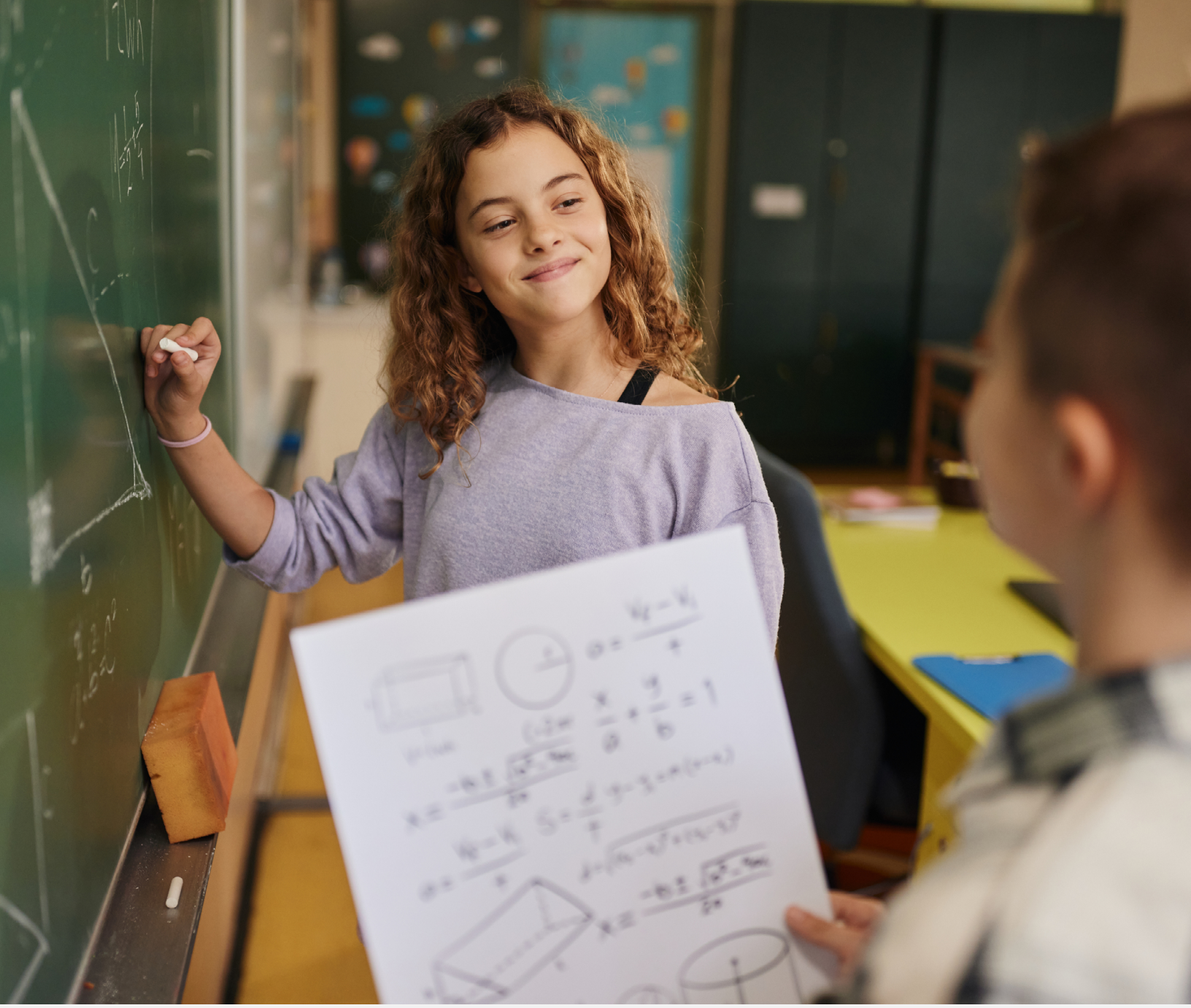

# Positive Conditions for Mathematics Learning

## An Overview of the Research

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LEARNING POLICY INSTITUTE

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# Executive Summary

United States math achievement has long lagged behind that of other nations and has been relatively stagnant for 8th-graders on national assessments over the past 2 decades. The need to understand how teachers can better support mathematics learning is particularly acute in the wake of pandemic-era learning disruptions, which impacted already low math performance more than other subject areas. According to multiple analyses, the negative effects of disrupted learning hit students hardest in districts and schools serving higher proportions of students from low-income families and historically marginalized racial and ethnic groups. However, even prior to the pandemic, United States math performance outcomes have long featured significant racial and socioeconomic achievement gaps.

