicing serves helps one's tennis game.[28]
- When students are struggling, teachers can explicitly remind their students that the mind grows stronger as a result of doing hard work, and that over time and with continued effort, understanding the material and solving the problems will get easier.[29]
- Teachers can also remind students about the malleability of intelligence when they make progress, pointing out that their brains are actively building new connections as they study.

Potential roadblocks and solutions

Roadblock 1.1. Some adults may believe that intelligence and abilities are innate or fixed and that people who are "naturally" good at something will excel in that domain. It can be difficult to convince students that effort will make a significant difference when some adults seem to favor "natural ability" explanations for success over "effort and hard work" explanations.

Solution. Some teachers may view abilities and intelligence as static characteristics that are fixed at birth. Neurologists used to believe this as well, but they no longer do. Thus, teachers as well as students need to take the neuroscience seriously and examine and modify their preconceptions about the nature of human intelligence. Only then can they genuinely help both students and parents understand that our brains are constantly creating and refining new synaptic connections, based on our experiences and the activities we regularly practice. Teachers should consider the following two studies. In one, researchers found that cab drivers had enlarged portions of the part of the brain that is important in performing spatial tasks (right posterior hippocampus) relative to a control group of adults whose employment required less use of spatial navigational skills.[30] Among the cab drivers in this study, the number of years spent driving taxis was positively correlated with the size of the right posterior hippocampus. In a related study, researchers found that in a sample of adults who were not taxi drivers, there was no correlation between size of the posterior hippocampus and navigational expertise.[31] These two sets of findings suggest that experience with complex route finding caused the increased size of the relevant

[27] Aronson, Fried, and Good (2002); Good, Aronson, and Inzlicht (2003); Blackwell, Trzesniewski, and Dweck (2007).
[28] Good, Aronson, and Inzlicht (2003).
[29] Ibid.
[30] Maguire, Gadian, Johnsrude, et al. (2000).
[31] Maguire, Spiers, Good, et al. (2003).

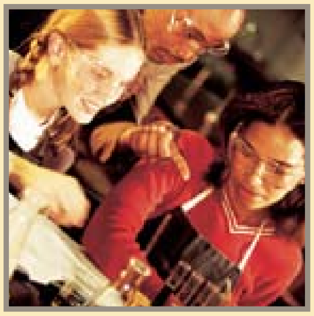
brain structure. This is just one example of research that underlines the fundamental flexibility of the human brain in creating new synaptic connections for tasks that are repeated and practiced over time.

Roadblock 1.2. By the time students enter high school, some girls perceive themselves to be less capable than boys in math and science. They may believe that their abilities in this domain are not significantly expandable or that they are innately less likely than boys to do well in these domains.

Solution. Teachers will need to keep in mind that girls perform as well as or even better than boys in school, including on exams and course grades in math and science classes; boys outperform girls only when we look at scores on advanced standardized tests. Experts disagree as to why girls' equal or superior classroom performance in math and science does not carry over to their performance on high-stakes standardized tests.[32] Thus, teachers can emphasize to students that high scores on advanced standardized tests do not in the long run determine success in science- and math-related fields. Many different skills are needed for success in these domains, including the content knowledge gained in coursework and through experience, as well as excellent writing and communication skills. There is no reason to believe that girls are biologically programmed to perform less well than boys in math- and science-related careers, and there are many reasons to believe that women, once rare in math and science careers, will continue to close the gap, as they have for the past several decades. Again, the best way for teachers to respond with genuine encouragement to girls' doubts about their innate aptitudes in math and science is to be clear that the male advantage in math has little grounding in science and is limited to standardized tests. Appreciating the fact that girls perform better on standardized math tests when they believe that their math abilities are not fixed is one powerful way to start.

[32] Gallagher and Kaufman (2005).

Recommendation 2: Provide prescriptive, informational feedback.



We recommend that teachers provide students with prescriptive, informational feedback regarding their performance in math and science courses. Prescriptive, informational feedback focuses on strategies, effort, and the process of learning. Examples include identifying gains in children's strategy use, praising effort, or identifying gaps or errors in problem-solving. Although this type of feedback overlaps with the type of feedback that teachers provide during formative assessment, this recommendation specifically targets feedback that focuses students' attention on their *beliefs* about why they did or did not perform well on a particular task. Prescriptive, informational feedback enhances students' beliefs about their abilities, typically improves persistence, and improves performance on tasks. In addition, students' beliefs about their abilities are related to their math- and science-related choices.[33]

Level of evidence: Moderate

The panel judges the quality of the evidence on the relation between prescriptive, informational feedback and students' beliefs about their math and science abilities and their performance on math- and science-related tasks to be *moderate*, based on a set of small experimental studies using random assignment that focus specifically on children performing math or math-related tasks[34] and supporting research on the effects of different types of feedback on a variety of tasks.[35] The supporting research on feedback includes many studies that vary in terms of design, including small experimental studies, longitudinal and cross-sectional correlational studies, and qualitative studies. Many of the experimental studies on the effects of different types of feedback have been conducted with children.

Brief summary of evidence to support the recommendation

Students often receive feedback regarding their performance in the form of grades, test scores, or statements from teachers regarding the accuracy of a response. However, all forms of feedback are not equal in their impact on students' beliefs about their abilities in a given domain, such as math or science, nor in their impact on performance. In particular, when teachers provide specific, informational feedback in terms of strategies, effort, and the process of learning (e.g., "you worked really hard at that subtraction problem"), rather than general praise (e.g., "good job") or feedback regarding global intelligence (e.g., "you're smart"), students' beliefs about their abilities and their performance are positively influenced.[36]

Many teachers know that providing informational feedback helps create a positive learning environment. Indeed, the use of classroom formative assessment is linked to substantial learning gains.[37] When teachers give informational feedback (e.g., pointing out to a student a specific problem in her logic rather than simply noting that the answer is incorrect) students' achievement and attitudes improve.[38] During whole-class instruction, when teachers combine positive comments with specific information about how to solve a problem, students are less likely to report that they engage in self-defeating behaviors (e.g., putting off doing their homework until the last minute) or

[33] See Hackett (1985) for a classic study supporting this conclusion in the context of mathematics; Fouad and Smith (1996) discuss this relationship in middle school students.
[34] Mueller and Dweck (1998); Elawar and Corno (1985); Miller, Brickman, and Bolen (1975).
[35] See Bangert-Drowns, Kulik, Kulik, et al. (1991) for a synthesis of studies on feedback and Henderlong and Lepper (2002) for a recent review on the effects of praise on children's intrinsic motivation.
[36] Mueller and Dweck (1998); Elawar and Corno (1985); Miller, Brickman, and Bolen (1975).
[37] See Black and Wiliam (1998) for a recent discussion of the literature on feedback and formative assessment.
[38] Elawar and Corno (1985).

avoid asking for help when they don't understand assignments.[39] In addition, research suggests that positive substantive feedback that provides information about students' progress toward goals and progress in learning is related to children's motivational beliefs, such as their self-concept of ability and self-efficacy. An observational study of math classrooms illustrates how including such feedback during instruction can support students' self-efficacy in mathematics.[40] Even though the research demonstrates the critical and potentially powerful role that appropriate feedback can play, it does not appear that teachers typically use prescriptive, informational feedback. In fact, a recent descriptive study of teacher feedback used in 58 third-grade mathematics classrooms suggests that the primary form of feedback teachers use during instruction is general praise, such as "that's very good," which does not provide any useful information to students.[41]

Experimental work suggests that feedback given in the form of praise focused on global intelligence (e.g., "you're smart") may have a negative impact on future learning behavior in comparison to praise about effort (e.g., "you must have worked hard").[42] Elementary school students who were given praise about their intelligence after correctly solving a problem were likely to attribute future failures to lack of ability, have lower interest, show less persistence on future tasks, and have a goal for future tasks of looking smart. In contrast, children who were given praise about their effort were more likely to believe that subsequent failure was due to lack of effort, show higher persistence on difficult tasks, and have a goal of mastering challenging tasks or concepts rather than just "looking smart." Thus, teacher feedback that attributes student success to effort (e.g., "you've been working hard") and task-specific ability (e.g., "you did very well at solving this division problem") strengthens self-efficacy beliefs about mathematics. These beliefs, in turn, influence a child's future persistence on difficult tasks and, ultimately, overall performance.