The factors contributing to disparate outcomes in math achievement are complex. Systemic barriers abound. In particular, these include students' inequitable access to well-prepared math teachers, high-quality curriculum and instruction, and advanced coursework. Resolving systemic disparities in students' opportunities to learn math will be essential to improving U.S. learning outcomes in math and will require the careful design and implementation of policies that address each of these conditions.

However, educators need not wait for the resolution of systemic issues to begin creating more equitable learning opportunities within their own classrooms. A significant and growing body of research suggests that what happens in the classroom greatly influences student achievement in math, particularly for historically marginalized student groups. Deepening understanding of the classroom conditions that are most conducive to math learning will help pave the path toward math classrooms in which all students can thrive and achieve their potential.

## Why Classroom Conditions Matter

Recent syntheses of research from the fields of neuroscience, psychology, and other developmental and learning sciences emphasize the impact of the classroom environment on student learning. Commonly referred to as the science of learning and development (SoLD), this body of research finds that students learn best in environments where they feel a sense of physical, emotional, and identity safety; hold positive relationships with adults and peers; and experience belonging, purpose, and affirmation. These positive conditions promote healthy development, supporting both cognitive growth and physical, psychological, social, and emotional development. They can also help to counter the negative effects of stress and trauma, which impact the brain in ways that biologically impair learning.

Attending to learning conditions in math classrooms is particularly important due to the prevalent fear and anxiety that students experience related to math. Creating math classroom environments that are more aligned with students' developmental needs can help to resolve the common experience of "math anxiety" and thereby enable more positive and productive math learning experiences.

## Report Overview

This report synthesizes research findings from the fields of mathematics teaching and learning, educational psychology, and the learning sciences to identify key classroom learning conditions that matter for K–12 math learning. To organize discussion of the research literature, the report is divided

into four sections, each describing a different classroom condition that emerged as important for student learning. The literature provides evidence that students learn math best when they can do the following:

1. Experience **positive relationships** with their teachers
2. Feel a sense of **belonging** in their classroom community and the broader mathematics community
3. Adopt a **growth mindset**, meaning the belief that their mathematical ability can be cultivated through effort
4. Engage with **high-quality instruction** delivered by teachers who hold high expectations and offer strong supports for their success

Each section of the report reviews the research findings of greatest relevance for teachers and articulates research-supported practices that can foster positive math learning experiences.

## The Importance of Positive Relationships

A large body of research has found that students who report positive relationships with their teachers tend to experience other positive academic outcomes, including elevated math achievement. Different studies found that positive teacher–student relationships increased student self-efficacy, intrinsic motivation for learning math, classroom engagement, and sense of mathematics identity—with each of these qualities linked to heightened math achievement. Other studies provide evidence that emotionally supportive teachers create environments in which all students, including those students with doubts about their ability to succeed in math, feel safe to participate fully in the learning process.

The literature also points toward several relationship-based approaches that can support improvements in students' experiences within their math classrooms. For instance, teachers can:

- cultivate caring classroom relationships by providing sincere encouragement, creating space for students to share their personal identities and experiences, incorporating one-on-one teacher–student interactions, and explicitly communicating expectations;
- collect data on students' perceptions of teacher–student relationships to monitor the quality of their classroom interactions; and
- couple classroom care and support with high expectations and quality instruction.

## The Importance of Belonging

For students, the feeling that they are "personally accepted, respected, included by others in the school social environment" helps to establish the classroom as a psychologically safe space for social and cognitive inquiry, experimentation, and growth. Developmentally, this is very important, particularly during adolescence. A developing research base suggests that, in addition to social belonging, it is also important for students to feel a sense of "mathematics belonging," or a sense that they are

socially accepted as an able "doer" of math. Mathematics belonging matters, at least in part, to counter the prevalent gender- and race-based stereotypes about innate mathematical ability that many students internalize.

Teachers' practices can influence students' sense of social and mathematics belonging. For instance, teachers can:

- position students as mathematically competent during classroom interactions;
- support the development of positive and collaborative peer relationships; and
- examine their own beliefs about mathematical ability and cultivate more inclusive practices that communicate value for students as members of the classroom mathematics community.

## The Importance of a Growth Mindset

Students' beliefs about their abilities to learn and succeed in math matter for their learning. Researchers and practitioners alike commonly discuss students' beliefs about their ability to learn and succeed through the lens of mindset theory. Students either ascribe to a "fixed" mindset, whereby they view ability and intelligence as static and innate, or a "growth" mindset, whereby they view ability and intelligence as malleable and able to be developed over time. Growth mindset aligns with contemporary scientific understandings of how the brain works and positively associates with student math learning outcomes.

Fortunately, research shows that interventions designed to teach students a growth mindset positively impact their math outcomes, with particularly notable effects for economically disadvantaged and academically high-risk students. For instance, teachers can:

- learn more about what it means to have a growth mindset so that they can further establish a classroom context that encourages students' own growth mindsets;
- provide students with explicit instruction about the malleable nature of human intelligence and ability;
- adopt teaching practices that reinforce a growth mindset orientation and equip students with strategies that help them learn and grow in response to failure; and
- collect data on students' perceptions of their teacher's growth mindset orientation.

## The Importance of High-Quality Instruction

Classroom learning conditions that allow students to feel emotionally safe, supported, and able to succeed establish the necessary preconditions for deep engagement in academic learning opportunities. However, these developmentally enabling classroom conditions must be coupled with high-quality math instruction for students to achieve to their potential and thrive as mathematical thinkers, learners, and doers.

Teachers, supported by well-designed curricular materials, can promote students' mathematical growth and development through high-quality instruction. For instance, teachers can:

- emphasize conceptual understanding rather than algorithmic problem-solving;
- give students opportunities to grapple with mathematically challenging content that is within reach but that also allows them to creatively flex their skills and knowledge;
- create opportunities for well-structured collaborative learning;
- offer instructional tasks that allow for multiple means of solving, which better mirror real-world math problems and are more interesting and stimulating for students;
- provide culturally relevant and empowering learning experiences that leverage students' assets to support, extend, and solidify their math learning; and
- include timely evidence-based interventions, when needed, to address student knowledge gaps and areas where they need additional skills development.

## Conclusion

Both developmentally and cognitively, students benefit from learning math in classrooms that provide them with supportive relationships, a strong sense of belonging within the classroom and broader mathematics community, and a firm conviction in their capacity to grow their mathematical abilities through experience and practice. In such classrooms, students are better situated to benefit from high-quality math instruction. When experienced together, these four positive classroom conditions set the foundation to promote math learning experiences that are characterized not by fear but instead by the excitement of discovering mathematical relationships and grappling with challenging and meaningful problems in the context of a supportive classroom community.

# Introduction

The need to understand how teachers can better support math learning is particularly acute in the wake of pandemic-era learning disruptions, which impacted already low math performance more than other subject areas.[1] Between 2019 and 2022, 49 states experienced significant declines in 8th-grade public school students' math performance on the National Assessment of Educational Progress (NAEP), which researchers attributed to lost opportunities for learning due to schooling disruption.[2] According to multiple analyses, the negative effects of disrupted learning hit students hardest in districts and schools serving higher proportions of students from low-income families and historically marginalized racial and ethnic groups.[3] The 2024 NAEP data shows that average student achievement has not yet fully rebounded. Although numerous states have begun to see improvements to 4th-graders' average scores, there were no states in which 8th-grade students' average scores significantly increased between 2022 and 2024. In fact, 8th-graders' average math scores significantly *decreased* in four states.[4]

Even before the pandemic, United States math achievement was lackluster. Student math outcomes on the NAEP, known as The Nation's Report Card, gradually inched up for 4th-graders yet remained relatively stagnant for 8th-graders over the past 2 decades.[5] International standardized assessments show that average U.S. math achievement lags behind that of other nations in the Organisation for Economic Co-operation and Development (OECD).[6] As of 2022, only a small fraction of American students were achieving at the levels of other students from high-achieving countries.[7]

Math performance outcomes in the United States have long featured significant racial and socioeconomic achievement gaps, which result from a confluence of factors impacting students' opportunities to learn.[8] These outcome differences contribute to disparities in science, technology, engineering, and math (STEM) degree attainment—particularly in physical science and engineering—and subsequent entry into associated career fields.[9] While these disparities have shown gradual improvement, women and Hispanic, Black, American Indian, and Alaska Native persons continue to be severely underrepresented both in terms of degree attainment and workforce representation within most STEM fields.[10]

The factors contributing to disparate outcomes in math achievement are complex. Systemic barriers abound: In particular, these include students' inequitable access to well-prepared math teachers, high-quality curriculum and instruction, and advanced coursework.[11] The persistent tracking of students in math courses based on their perceived ability—a practice that can be subject to unconscious racial biases[12]—further expands the gap between the learning opportunities available to different student groups and the gaps in their resulting achievement outcomes and attitudes toward math.[13] Resolving systemic disparities in student access to quality math instruction will be essential to improving U.S. learning outcomes in math and will require the careful design and implementation of policies that address each of these conditions.

However, educators need not wait for the resolution of systemic issues to begin creating more equitable learning opportunities within their own classrooms. A significant and growing body of research suggests that what happens in the classroom greatly influences student achievement in math. This is particularly the case among historically marginalized student groups and during the middle school years, a time when students' general school motivation and math engagement can sharply decline.[14] Deepening the shared understanding of the classroom conditions that are most conducive to math learning will help pave the path toward math classrooms in which all students can thrive and achieve their potential.