Finally, why is prescriptive, informational feedback important to enhancing girls' beliefs about their abilities? As discussed in the overview, girls tend to lack confidence in their math and science abilities even when they do well in math and science courses. Providing informative feedback focuses students' attention on what to do when they do not solve a problem correctly rather than letting girls attribute wrong answers to a lack of ability. When students experience success, providing informative feedback directs their attention to what they did to achieve that success (e.g., worked hard, tried multiple strategies, used the procedures in the correct order) rather than allowing girls to attribute that success to having a certain amount of ability.

How to carry out the recommendation

What can teachers do to make sure that the feedback they give students will help improve both their motivation to learn new material and their performance, even in the face of failure?

- Provide positive, substantive feedback to students as they solve problems to encourage students to correct misunderstandings and learn from their mistakes.[43] Teachers should create a classroom environment in which learning, improving, and understanding are emphasized. In such an environment, when children give an incorrect answer, it becomes an opportunity for learning.

- Highlight the importance of effort for succeeding at difficult tasks. By attributing success to effort rather than to global intelligence, expectations for future success are supported. Praising general intelligence implies that natural intellectual gifts determine success (and failure) rather than effort; this can be a debilitating mindset for students when confronted with failure on a difficult task.[44]

- Keep a balance between learning on the one hand and performance on the other. Grades matter, but students who focus single-mindedly on their grades may come to care so much about performance that they sacrifice learning opportunities.[45]

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[39] Turner, Midgley, Meyer, et al. (2002).
[40] Schweinle, Turner, and Meyer (2006).
[41] Foote (1999).
[42] Mueller and Dweck (1998).
[43] Schweinle, Turner, and Meyer (2006); Turner, Midgley, Meyer, et al. (2002).
[44] Mueller and Dweck (1998); see Foersterling (1985) for a review of research on attributional feedback.
[45] Dweck (2002); Mueller and Dweck (1998).

Potential roadblocks and solutions

Roadblock 2.1. Some teachers may find it difficult to focus on effort and strategy use rather than on performance. Too often, the attention of many students (and sometimes their parents) is on report card grades and exam scores. In addition, many teachers are required to assess and report performance in terms of grades or exam scores.

Solution. Teachers can draw attention to students' efforts when possible. When explaining exam scores or grades on an assignment, teachers can provide comments on effort and strategy. Teachers can routinely comment on the combined efforts of a class as students are working on assignments or projects.[46] Feedback specific to individual students is best delivered in a one-on-one context.[47] Teachers can also design assignments that reward effort. For example, students can be encouraged to submit drafts on which feedback can be given and then revised versions submitted for a grade.

Roadblock 2.2. Teachers whose schedules are already stretched may find it difficult in the course of the average school day to give each student detailed feedback on problem-solving and strategy use.

Solution. Feedback or praise does not need to be given all the time.[48] In fact, informative feedback, and particularly praise focused on effort, should be given only when it is genuine. Giving students praise on simple tasks may undermine motivation. When praise is warranted, teachers can focus on effort, using phrases such as, "you worked really hard." Teachers can be strategic in when and how they provide detailed informative feedback. For example, it often is appropriate to give such feedback to an entire class after a test or exam, especially when most students make a specific error. A class review after an assignment or test also is a good way to provide all students with informative feedback.

Roadblock 2.3. Many teachers rely heavily on standardized assessment techniques, which provide little feedback and can foster a performance rather than a learning orientation regarding scores.

Solution. Effective math and science programs provide continual, multiple assessments of student knowledge so that appropriate adjustments can be made throughout the year. Lessons should include formative and summative assessments of student progress, providing feedback to students long before the annual standardized assessments are taken. Teachers can also use peer feedback and critique as a classroom activity—providing clear criteria for feedback and critique to students at the outset.

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[46] Turner, Midgley, Meyer, et al. (2002).
[47] Ward (1976).
[48] Henderlong and Lepper (2002) provide a recent discussion of the research on praise.

Recommendation 3: Expose girls to female role models who have succeeded in math and science.

We recommend that teachers expose girls to female role models who have succeeded in math and science. Research demonstrates that triggering negative gender stereotypes can create problems for girls and women on tests of mathematics and spatial reasoning.[49] Exposure to female role models who have succeeded in math has been shown to improve performance on math tests and to invalidate these stereotypes.[50]

Level of evidence: Low

We rated the level of evidence that supports this recommendation as *low*. This recommendation is based on our extrapolation of relevant research, including four small experimental studies with college students.[51] Although the experiments that support the recommendation have strong research designs (internal validity) for supporting causal claims, these studies were conducted with college students rather than girls from kindergarten through high school and were short laboratory experiments, rather than real-world classroom studies conducted with students over extended periods of time. Thus, the applicability of these studies to the effects of exposing girls to female role models in natural contexts (e.g., classrooms) is limited.

In addition to these studies that explicitly address the effect of exposure to female role models on young women's math performance and beliefs about their math abilities, there is related research that supports this recommendation. This research includes experimental evidence that negative stereotypes can impede performance[52] and one small, cross-sectional observational study showing that children are aware of math-related gender stereotypes.[53]

Brief summary of evidence to support the recommendation

Researchers have found that negative stereotypes can affect performance in test-taking situations[54] and have labeled this phenomenon "stereotype threat." Stereotype threat arises from a psychologically threatening concern about confirming a negative stereotype, both in one's own eyes and in the eyes of others. For both self and others, the existence of the stereotype fosters negative beliefs about the meaning of difficulty or low performance—namely, that one lacks ability. Thus, when a woman is told that her math abilities are being evaluated, she is likely to perform worse on a standardized math test than a man with similar course grades and performance on assignments, because of the anxiety, deficits in short-term memory, and negative thoughts that have been shown to accompany stereotype threat. Studies also show that stereotype threat can lead young adolescent girls and women to choose unchallenging problems to solve,[55] lower their performance expectations,[56] and devalue mathematics as a career choice.[57] Thus, negative stereotypes can impair engagement and confident performance of girls and women in science, technology, engineering, and mathematics.

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[49] Aronson (2002); Aronson and Steele (2005); Steele, Spencer, and Aronson (2002).
[50] Marx and Roman (2002); McIntyre, Paulson, and Lord (2003).
[51] Ibid.
[52] For reviews of the research, see Aronson and Steele (2005); Steele, Spencer, and Aronson (2002).
[53] Steele (2003).
[54] Several experimental studies have been conducted with college students that demonstrate the stereotype threat phenomenon. For example, see Gonzales, Blanton, and Williams (2002); Spencer, Steele, and Quinn (1999); Steele and Aronson (1995).
[55] Aronson and Good (2002).
[56] Stangor, Carr, and Kiang (1998).
[57] Davies, Spencer, Quinn, et al. (2002).