## Why Classroom Conditions Matter

Recent syntheses of research from the fields of neuroscience, psychology, and other developmental and learning sciences emphasize the impact of the classroom environment on student learning.[15] Commonly referred to as the science of learning and development (SoLD), this body of research provides evidence that students learn best in environments where they feel a sense of physical, emotional, and identity safety; hold positive relationships with adults and peers; and experience belonging, purpose, and affirmation.[16] These positive conditions promote healthy development, supporting students' cognitive growth and their physical, psychological, social, and emotional development.[17] They can also help to counter the negative effects of stress and trauma, which impact the brain in ways that biologically impair learning.[18]

Students learn best in environments where they feel a sense of physical, emotional, and identity safety; hold positive relationships with adults and peers; and experience belonging, purpose, and affirmation.

In the classroom, teachers play a central role in establishing the daily learning conditions that students experience. Through interpersonal relationships, classroom management practices, and instructional strategies, teachers can attend to the social-emotional developmental needs of students. When students' developmental needs for safety, positive relationships, belonging, and meaningful engagement are met, they are better positioned to engage with cognitively demanding learning experiences.[19]

Attending to learning conditions in math classrooms is of particular importance due to the prevalent psychological fear and anxiety that students—and adults, including many elementary math teachers[20]—experience in relation to math. This phenomenon is commonly referred to as "math anxiety."[21] Research on the neural basis of math anxiety finds that children with high math anxiety perceive math as threatening: They respond to situations requiring mathematical engagement with high levels of neural activity in the area of the brain that processes emotions and fearful stimuli.[22] At the same time, they exhibit lower levels of neural activity in the brain areas that engage in mathematical and numerical reasoning compared to peers without math anxiety. Researchers hypothesize that the emotional reaction experienced by students with math anxiety diverts attention away from the task at hand, co-opting the student's ability to engage deeply in mathematical cognition and even reducing their working memory (i.e., the amount of information they can temporarily store and manipulate to process complex cognitive tasks).[23]

Unsurprisingly, researchers have linked the experience of math anxiety with numerous negative outcomes, such as reduced math achievement and a tendency to avoid college math courses and majors or career paths that require math.[24] It's worth also noting, however, that many math anxiety researchers theorize that math anxiety can emerge as a *result* of students' early struggles with math—and then kick off a vicious cycle by impeding their ongoing learning.[25] For this reason, any conversation about learning conditions in math classrooms needs to also include discussion of how to improve the quality of math instruction, in addition to the social and emotional experiences of students.

By cultivating classroom conditions that attend to students' developmental and learning needs, teachers can create environments that ameliorate students' anxiety and develop the sense of safety that is necessary for deep cognitive engagement with math. This report examines the research literature on the characteristics of classrooms that promote math learning—with particular attention to the social and

emotional developmental needs of students—with the goal of identifying the teaching practices that create more positive environments for math learning. With this report in hand, teachers can be better positioned to provide developmentally supportive, rather than threatening, math learning experiences that enable learners to engage deeply in their math learning, achieve at high levels, and pursue rewarding careers in STEM and other fields that require quantitative reasoning skills.

## Report Overview

This report synthesizes research findings from the fields of mathematics teaching and learning, educational psychology, and the learning sciences to identify key classroom learning conditions that matter for K–12 math learning. In their review of literature, the authors focused on malleable conditions that teachers have the ability to influence through their classroom practice.

Notably, this report is not intended to be a systematic or fully comprehensive literature review. Instead, the authors endeavor to provide a broad overview of topics at the intersection between the science of learning and development and mathematics teaching and learning. To this end, they conducted comprehensive database searches to find research articles that examined, in the context of math instruction, constructs identified in the science of learning and development as developmentally important for learning. In particular, they focused on physical, emotional, and identity safety; positive relationships with adults and peers; and the experience of belonging, purpose, and affirmation.[26]

Given the subject-specific focus of this review, literature on effective math instructional practices was also examined as a necessary complement to socially and emotionally positive learning conditions. However, the authors did not review research specifically related to effective math teaching in relation to curriculum, standards, or licensure. In addition to identifying relevant articles through database searches, the authors examined the citations of highly relevant studies to identify additional articles for review, which helped to build an understanding of applicable bodies of research. After initial screenings, this process resulted in the identification and full review of more than 70 articles.