Research also indicates that when some women take tests, a certain amount of stereotype threat is generally operative—that is, stereotype threat is the default unless measures are taken to counter it in the testing situation.[58] It is also the case that circumstances can be more or less threatening depending on the number of stereotype cues in the environment. For example, when men outnumber women in the room when taking a test, women perform worse than when they outnumber men, and women seem to perform better still when no men are present.[59]

Evidence from four random-assignment experiments indicate that exposing women to female role models who are high-achieving or who are perceived as math experts can mitigate the effects of stereotype threat on math test performance.[60] These studies show that even brief exposure to women who are perceived to be experts in math can improve female students' performance on math tests.

Although we did not identify experimental studies testing the effect of exposure to successful role models on the math or science performance of girls, experimental studies demonstrate that calling attention to gender decreased performance on math tests in 12-year-old girls but not in younger girls (10- and 11-year-olds).[61] In addition, researchers have found that by age 10 or so, simply being evaluated is enough to evoke stereotype threat with respect to academically stigmatized ethnic minority students.[62] These studies demonstrate that stereotype threat can be a problem by the time girls reach middle school.

Because the research on the effects of stereotype threat and exposure to positive female role models has primarily been documented with adult women, we considered related research on awareness of gender stereotypes by girls in general. Evidence from one small, cross-sectional observational study suggests that elementary-school-aged girls are aware of the stereotype that men are considered to be better at math than women, but that they view girls and boys to be equally good at math.[63]

Table 3. Percent of degrees awarded to women in engineering subfields in 1966, 1985, and 2004

	Bachelor's			Master's			Doctorate		
	1966	1985	2004	1966	1985	2004	1966	1985	2004
Aeronautical Engineering	.3	8.4	17.8	.8	5.1	17.1	0	4.0	11.9
Chemical Engineering	.8	23.4	35.4	.7	15.7	27.7	.5	8.1	23.9
Civil Engineering	.4	13.8	24.2	.4	11.7	27.2	0	5.1	19.6
Electrical Engineering	.3	11.5	14.2	.6	8.8	19.6	.4	4.9	13.5
Industrial Engineering	.4	29.1	33.2	.5	15.5	21.3	0	6.5	19.4
Mechanical Engineering	.2	10.5	13.6	.3	7.0	12.4	.2	5.1	11.1
Materials & Metallurgical Engineering	.9	22.4	31.2	.8	15.8	24.9	.9	10.6	17.7
Other Engineering Subfields	.8	16.0	29.9	.8	11.5	24.7	.4	6.3	24.9

SOURCE: National Science Foundation. Division of Science Resources Statistics. 2006. *Science and Engineering Degrees: 1966-2004.*

[58] E.g., Inzlicht and Ben-Zeev (2000); Inzlicht, Aronson, Good, et al. (2006).
[59] Ibid.
[60] Marx and Roman (2002); McIntyre, Paulson, and Lord (2003).
[61] Good and Aronson (2007).
[62] McKown and Weinstein (2003).
[63] Steele (2003).

Although the negative stereotype that women cannot perform as well as men in math and science exists and can affect students' performance, the stereotype is not necessarily accurate. As we indicated in the overview, women earn a substantial proportion of the bachelor's and master's degrees in math and in many science disciplines (see figure 2). Even in engineering, the proportions of degrees that women now earn have substantially changed over the last 40 years.[64] Table 3 shows the percent of degrees awarded to women by engineering subfields in 1966, 1985, and 2004. In 1966, women earned less than 1 percent of the bachelor's degrees in any engineering subfield. By 2004, women earned about one-third of the bachelor's degrees in chemical engineering (35 percent), industrial engineering (33 percent), and materials and metallurgical engineering (31 percent). Exposing girls to female role models may help negate the stereotype and encourage more girls to pursue math- and science-related careers.

How to carry out the recommendation

To counteract the negative stereotypes regarding women's math and science abilities, teachers should provide exposure to female role models who are experts in math and science fields. Experimental studies with college women indicate that learning about women who have achieved success in math or science can help attenuate the effects of negative stereotypes.[65] Teachers can expose students to female role models in a number of ways:

- Assign biographical readings about women scientists, mathematicians, and engineers.
- Call attention to current events highlighting the achievements of women in math or science.
- When talking about potential careers, make students aware of the numbers of women who receive advanced degrees in math- and science-related disciplines. The National Science Foundation publishes statistics on women in the sciences, math, and engineering each year. This information is available on its website (www.nsf.gov/statistics).

In addition, we suggest that teachers invite women or older students who can serve as role models in math or science to be guest speakers or tutors. Learning about role models who have achieved in math or science, whether through biographies or personal conversations:

- Teaches students that struggle and eventual success are normal. This knowledge seems to reduce anxiety and boost motivation when the student encounters challenges in work related to science, technology, engineering, or mathematics. A role model who communicates this may serve as a greater inspiration to persist through difficulty than someone for whom achievement appears effortless.[66]
- Conveys to students that becoming good at math or science takes hard work and that self-doubts are a normal part of the process of becoming expert at anything worthwhile.[67]

At least some female role models should be "attainable." Research supports the idea that older students who overcame initial difficulty with hard work eventually to become high performers can be effective role models.[68] A famously gifted female engineer for whom math and science always came easily and naturally is not always the best role model because she can be written off as an the exception—a rare case who triumphed through talent rather than hard work.

In addition, many mentoring programs have been created for young women in an attempt to provide them with role models and foster their interest in mathematics and science.[69] Mentoring is a broad term used to describe formal and informal programs in which mentors, who are people with expertise in a field, help people develop and accomplish their educational and career goals. Little rigorous research exists assessing mentors' effectiveness in math and science per se, but mentoring programs may provide many high-school-age girls with exposure to and connections with a woman who has succeeded in math and science. However, some promising research illustrates the effects of mentoring programs in increasing the numbers

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[64] National Science Foundation (2006b).
[65] Marx and Roman (2002); McIntyre, Paulson, and Lord (2003).
[66] Ibid.
[67] Ibid.; Wilson and Linville (1985).
[68] Good, Aronson, and Inzlicht (2003).
[69] Building Engineering and Science Talent (2004).

of minority students pursuing advanced degrees in science, technology, mathematics, and engineering.[70] In addition, rigorous experimental research has shown that mentors can positively affect young adolescents' behaviors (e.g., school attendance, drug and alcohol use).[71] Teachers may choose to support a young girl's interest in math or science by helping her to find a suitable mentoring program.

Potential roadblocks and solutions

Roadblock 3.1. School hours alone may not provide enough opportunities for girls to be exposed to female role models, particularly if many of the science and math teachers in a given school are male.

Solution. Teachers need to encourage parents to take an active role in providing opportunities for girls to be exposed to women working in the fields of math and science. Teachers might encourage parents to sign up girls for activities where women work in math- and science-related careers, such as at an aquarium, a hospital, or a scientific laboratory. In addition, several national organizations provide conferences designed to encourage girls' participation in math and science careers.

Roadblock 3.2. Many girls see math- and science-related careers as male oriented. If girls believe that careers in mathematics and science are nontraditional choices for women, they may be less likely to take advanced courses in math and science in high school or to choose a college path that leads to careers in math and science.

Solution. It is certainly true that the stereotype of the high achieving woman in math is a nontraditional one, and media images do not help this.[72] To counteract this stereotype, teachers can call attention to the fact that many women today are becoming mathematicians and scientists. The National Science Foundation publishes current statistics on the numbers of women and men receiving bachelor's, master's, and doctoral degrees in math and science.[73]

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[70] Maton and Hrabowski (2004); Summers and Hrabowski (2006).
[71] Tierney and Grossman (2000).
[72] E.g., Davies, Spencer, Quinn, et al. (2002).
[73] See National Science Foundation at http://www.nsf.gov/statistics/wmpd/ for current statistics on the numbers of women and men receiving degrees in math and science.