To organize discussion of the relevant research literature, the report is divided into four sections, each describing a different classroom condition that emerged from the literature review as important for student learning. The literature provides evidence that students learn math best when they can do the following:

1. Experience **positive relationships** with their teachers
2. Feel a sense of **belonging** in their classroom community and the broader mathematics community
3. Adopt a **growth mindset**, meaning the belief that their mathematical ability can be cultivated through effort
4. Engage with **high-quality instruction** delivered by teachers who hold high expectations and offer strong supports for their success

The divisions between these sections are heuristic in nature and, in reality, considerable overlap exists between many of the conditions; for instance, a student's relationship with their teachers greatly influences their sense of belonging.[27] Nonetheless, treating these conditions as distinct allows us to draw attention to different components of the classroom experience that emerged as salient in the literature. Each section of the report reviews the research findings of greatest relevance for teachers and articulates research-supported practices that can foster positive learning experiences.

# The Importance of Positive Relationships

*Positive teacher–student relationships matter for students' math engagement and achievement.*

Relationships matter for student learning.[28] Teacher–student relationships, in particular, have attracted the attention of researchers for decades. A large body of research, as described below, has found that students who report positive relationships with their teachers tend to experience other positive academic outcomes.

One meta-analysis of more than 90 research articles focused on students in grades PreK–12 found significant medium to large associations between positive teacher–student relationships and student engagement and found small to medium associations with achievement.[29] The meta-analysis also concluded that the positive association between teacher–student relationships and academic outcomes was strongest for specific student groups, namely, students who identified as members of racial and ethnic minority groups or came from lower-income families. Positive relationship associations were also stronger for students enrolled in middle or high school compared to elementary school. Unfortunately, these secondary schooling years also tend to be a period during which teacher–student relationships can become less personal and less positive as middle and high schools organize adolescents into larger classes and create schedules that require them to cycle among multiple teachers' classrooms each day.[30]

Some studies have examined what mediates the positive associations between teacher–student relationships and student math outcomes. In other words, they have asked the question: When a student experiences a positive relationship with their teacher, how does this relationship then bolster their math learning and achievement? The following have emerged as important pathways through which positive teacher–student relationships work to improve student academic outcomes:

- **Increased Self-Efficacy and Intrinsic Motivation.** In a large-scale nationally representative study of 14,639 10th-graders, students with more positive perceptions of their teacher–student relationships reported significantly higher levels of self-efficacy and intrinsic motivation in math than their peers who reported less positive teacher–student relationships.[31] Students' self-efficacy, or their belief in their ability to accomplish specific math goals, and their intrinsic motivation, or them having greater interest in learning math, correlated positively with their math achievement. Evidence also suggests that positive teacher–student relationships may affect some students differently. In a longitudinal study of nearly 1,500 5th- and 6th-grade Hispanic students, researchers measured students' perceptions of teacher caring by asking students whether their teacher takes "a personal interest in them as individuals," empathizes with their feelings, and listens and responds to their concerns.[32] These perceptions of teacher care were positively associated with students' math self-efficacy and standardized test scores, with this association being stronger for English learner Hispanic students as compared to their English-fluent Hispanic peers.

- **Greater Sense of Belonging and Enjoyment of Math Learning.** A smaller-scale study found that 7th- and 8th-grade students who perceived higher levels of affective support from their math teachers reported, on average, a greater sense of belonging, higher academic enjoyment and self-efficacy, and lower academic hopelessness. These factors, in turn, were associated with greater self-reported levels of academic effort.[33]

- **Increased Engagement.** A study of 5th- and 6th-grade students found that students who perceived their teachers as warm and emotionally supportive tended to report greater engagement in the learning process. This increased engagement linked, in turn, to heightened math achievement.[34] Furthermore, there is limited evidence that positive relationships may improve the *quality* of student engagement, with one study finding that teachers who provided high emotional support early in the school year tended to have higher levels of mathematical discourse in their classrooms later in the year (as evaluated by an external observer).[35]

- **Greater Sense of Mathematics Identity.** A large-scale nationally representative study of nearly 20,000 9th-graders examined how teacher practices influence students' mathematics identity—their beliefs about their "ability to participate and perform effectively in mathematical contexts" and be socially recognized as someone capable of doing so.[36] In this study, Luis Miguel Fernández and colleagues found that students reported, on average, a greater sense of mathematics identity when they believed that their teacher valued and listened to all student ideas, treated students fairly and with respect, thought every student could be successful, and communicated that "mistakes are OK so long as all students learn."[37] In this study, students' mathematics identity mediated the association between students' positive teacher relationships and their math achievement.

Further evidence suggests that emotionally supportive teachers create environments in which all students, including students with doubts about their ability to succeed in math, feel safe to participate fully in the learning process. In a study of 387 5th-grade students and their 63 math teachers, an independent observer rated classrooms on the teachers' levels of emotional support, which the study conceptualized as "the teachers' connection to and responsiveness toward students, awareness of students' individual differences and needs, and willingness to incorporate students' points of view into learning activities."[38] Students in classrooms rated with high levels of emotional support reported higher levels of mathematical and social engagement. Notably, students who reported low math self-efficacy generally also reported lower math engagement than their more efficacious peers, but these associations did not occur for students in classrooms with higher teacher emotional support (based on classroom observations).[39]

The findings from this study suggest that emotional support from teachers can help to reengage students who initially come to class with lower confidence in their mathematical abilities, potentially by minimizing the feeling of inhibition that may otherwise keep them from participating fully in classroom activities and interacting comfortably with peers. Put differently, in emotionally supportive environments, students can feel safe to take academic risks in their learning and fully engage with classroom learning opportunities.