Recommendation 4: Create a classroom environment that sparks initial curiosity and fosters long-term interest in math and science.

To encourage more girls to choose careers in the fields of science, technology, engineering, and math, we recommend that teachers use strategies designed to generate initial interest in specific math and science activities and build on this initial interest to foster sustained interest in math and science content. Few teachers would be surprised by research indicating that students' interest is linked to academic performance and choices for both girls and boys. When students are interested in mathematics and science, they tend to get better grades in mathematics and science, take more advanced mathematics and science courses, and are more likely to pursue mathematics- and science-related college majors.[74]

Level of evidence: Moderate

A number of studies have shown that students' interest predicts both concurrent and long-term performance in and choice of math and science courses, majors, and careers.[75] In addition, several small-scale experimental studies have examined the effect of specific strategies (e.g., using practical problems as a context for learning math or science skills) on students' interest and learning. The panel judges the quality of the evidence supporting this recommendation to be *moderate*, based on five small-scale experiments that focus specifically on children learning in math and science contexts[76] as well as supporting experimental studies on interest in other domains or with adult populations and correlational studies of students' interest and course-taking or career choices.[77]

Brief summary of evidence to support the recommendation

Researchers have found gender differences in students' interests, with boys typically more interested in activities and careers involving scientific, technical, and mechanical pursuits and girls more interested in activities and careers that involve social and artistic pursuits.[78] These differences in interests are apparent by middle school and are reflected in undergraduate degree and career choices. Even highly mathematically able youth who were identified in adolescence and followed longitudinally showed gender effects in their choice of degrees. The ratio of male to female undergraduate degrees in math and science is 2.4:1.[79]

To make math and science content more interesting to students, it is helpful to think about what "interest" means. In research on learning, the word *interest* is used in two different ways. The first, which might be called *long-term* or *individual interest*, is a relatively stable and personal preference toward certain types of activities. A second kind of interest, which might be called *curiosity* or *situational interest*, is a more immediate response to particular aspects of situations or problems.[80] It is true, as noted above, that gender differences have been found in students' long-term interests. But many expert teachers realize that an important way to cultivate students' long-term interests in math and science is to build upon their initial curiosity. Research (as well as intuition) suggests that curiosity can serve as a hook to engage students in math and science content.[81] Once

[74] Simpkins, Davis-Kean, and Eccles (2006); Updegraff and Eccles (1996).
[75] Ibid.
[76] Cordova and Lepper (1996); Parker and Lepper (1992); Ginsburg-Block and Fantuzzo (1998); Turner and Lapan (2005); Phelps and Damon (1989).
[77] For a recent review of this literature, see Hidi and Renninger (2006).
[78] Lapan, Adams, Turner, et al. (2000).
[79] Webb, Lubinski, and Benbow (2002).
[80] Mitchell (1993); Hidi and Renninger (2006).
[81] Hidi and Renninger (2006).

students' interest in a topic or content area is sparked, teachers can then build on that curiosity, providing students with opportunities to engage with interesting material and potentially transforming that initial curiosity into long-term interest.

How to carry out the recommendation

Teachers can take several actions to create a classroom environment that sparks initial interest and may foster long-term interest.[82] To spark initial interest, teachers can provide students the opportunity to see how the skills and knowledge they are learning in mathematics and science classes can be used to solve interesting and meaningful problems. For example, teachers can:

- Embed mathematics word problems and science activities in interesting contexts.[83] For elementary school children, embedding mathematical practice in fantasy contexts (e.g., saving a planet from an alien invasion, searching for buried treasure or criminals) has been found to be highly motivating and interesting and has led to improved performance.[84] For middle school children, embedding mathematical practice in the contexts of real-world problems (e.g., figuring out how to build an effective skateboard ramp given a limited budget or a hovercraft that "flies" multiple students) can be both motivating and support learning.[85]

- Provide students with access to rich, engaging, relevant informational and narrative texts as they participate in classroom science investigations. For example, during weeklong series of science investigation activities where elementary school children learn about owls and birds and have the opportunity to dissect owl pellets and discuss what they find, the children are also asked to read from both informational and narrative texts that focus on owls. Embedding the reading activities into the context of science investigation serves to generate situational interest and further curiosity.[86]

- Use project-based learning, group work, innovative tasks, and technology to stir interest in a topic. Using web-based presentations of content and animated presentations of changes that occur during chemical bonding supports student exploration of key chemical concepts and is associated with improved learning. Other research shows that when students are asked to solve the series of problems presented in a video-based adventure as members of teams, they outperform their counterparts who are asked to solve the problems individually.[87]

- Examine the large variety of tools designed for teachers to use with girls and young women to spark initial curiosity about science and mathematics content. Many of these tools incorporate the principles that have been discussed in this practice guide. A listing of these tools is published in a volume entitled *New tools for America's workforce: girls in science and engineering* and can be downloaded at http://www.nsf.gov/publications/.[88]

Teachers can capitalize on that initial situational curiosity by providing students with opportunities to deepen their knowledge and understanding of particular math and science content and to broaden their understanding of how what they are learning today connects to their future goals. Teachers should also consider providing students with access to female role models who have been successful in mathematics and science careers to nurture long-term individual interest (see Recommendation 3).

- Encourage middle and high school students to examine their beliefs about which careers are typically female-oriented and which are typically male-oriented. Encourage these students to learn more about careers that are interesting to them but that they believe employ more members of the opposite gender. Connect mathematics and science activities to careers in ways that do not reinforce existing gender stereotypes of these careers.[89]

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[82] Mitchell (1993); Hidi and Renninger (2006).
[83] Renninger, Ewen, and Lasher (2002).
[84] Cordova and Lepper (1996); Parker and Lepper (1992).
[85] Bottge, Rueda, Serlin, et al. (2007).
[86] Guthrie, Wigfield, Humenick, et al. (2006).
[87] Barron (2000); Linn, Lee, Tinker, et al. (2006); Phelps and Damon (1989); Kaelin, Huebner, Nicolich, et al. (2007).
[88] National Science Foundation (2006a).
[89] Turner and Lapan (2005); Ji, Lapan, and Tate (2004); Lapan, Adams, Turner, et al. (2000).

Potential roadblocks and solutions

Roadblock 4.1. Teachers may be reluctant to incorporate aspects of youth culture into a lesson because they lack familiarity with students' interests. Teachers may be concerned that they might look silly by connecting to something long out-of-date in students' minds.

Solution. Certainly it is a challenge to follow cultural trends and fads in students' interests; it is likely that students do not expect their teachers to be able to keep up and may even be surprised when one is able to do so. However, connecting to trends in popular culture is only one potential strategy for arousing students' curiosity. Teachers can also seek to connect math and science content with other contexts that are of interest to students of all ages and generations, including history and current events. In addition, incorporating hands-on activities, group work, and technology into lessons can make the content more interesting for students.

Roadblock 4.2. Teachers may be reluctant to incorporate interesting activities, because of the belief that some activities might distract students and not serve the goals of the lesson.

Solution. Teachers should not interpret this recommendation as suggesting that *all* activities in math and science classes should take the form of games or fun activities. While games can be fun and exciting for students, it is also true that some games and activities that are not tightly linked to learning objectives may indeed distract students and be counterproductive to learning. Teachers should strive to achieve a balance between enhancing activities so that they incorporate some material that sparks interest while ensuring that content learning remains the primary goal of the lesson.