In emotionally supportive environments, students can feel safe to take academic risks in their learning and fully engage with classroom learning opportunities.

Overall, the existing literature—although correlational—suggests the importance of positive relationships for students' engagement with and learning of math. It also points toward several relationship-based approaches that can support improvements in students' experiences within their math classroom. For instance, teachers can do the following:

- **Cultivate Caring Classroom Relationships.** The affective support that teachers provide to their students matters for their learning. Teachers can develop caring relationships with their students by providing sincere encouragement, creating space for students to share their personal identities and experiences, incorporating one-on-one teacher–student interactions, and explicitly communicating expectations.[40] As stated previously, this may be particularly important for students from minoritized racial and ethnic groups, from low-income families, or who have low confidence in their mathematical ability. A number of researchers further emphasize that classroom caring requires teachers to acknowledge and attend to the racial and cultural specificity of their students by addressing social inequity and oppression rather than operating with the goal of colorblindness.[41] In addition to this, it's worth underscoring that teacher-perpetuated racial and ethnic discrimination can greatly damage the math classroom learning environment. One large-scale longitudinal study found that, in math classrooms where students report more frequent instances of teacher-perpetuated racial or ethnic discrimination, *all* students—not just those who are directly discriminated against—tended to view their teacher as less supportive and "less sensitive to students' needs and perspectives."[42] Classroom engagement, course grades, and test scores were worse, on average, in these math classrooms.

- **Collect Data on Students' Perceptions of Teacher–Student Relationships**. For teachers to work on improving classroom climate, they need to monitor how their students perceive their teachers' support efforts. However, research suggests that many teachers face two main challenges when looking at their data. First, students in the same classroom can perceive their teachers' affective support differently.[43] Second, teachers can have a difficult time assessing the quality of their classroom interactions. For example, one study found that students' and independent observers' perceptions of the quality of teacher–student interactions in a math classroom both better predicted students' math engagement and outcomes than the teachers' own perceptions of interactional quality.[44] Other studies found notable gaps of relationship quality between White teachers' perceptions and their Black and Hispanic students' perceptions.[45] Taken together, these findings suggest that teachers may benefit from gathering data on students' perceptions of their classroom experiences rather than relying on their own subjective interpretations.

- **Couple Classroom Care and Support With High Expectations and Quality Instruction.** Although numerous studies furnish evidence that positive teacher–student relationships promote student learning and engagement, others suggest that students require more than just a feeling of bonhomie within the classroom. While relationships can lay the groundwork for student learning, high-quality and cognitively demanding instruction remains essential for learning. (See The Importance of High-Quality Instruction for further discussion.) It is worth emphasizing that teachers should *not* downgrade their expectations for student learning out of a desire to spare the feelings of mathematically underperforming students, nor should teachers, out of a desire to be caring, comfort students with reassurances that not everyone is a "math person." When this happens, students miss out on opportunities to learn and may, as one study finds, end up less motivated and with lower expectations for their own performance.[46]

# The Importance of Belonging

*When students feel a sense of belonging, both socially and mathematically, they tend to be more engaged and academically successful.*

Students learn best when they feel a sense of social belonging in their school and classroom community.[47] For students, the feeling that they are "personally accepted, respected, included by others in the school social environment" helps to establish the classroom as a psychologically safe space for social and cognitive inquiry, experimentation, and growth.[48] Developmentally, this is very important, particularly during adolescence.[49]

Numerous studies provide evidence that students who feel a sense of belonging in their school or classroom community tend to experience more positive social-emotional and academic outcomes. A meta-analysis of 82 studies found positive correlations between secondary students' sense of belonging with their engagement, educational motivation and attitude, self-concept, self-efficacy, and academic achievement.[50] Other individual studies have reported associations between students' sense of belonging and their academic motivation, effort, and expectations for success.[51] They also found that students who feel like they belong were more likely to report a mastery orientation toward learning—even after controlling for self-efficacy.[52] One researcher hypothesized that students who feel a sense of social belonging no longer need to exert effort "avoiding the negative appraisals of others or approaching material from a solely competitive framework" and thus can better focus on their learning.[53]