Roadblock 4.3. Teachers may be hesitant to use time-intensive methods such as hands-on activities and group work, given the pressure that many feel to keep up with curriculum pacing guides.

Solution. It is true that creating interesting and innovative tasks is time-consuming on many levels—increased preparation time for teachers, more time needed to cover the material in class, and frequently more time for teachers to grade or evaluate students' work. Teachers need to achieve a balance between incorporating interesting tasks and lesson formats and covering the required curriculum. But, despite increased time demands, using interesting tasks and instructional formats may be worth the extra effort: Research indicates a strong link between interest and academic performance, for both girls and boys. In addition, as a teacher and her students become more accustomed to doing things a bit differently (e.g., using group work or using project-based learning), the extra effort required to implement these kinds of activities can decrease.

Recommendation 5: Provide spatial skills training.

We recommend that teachers provide spatial skills training for girls. Researchers have found that spatial skills are associated with performance on math tests and that spatial skills can be improved with practice on certain types of tasks.[90]

Level of evidence: Low

We consider the level of evidence to support this recommendation to be *low* because of the lack of experimental or rigorous quasi-experimental studies that directly examine the effects of spatial skills training on girls' math or science performance. Our recommendation to improve math and science performance through spatial skills training represents an extrapolation based on the broader relevant research literature.[91]

Brief summary of evidence to support the recommendation

When we look at girls' math and science performance in school, we see that they are doing well on tests that are closely related to the curriculum they are taught in school. As noted earlier, girls, on average, graduate from high school with slightly more math and science classes than boys and with higher grades. Girls now obtain almost half of all undergraduate degrees in mathematics and the majority of degrees in health-related fields. But, as noted at the beginning of this guide, girls and women are underrepresented in physics, computer science, engineering, and chemistry at the undergraduate level, and their numbers fall off as they move beyond the undergraduate degree.[92]

We find the largest between-gender differences with standardized examinations that do not match any particular curriculum. We are referring to the standardized tests that are used for admission to undergraduate and graduate programs and for state and international comparisons. As already discussed, one possible reason that girls and women perform less well on these tests in mathematics and science is stereotype threat, but the differences are found on specific items on these tests, which suggests that there are gender differences in how certain types of questions are solved or not solved. For example, numerous researchers have found that when math items are highly spatial in nature, boys solve more of these questions correctly.[93] Consider the conclusion from a study of 24,000 ninth-graders, which showed that males perform better on items that require significant spatial processing and females outperform males on items requiring memorization.[94] Additional support comes from an analysis of the mathematical test questions that showed the largest gender differences favoring males on an international math assessment.[95] The items included calculating the height of a mountain, calculating the distance between two intercepts on a plane, calculating the length of a string, calculating the perimeter of a polygon, and other similar problems that are spatial in nature. There is evidence that gender differences in math problem-solving strategies begin as early as first grade, with girls

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[90] Doolittle (1989); Newcombe (2002); McGraw, Lubienski, and Struchens (2006).
[91] Ben-Chaim, Lappan, and Houang (1988); Piburn, Reynolds, McAuliffe, et al. (2005).
[92] A summary of research can be found in Halpern, Benbow, Geary, et al. (2007).
[93] E.g., Bielinksi and Davison (2001); Doolittle (1989); Gallagaher, De Lisi, Holst, et al. (2000); Geary, Saults, Liu, et al. (2000); Gierl, Bisanz, Bisanz, et al. (2003).
[94] Gierl, Bisanz, Bisanz, et al. (2003).
[95] Casey, Nuttall, and Pezaris (2001).

using more overt strategies, such as counting, and boys using more conceptual spatial strategies.[96]

A large research literature shows that boys outperform girls on many tests of spatial skills, especially ones that require visualizing what an object will look like when it is rotated in space.[97] Researchers have established that spatial skill performance is correlated with performance in mathematics and science.[98] For example, researchers have found that kindergarteners' ability to perceive and discriminate among various shapes and geometric forms predicts their later performance in fourth-grade math.[99] Scores on a spatial visualization test, for example, have correlated with subsequent test scores in geology.[100] Other evidence supporting the idea that spatial abilities are important in math and science was provided by researchers who found that scores on a test of mental rotation, which measures how well students can visualize an irregular shape when it is rotated in space, accounted for a large proportion of the male-female difference on standardized examinations.[101] Additionally, geometry items comprise close to one-third of the questions on the math portion of the SAT, and the largest differences between males and females are found on geometry items.[102] Spatial skills, therefore, figure importantly in the male-female test score gap.[103]

In mathematics, researchers have studied the way that representations affect the learning of complex mathematical ideas. For example, in a study of the strategies used to solve mathematical problems, researchers found that overall, the male students were more likely than female students to use a flexible set of general strategies and more likely to solve problems correctly when the solution required a spatial representation, a short cut, or the maintenance of information in spatial working memory.[104]

Several studies have documented that women who undergo specific spatial skills training programs show improved performance in the specific domain of their training.[105] In one study, for example, researchers designed and implemented a course to improve the spatial visualization skills of first-year engineering students.[106] In this course, students learned effective strategies for mentally representing objects, and for using graphs, diagrams, charts, and maps as tools for thinking about topics in science and mathematics. Notably, retention in the engineering program for female engineering students who took the spatial visualization course was 77 percent, whereas retention was only 47 percent among those who did not take the course. Although both females and males participated in the spatial training course, more females scored low on tests of spatial visualization at the start of the program, and females showed greater gains in retention in the engineering program as well as in grades. Other researchers examined the effects of spatial training when using information about maps and found that when students were taught how to project lines of longitude and latitude and to visualize the curve of the Earth's surface, their map skills improved.[107]

Several studies, including a few experiments using random assignment, have directly examined spatial skills training in school-age children. In these studies, children who received training in a specific spatial skill (e.g., mental rotation, spatial perspective, embedded figures) improved their performance on related visual and spatial measures more than children who did not receive this training.[108] In a recent synthesis of the spatial skills training literature, such training was found to improve the visual and spatial skills of both children and adults.[109] Thus, targeted training can serve to improve spatial skills performance beginning in early childhood and continuing into adulthood.

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[96] Carr, Jessup, and Fuller (1999).
[97] E.g., Battista (1990); Bielinksi and Davison (2001); Doolittle (1989); Harris and Carlton (1993); McGraw, Lubienski, and Struchens (2006).
[98] Casey, Nuttall, and Pezaris (2001); Kurdek and Sinclair (2001); Piburn, Reynolds, McAuliffe, et al. (2005).
[99] Kurdek and Sinclair (2001).
[100] Piburn, Reynolds, McAuliffe, et al. (2005).
[101] Casey, Nuttall, and Pezaris (2001).
[102] Harris and Carlton (1993).
[103] E.g., Bielinksi and Davison (2001); McGraw, Lubienski, and Struchens (2006).
[104] Gallagher, De Lisi, Holst, et al. (2000).
[105] Halpern (2000).
[106] Sorby (2001).
[107] Muehrcke and Muehrcke (1992).
[108] Connor, Schackman, and Serbin (1978); DeLisi and Wolford (2002).
[109] Marulis, Liu, Warren, et al. (2007).

To reiterate, the mathematical test items that show the greatest difference favoring boys are spatial in nature. Spatial skills can be improved with training. When spatial skills training was given to college students in engineering, grades in courses that use spatial skills improved and retention in engineering programs, especially for women students, improved. In addition, spatial ability predicted which courses high school students liked best (with math and science courses positively related to spatial ability) and the careers in which students were employed when they were in their 30s (with spatial ability positively related to careers in math, science, and engineering).[110]

How to carry out the recommendation

Teachers can provide spatial skills training with a variety of age-appropriate activities. In particular, teachers can:

- Encourage young girls to play with toys that require the application of spatial knowledge, such as building toys.[111]
- Teach older girls to mentally image and draw mathematics or other assignments so that they become as comfortable with spatially displayed information as they are with verbal information.[112]
- Require answers that use both words and a spatial display.[113]
- Provide opportunities for specific training in spatial skills, such as mental rotation of images, spatial perspective, and embedded figures.[114]

Potential roadblocks and solutions

Roadblock 5.1. Some teachers may not feel prepared to provide spatial skills training.

Solution. Many materials are available to help teachers include spatial skills in their everyday curriculum. Free software and lesson plans for grades K to 12 are available on websites dedicated to the topic of spatial skills training. In addition, published materials are available offering ideas to teachers for incorporating spatial skills training in their everyday curriculum.[115]

Roadblock 5.2. Learners in any classroom will vary in their spatial abilities, making it difficult for teachers to know how to target their teaching in this domain.

Solution. Tools and lesson plans available on the Web can be used by learners at different levels of ability. In addition to published materials, special workshops for teachers that vary by grade level could also help teachers begin to plan lessons, as well as ready-to-use sample exercises and online training programs.

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110 Shea, Lubinski, and Benbow (2001).
111 Deno (1995).
112 Gerson, Sorby, Wysocki, et al. (2001).
113 Casey, Nutall, and Pezaris (2001).
114 Sorby and Baartmans (2000).
115 Casey (2003).

Conclusion

To conclude, let us revisit our recommendations. What do we recommend that teachers do to encourage girls and young women to choose career paths in math- and science-related fields? One major way is to foster girls' development of strong beliefs about their abilities in these subjects—beliefs that more accurately reflect their abilities and more accurate beliefs about the participation of women in math- and science-related careers. Our first two recommendations, therefore, focus on strategies that teachers can use to strengthen girls' beliefs regarding their abilities in math and science: (1) Teach students that academic abilities are expandable and improvable; and (2) Provide prescriptive, informational feedback. Our third recommendation addresses girls' beliefs about both their abilities and the participation of women in math- and science-related careers: (3) Expose girls to female role models who have succeeded in math and science.

In addition to beliefs about abilities, girls are more likely to choose courses and careers in math and science if their interest in these fields is sparked and cultivated throughout the school years.[116] Our fourth recommendation focuses on the importance of fostering both situational and long-term interest in math and science, and provides concrete strategies that teachers can use to do so.

In addition to beliefs and interests, a final way to encourage girls in math and science is to help them build the spatial skills that are crucial to success in many math- and science-related fields, such as physics, engineering, architecture, geometry, topology, chemistry, and biology. Research suggests that spatial skills, on which boys have typically outperformed girls, can be improved through specific types of training. Thus, our final recommendation is that teachers provide students, especially girls, with specific training in spatial skills.

[116] Wigfield, Eccles, Schiefele, et al. (2006).

Appendix: Technical information on the studies

Recommendation 1:

Teach students that academic abilities are expandable and improvable.

Level of evidence: Moderate

The panel rated the level of evidence as *Moderate.* We were able to locate two small experiments demonstrating support for the practice of improving students' performance by teaching them that academic abilities are expandable and improvable.[117] In the first study, 138 girls and boys in seventh grade participated in the study that examined the effect of teaching students about the expandability of their abilities on end-of-year math and reading achievement test scores.[118] The second study was conducted with 95 girls and boys in seventh grade and examined the effect of such instruction on students' end-of-semester math grades.[119] In addition, we identified a small experiment with 79 female and male college students that demonstrated support for this practice improving students' end-of-term grade point averages.[120] All three studies included students from ethnically and socioeconomically diverse backgrounds.

These studies share the following features: Students or groups of students were randomly assigned to treatment and control conditions, where some were taught that intelligence is malleable and abilities are expandable, while others were not taught this but spent an equal amount of time engaged in learning something new. In all three studies, students in the group that was taught that abilities are expandable performed better than students in the control condition.

Example of an intervention that teaches students that academic abilities are expandable and improvable.

In our example study,[121] shortly after the school year began, 138 seventh-graders (both boys and girls) were randomly assigned a mentor, with whom they communicated throughout the school year. The mentors were 25 college students who were completing a required mentor-training course designed by the school district. The mentors' role was to offer advice to their assigned students regarding study skills and the transition to junior high, explicitly teach one of four messages, and help the students design and create a web page for their computer skills class in which the students advocated the experimental message conveyed to them by the mentor throughout the year.

The participating seventh-graders were randomly assigned to one of four conditions, representing a message taught by a mentor: (a) the incremental condition, in which students learned that intelligence is an expandable capacity that increases with mental effort; (b) the attribution condition, in which participants learned that many students experience difficulty when they move to a new educational level (such as junior high), but then improve their performance once they are familiar with their new environment; (c) a combined condition, in which students learned both the incremental and attribution messages; and (d) an antidrug control condition, in which students learned about the dangers of drug use. Each mentor had about six randomly assigned students across three of the four messages.

Students' math achievement was measured at the end of the school year using the Texas Assessment of Academic Skills, a statewide standardized achievement test administered to all students in the district.

Study results indicate that the boys in the antidrug condition performed significantly better on the math test than the girls; that is, the math score mean for the boys was 81.55, but the mean math score for girls was 74.00. However, in the three other conditions, the gender gap in math performance disappeared. The

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[117] Blackwell, Trzesniewski, and Dweck (2007); Good, Aronson, and Inzlicht (2003).
[118] Good, Aronson, and Inzlicht (2003).
[119] Blackwell, Trzesniewski, and Dweck (2007).
[120] Aronson, Fried, and Good (2002).
[121] Good, Aronson, and Inzlicht (2003).

math test scores of the girls in the experimental conditions were statistically equivalent to the scores of the boys across all conditions (i.e., in the incremental condition, the average math score for males was 85.25 and for females was 82.11; in the attribution condition, the average math scores of both boys and girls was 84.53; in the combined condition, the average math scores for females was 84.06 and for males was 82.30). Importantly, the large difference in test scores between boys and girls that was found in the control condition (i.e., antidrug message) was eliminated in the three experimental conditions. The experimental manipulations were particularly beneficial for the female students and demonstrated significant effects closing the gender gap in performance, indicating that the intervention procedures meaningfully increased girls' math scores compared to the control condition.

Recommendation 2:

Provide prescriptive, informational feedback.

Level of evidence: Moderate

The panel rated the level of evidence as *Moderate.* We were able to locate one high-quality study, which presented a series of six random assignment experiments demonstrating support for the practice of providing K–12 students with prescriptive, informational feedback as a way to improve student motivation and performance.[122] Two additional classroom-based experimental studies provide support for providing prescriptive, informational feedback during mathematics instruction.[123] We also drew on a recent substantive review of the literature that discusses the effects of praise on children's intrinsic motivation.[124] In addition, two high-quality longitudinal studies demonstrated the link between students' self-efficacy beliefs and their math- and science-related choices.[125]

In one of the longitudinal studies, researchers used a large random sample of students in 10 different school districts in southeastern Michigan to test the utility of students' math-related self-beliefs to explain variation in math course-taking.[126] Students examined in this study (n = 1,039) were followed from 9th to 12th grade, and were primarily from middle and lower middle class European American backgrounds. Self-concept of ability in math, utility of math, and interest in math were measured in the ninth grade using questionnaires. Grades in math, standardized test scores in math, specific course enrollment choices, and the number of math classes taken throughout high school were gathered from school record data. Findings indicated a strong and significant association between self-concept of math ability and performance in mathematics. In addition, the perceived utility of math had the strongest and most consistent association with the number of high school math courses taken, with boys perceiving math as having significantly greater utility than girls.