While ample research literature associates students' overall sense of belonging with learning outcomes,[54] there is a particularly pointed discussion around belonging within STEM subjects. A developing research base suggests that, in addition to general social belonging in school, it is important for students to feel a sense of "mathematics belonging."[55] Mathematics, as a discipline, has long been plagued by the incorrect notion that success in math requires an innate quantitative ability—that some people have the "math gene" whereas others do not.[56] This belief is articulated in the common refrain, repeated by students and adults alike, that "I'm just not a math person." For this reason, many students may have difficulty identifying as a member of the "mathematics community," or the group of people who can learn and excel in math and be socially recognized as having this ability.[57]

This impediment to students' sense of mathematics belonging may be exacerbated by additional gender- and race-based stereotypes about innate mathematical ability.[58] Indeed, adolescent female students as well as non-Asian racial and ethnic minority students report, on average, a lower sense of mathematics belonging than their male and White or Asian peers.[59] As a result of interactions with individuals and media sources (including teachers and textbooks) that express and reinforce stereotyped expectations, students may internalize these stereotypes and develop the sense that math is simply not "for them" or that they are not a "math person." To compound these factors, negatively stereotyped students also commonly experience elevated levels of stress when asked to perform a math-related task (a phenomenon referred to as "stereotype threat");[60] this can, in consequence, undermine their achievement.[61]

A recent study of middle school students shows that their competency expectations and sense of mathematics belonging—operationalized as their math-related feelings of acceptance, level of comfort, enjoyment of participation, and trust that their teachers will help them learn—predict their algebra learning, even when taking into account their prior algebra knowledge and self-concept.[62] A follow-up study found that sense of belonging was the only significant predictor of student learning as measured on a pre/post-test of algebra skills, even when considering students' socioeconomic status, perceptions of the importance of math, incremental view of mathematical ability, and interest in math.[63] Notably, this study also found that non-Asian racial and ethnic minority students reported lower levels of belonging than their Asian and White peers, even though there were no differences in their prior algebra knowledge.

Practices that help students identify themselves as "part of the mathematics community" may help to promote student learning, particularly for students who are members of negatively stereotyped racial and ethnic minority groups.

Together, these findings suggest that practices that help students identify themselves as "part of the mathematics community" may help to promote student learning, particularly for students who are members of negatively stereotyped racial and ethnic minority groups. This finding is reinforced, somewhat more broadly, by a recent qualitative study that examined the impacts of youth STEM programming on the later adult involvement in STEM fields for program participants who were predominantly from groups that have been historically underrepresented in STEM. The researchers reported that most of the participants who ended up having high adult STEM involvement noted the program's contribution to their STEM identity, and some additionally noted the social-emotional development from program participation.[64]

As suggested by the literature, teacher practices can influence students' sense of social and mathematics belonging.[65] There are numerous opportunities available to establish classroom conditions that promote students' sense of social and mathematics belonging. For instance, teachers can:

- **Position Students as Mathematically Competent.** Teachers can help students develop their sense of mathematics belonging by positioning them as mathematically competent during classroom interactions. For instance, teachers can highlight the value of student contributions in whole class contexts,[66] specifically through explicit statements that validate their mathematical reasoning.[67] They can also invite students to articulate or justify their thinking in ways that position them as competent problem-solvers who can explain mathematical thinking and procedures to their classmates.[68] Furthermore, by encouraging a student's classmates to respond to and build on their contributions, teachers can position these contributions as mathematically important while also contributing to a student's sense of social belonging.[69] Importantly, the goal is not to create a sense of *false* competence, but instead to draw students' attention to their areas of existing competence in order to encourage their engagement in further competency-building learning opportunities.
- **Support the Development of Positive and Collaborative Peer Relationships.** Students' relationships with their classroom peers greatly influence their sense of classroom belonging and impact their academic achievement.[70] However, due to the traditional individualistic orientation of math

classrooms, researchers note that students often have limited opportunities to develop the social relationships that can contribute to their sense of belonging in the math classroom.[71] By increasing opportunities for well-structured collaborative work in heterogenous ability groups, teachers can promote the development of mutually respectful peer-to-peer relationships that allow students to feel valued as members of the classroom community.[72] Heterogeneous ability groups also disrupt traditional practices of within-class ability tracking that can negatively impact students'—and particularly female students'—views of their competence in math.[73] Opportunities for collaboration can also be structured in ways that help students develop social-emotional competencies, such as their ability to empathize with others; listen to other points of view; and regulate their own emotions, thoughts, and behaviors that also support their math learning. A recent longitudinal study of nearly 50,000 elementary and middle school students found that students who self-reported improvements in their social-emotional measures (including social awareness and self-management) experienced significant positive growth on their scores on their subsequent standardized math assessment.[74]