In the second longitudinal study, researchers analyzed data from a sample of 227 youths from 5th through 12th grade to address longitudinal associations among students' math- and science-related activities, their math and science related beliefs, and math and science courses taken throughout high school.[127] The researchers focused on the physical sciences. Results indicated that youths' participation in out-of-school math and science activities during fifth grade significantly predicted their math and science beliefs at sixth grade (e.g., math and science self-concepts, perceptions of math and science importance, and interest in math and science). These beliefs measured at 6th grade predicted beliefs at 10th grade, and the 10th-grade beliefs predicted the number of high school courses students took, even after taking into account the predictive power of their math and science grades in 10th grade.

Together, these two studies suggest a strong relation between the math and science courses that students choose to take in high school and their beliefs regarding their abilities and interest in these subjects, as well as their perception of the importance of these subjects. Although these studies have high external validity, they do not answer questions regarding the direction of causality between students' self-concepts in math and

[122] Mueller and Dweck (1998).
[123] Elawar and Corno (1985); Miller, Brickman, and Bolen (1975).
[124] Henderlong and Lepper (2002).
[125] Simpkins, Davis-Keans, and Eccles (2006); Updegraff and Eccles (1996).
[126] Updegraff and Eccles (1996).
[127] Simpkins, Davis-Kean, and Eccles (2006).

science and their performance in these areas. The third study[128] presents a series of six randomized controlled experiments that demonstrate that performance on a math-related skill can be improved by manipulating fifth-graders' attributions regarding success and failure, thus increasing their beliefs regarding the likelihood that they will succeed on future related tasks.

Example of an intervention that uses prescriptive, informational feedback.

In a series of six experiments, the impact of ability versus effort feedback on fifth-graders' subsequent performance on the Standard Progressive Matrices,[129] designed to measure ability to form perceptual relations and to reason by analogy, was examined. The Standard Progressive Matrices is a nonverbal measure that correlates strongly with the Stanford Binet and Wechsler Scales of intelligence. In addition, studies of the Wechsler Preschool and Primary Test of Intelligence (Revised) show that math performance is moderately related to perceptual organization for every age group sampled. Thus, the Standard Progressive Matrices measures perceptual relations skills that are related to mathematics performance.

The number of participating fifth-graders for each of the six studies was: 128, 51, 88, 51, 46, and 48. The ethnically and socioeconomically diverse students (both boys and girls) were drawn from public schools in the midwest and the northeast. Students were randomly assigned to one of three conditions: (a) ability or intelligence praise; (b) effort praise; and (c) a control condition in which students received a general statement of praise with no attributions regarding either ability or effort.

In this series of studies, students were asked to do three sets of Standard Progressive Matrices. Following the first set, students received either positive praise regarding their intelligence or ability; positive praise regarding their effort; or nonspecific praise that did not offer an attribution for success. Students then completed a second set of matrices, following which they were told that they had performed "a lot worse" on this set than they had on the first set. After completing items measuring dimensions such as desire to persist on the problems, enjoyment of the problems, and attributions for their failure, students were then given a third and easier set of matrices to complete, thus yielding a measure of post-failure performance.

Findings from this series of studies indicate that fifth-graders who were praised for ability performed less well following subsequent failure, whereas students who were praised for effort did not. Following failure, students praised for effort rather than ability also showed greater task persistence and enjoyment and greater orientation toward mastery learning. Students in the control condition typically had scores between those of students in the ability-praise and effort-praise conditions.

In this series of studies, several alternative explanations were ruled out, including the possibility that: (a) praise for ability might have led children to have higher expectations for future performance, which might then have led to greater disappointment following failure; (b) having the same teacher administer both positive and negative feedback following task completion might have increased the desire of ability-praised children to perform well on the second set of matrices; and (c) ability-praised children might have interpreted the task as an intelligence test, thus leading to greater disappointment following failure. With these competing explanations ruled out through experimental manipulation, the authors conclude that ability-focused praise led the fifth-graders to view performance as an index of ability, resulting in decreased motivation and performance following failure. Students who were praised for effort rather than ability did not show these post-failure deficits in motivation and performance.

Recommendation 3:

Promote positive beliefs regarding women's abilities by exposing girls to female role models who have succeeded in math and science.

Level of evidence: Low

The panel rated the level of evidence that supports this recommendation as *Low,* based on four small experimental studies with college students. Although the experiments that support the recommendation have strong internal validity for supporting causal claims,

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[128] Mueller and Dweck (1998).
[129] Ibid.

these studies were conducted with college students rather than girls in kindergarten through high school and were short laboratory experiments, rather than real-world classroom studies conducted with students over extended periods of time. Thus, the generalizability of these studies to the effects of exposing girls to female role models over, for example, the course of a school year is limited.

In addition to these studies that explicitly address the effect of female role models on young women's math performance and beliefs about their math abilities, there is evidence that exposure to positive role models or mentors can have a positive effect on students' behaviors.[130]

In a set of three small experimental studies with college students, researchers demonstrated that the presence of female role models who are competent in math mitigated the negative impact of gender stereotypes on the math performance of female college students.[131] These studies provide evidence that exposure to competent female role models can close the female-male math gap in testing and improve young women's beliefs about their math abilities. However, these studies do not examine the efficacy of female role models with girls from kindergarten through high school.

In another small, random-assignment experiment with college women, a team of researchers found significantly improved performance on a test of items similar to those used for the GRE math test when the students first read about women's accomplishments in architecture, law, medicine, and invention.[132]

These four studies provide evidence of the positive effect of female role models on the test performance of young college women and on their beliefs about their math abilities. Some evidence suggests that exposure to positive role models or mentors can have a positive effect on students' behaviors. For example, a large-scale evaluation of Big Brothers/Big Sisters found positive effects of mentoring on young adolescents' school attendance and drug and alcohol use.[133] We cite these studies as providing evidence that the strategy (i.e., exposing girls to positive role models) in general has been shown to be effective for elementary to secondary school students in some outcome domains, although not specifically for improving outcomes in math or science.

Example of intervention using competent female role models with college students.

In our example study, a research team conducted a series of three random-assignment experiments examining the impact of competent female role models on the performance of college women in a setting that was represented to participants as a diagnostic testing situation for math.[134] The participants in each of these experiments were students who considered themselves to be good in math and to be motivated to do well on math exams. In experiment 1, 43 undergraduate women and men were randomly assigned to undergo the math testing situation with either a female or a male experimenter, both of whom were presented to the participants as being competent in math. Women performed as well as their male counterparts when the experimenter was a woman; women did not do as well on the math test when the experimenter was a man.

In experiments 2 and 3, participants were provided with the biographical sketch of a fictitious female experimenter who was not actually present; in the biographical sketches, the female experimenter's level of math competence was manipulated to be either high or low. The results of both experiments demonstrated that the improved performance on the math exam obtained in experiment 1 was dependent on the undergraduate women perceiving the female role model to be very compentent in math, as opposed to simply taking the test with a female experimenter with average math skills. In addition, in experiment 3, the researchers found that young women's perceptions of their math ability were higher when they were exposed to a female role model who was competent in math.

These studies provide evidence that a brief exposure to a compentent female role model can affect college women's performance on tests and their perceptions of their math abilities. An important limitation of these

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130 E.g., Tierney and Grossman (2000).
131 Marx and Roman (2002).
132 McIntyre, Paulson, and Lord (2003).
133 Tierney and Grossman (2000).
134 Marx and Roman (2002).

studies for our purposes is that the participants were students who self-identified as being good in math and being motivated to do well on math tests.

Recommendation 4:

Create a classroom environment that sparks initial curiosity and fosters long-term interest in math and science.

Level of evidence: Moderate

The panel rated the level of evidence as *Moderate*. There is a long and rich tradition of exploring ways to increase student interest in mathematics and science content in education research. In determining the level of evidence supporting this recommendation, we drew on several experimental and quasi-experimental studies. For example, we found two small-scale, randomized controlled trials that demonstrate support for the practice of providing elementary school students with an environment that improves learning in the areas of mathematics and computer science by fostering greater interest.[135] Others have experimentally evaluated the facilitative effect of peer collaboration on solving mathematics problems;[136] while yet another study[137] examined how participating in a career exploration module fostered middle school girls' interest in nontraditional careers (e.g., those in the areas of mathematics and science). Two additional quasi-experimental studies provide support for the benefits of this practice on students' motivation and comprehension of science texts.[138]

One study examined the impact of three interest-enhancing strategies on the motivation and performance of 70 fourth- and fifth-grade students in a related math task.[139] Another examined the influence of embedding a computer programming task in a fantasy context with 27 children.[140] In another program of research, two studies involving a total of 885 third-grade students investigated reading comprehension of science texts.[141] Finally, another set of studies examined 133 third-grade and 106 fifth-grade students from two low-income schools with predominantly African-American populations.[142]

Across these studies, students in the high-interest conditions outperformed students in control conditions on study-specific indices of interest, motivation, and learning. The learning activities in each of these interventions share some or all of the following features: They were designed around contexts that students found engaging, made available a range of texts, used real-life settings, used technology, provided students' with choice, and used group work.

Example of intervention that improves math performance through increasing interest.

In this study, mathematics instruction was embedded in fantasy or nonfantasy computer games in order to study the impact of intrinsic interest on math performance.[143] Seventy students (both boys and girls) were randomly assigned to play computer games designed to teach specific math skills (the hierarchy of the order of operations and the proper use of parentheses in arithmetic expressions) in one of five conditions: (a) in a basic, unembellished version that served as a control condition, students played a math game on the computer in which they were required to learn and correctly use the target skills in order to win the game; (b) in two generic fantasy conditions, the activity was presented within fantasy contexts (spacetrip and treasure island) designed to increase children's intrinsic interest in the game; in the first generic fantasy condition, the students had some choice regarding at least six details that were incidental to the game itself (e.g., type and color of spaceship to use), whereas (c) in the second generic fantasy condition, these details were provided randomly by the computer; (d) in two personalized fantasy conditions, several generic referents in the program were replaced with details that were personally relevant to the child (e.g., child's name, favorite foods to bring along on the spacetrip), obtained from a

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[135] Cordova and Lepper (1996); Parker and Lepper (1992).
[136] Ginsburg-Block and Fantuzzo (1998); Phelps and Damon (1989).
[137] Turner and Lapan (2005).
[138] Guthrie, Wigfield, Barbosa, et al. (2004); Guthrie, Anderson, Alao, et al. (1999).
[139] Cordova and Lepper (1996).
[140] Parker and Lepper (1992).
[141] Guthrie, Wigfield, Barbosa, et al. (2004).
[142] Guthrie, Anderson, Alao, et al. (1999).
[143] Cordova and Lepper (1996).

pretest questionnaire; in the first personalized fantasy condition, the students had some choice regarding at least six details incidental to the game itself, whereas (e) in the second personalized fantasy condition, the students did not have a choice. Thus, the five conditions were: no-fantasy control condition; generic fantasy, no choice; generic fantasy, choice; personalized fantasy, no choice; personalized fantasy, choice.

The intervention consisted of five sessions. In the first session, participating students were pretested on their knowledge of the target math skills, and also completed several measures of their global motivational orientation. In the next three sessions, each child played with one randomly assigned version of the computer games. These sessions were scheduled about five days apart and lasted about 30 minutes each. In the fifth session, students completed posttests on the target math skills, as well as several additional attitudinal measures. Dependent measures included self-reports of interest and enjoyment, behavioral commitments to continued task engagement, preferences for increasingly challenging tasks, and direct measures of students' online involvement in the activities.

The results of the intervention indicate that students exposed to each of the three specific strategies designed to heighten student interest (contextualization, choice, and personalization) showed significantly greater motivation, involvement, and learning of the target math skills than those students in the control condition.

Recommendation 5:

Provide spatial skills training.

Level of evidence: Low

The panel rated the level of evidence as *Low.* That is, the evidence for the recommendation is based on the expert opinion of panel members, justified by high-quality research in related domains.

The panel located two high-quality studies of spatial skills training focused on skills that are generally considered important in math and science achievement. One study was a small-scale, random-assignment experiment with college students[144]; the other was a quasi-experiment with elementary or middle school students.[145] Both studies focused on the improvement of specific spatial skills. Although there is agreement among experts that the relevant skills are important to specific aspects of math and science performance, the transfer of these skills more generally to achievement in math and science courses has not been directly demonstrated. The evidence supporting the practice of spatial skills training as a way to improve performance in math and science courses in K–12 is thus indirect.

In the first study, 103 college students taking an introductory geology course were in one of four sections randomly assigned to either an experimental or a control condition.[146] Both experimental and control sections used the same laboratory manual; however, the two experimental sections used additional computer-based modules that allowed extensive student involvement with images that could be manipulated. Students were administered a content assessment and two spatial-visual measures as pretests and posttests. Study results indicate that students in the experimental sections improved their spatial visualization skills significantly more than did students in the control sections and that pre-existing gender differences with regard to spatial visualization were eliminated in the experimental sections. That is, final posttest scores of males and females on the spatial visualization tasks were not different from one another.

In the second study, researchers examined the impact of spatial visualization skills training on about 1,000 fifth- through eighth-grade students.[147] Before instruction, there were significant differences by sex in spatial visualization performance (favoring boys). After the intervention, middle school students, regardless of sex, gained significantly from the training program. Retention of the impact persisted after a 4-week period and after 1 year. The persistent gender differences found in performance after training in this younger sample are important to note. This research suggests that the spatial skills of both boys and girls are susceptible to

[144] Piburn, Reynolds, McAuliffe, et al. (2005).
[145] Ben-Chaim, Lappan, and Houang (1988).
[146] Piburn, Reynolds, McAuliffe, et al. (2005).
[147] Ben-Chaim, Lappan, and Houang (1988).

training; however, it leaves open the question of how to close the gender gap in spatial skills performance.

Example of intervention that improves spatial skills.

The quasi-experiment supports the practice of using spatial skills training to improve specific skills that experts consider to bear a relationship to performance in mathematics, science, and engineering.[148] Spatial visualization is a subset of spatial skills that involves the ability to mentally manipulate and rotate objects. In this study, about 1,000 fifth- to eighth-grade students at three sites in and around a large midwestern city participated in a 3-week spatial visualization unit that engaged them in concrete activities with small cubes, such as building and drawing representations. The spatial visualization test was used as a pretest and post-test measure. After the instruction intervention, middle school students, regardless of sex, gained significantly from the training program in spatial visualization tasks. Boys and girls responded similarly to the training program, indicating that spatial visualization skills can be improved when appropriate training is provided. The retention of the training effects 4 weeks and 1 year later underscores the potential long-term benefits of spatial skills training.

[148] Ibid.

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