- **Examine Their Own Beliefs About Mathematical Ability and Cultivate More Mathematically Inclusive Practices.** Teachers' beliefs about how students learn math and who typically (or "naturally") excels at math shape their classroom practices and send students signals that influence their sense of mathematics belonging and classroom engagement.[75] Practices that communicate to students that they are accepted as members of the classroom mathematics community, allow them to feel comfortable and enjoy participating, and build students' trust that their teachers will help them learn in their math classroom can help promote a strong sense of belonging. These practices also have been positively associated with students' math learning.[76] For example, culturally responsive and affirming teaching practices and curricular materials can communicate to students from historically marginalized groups that their teacher views them as able doers of math, which can enhance students' enjoyment and level of comfort when participating in math learning opportunities. (See The Importance of High-Quality Instruction for more on culturally responsive instructional practices in math.)

# The Importance of a Growth Mindset

*Students exhibit better learning outcomes when they believe that their mathematical ability can be cultivated through effort.*

Students' beliefs about their ability to learn and succeed in math matter for their learning. As discussed previously, the pervasive myth that some people are "math people" while others are not is a damaging myth for math learners. It is also patently false based on what is known about the human brain. In recent years, neuroscientific research has shown that all students, including those who have been diagnosed with mathematical learning disabilities, have the ability to build the brain pathways that support mathematic learning and that children's brains respond with "remarkable plasticity" to math training interventions.[77] That is, brains continually forge new connections based on experiences, which means all students can build their capacity to learn math all throughout their schooling.

Researchers and practitioners alike commonly discuss students' beliefs about their ability to learn and succeed through the lens of mindset theory. Mindset theory posits that learners tend to fall into one of two categories: They either have a "fixed" mindset whereby they view ability and intelligence as static and innate (e.g., you either *are* or *are not* a math person), or they have a "growth" mindset whereby they view ability and intelligence as malleable and able to be developed over time.[78] The latter stance aligns with contemporary scientific understandings of how the brain works.

Students' mindsets influence the way they engage with learning. Students with a fixed mindset tend to be more focused on performance than on mastering academic content.[79] Even for high performers, the fear that failure will expose them as someone without innate ability always operates, whether consciously or not, in the background. Because of their need to protect their sense of competence, students with fixed mindsets tend to prefer easy over effortful tasks and enjoy challenging work less,[80] likely due to the worry that any need to exert effort will be interpreted as a sign of low ability. They respond to failure with a sense of helplessness, since it is, from their perspective, an indication of an innate and unchangeable ability deficit.[81]

Carol Dweck, the Stanford psychologist who popularized the concept of mindsets, hypothesizes that students with a growth mindset are free of this psychologically threatening framework.[82] As a result, they are more likely to embrace challenging academic work, viewing effort as an indicator that learning is taking place, and are better able to bounce back after failure, viewing these instances as an opportunity for learning.[83]

Researchers have found positive associations between students' mindsets and their math learning outcomes. In California, a study following 221,840 students in 4th through 7th grade for a full academic year found that student mindsets correlated with their rate of growth on math and English language arts assessments in the following school year, even when controlling for student background, previous achievement, and measures of other social-emotional skills.[84] The researchers who ran the study estimated the observed effect of a strong growth mindset (relative to a fixed mindset) on average math growth to be the equivalent of 23–31 additional days of learning. A follow-up longitudinal study of

49,216 elementary and middle school students from the same districts examined how changes over time in students' self-reporting of certain social-emotional measures, including growth mindset, would impact their academic performance.[85] The data showed that changes in students' self-reported growth mindset–oriented beliefs over time quickened their rate of growth on standardized math and English language arts assessments. Among other social-emotional measures—including student self-efficacy, social awareness, and self-management—growth mindset held the strongest effect on students' math achievement growth.

The role of growth mindsets may play a more important role for some students than others. International analyses of 2018 achievement data from approximately 600,000 15-year-old students in 78 countries found that students who expressed a growth mindset scored slightly higher on the math assessment, after controlling for the socioeconomic profile of students and schools, although the effect size was small.[86] These students also reported lower levels of fear of failure than their fixed-mindset peers. Researchers found a greater benefit of having a growth mindset for female, immigrant, and socioeconomically disadvantaged students.

> Research shows that interventions designed to teach students a growth mindset positively impact their math outcomes.

Fortunately, research shows that interventions designed to teach students a growth mindset positively impact their math outcomes. In-person and virtual experimental interventions designed to teach K–12 students a growth mindset have been associated with increases in general classroom motivation;[87] math grades, particularly among lower-achieving students;[88] achievement on math standardized tests, particularly for female students;[89] and enrollment in advanced math courses.[90] While the strength of the relationship between growth mindset interventions and academic achievement continues to be debated,[91] meta-analyses find evidence that economically disadvantaged and academically high-risk students tend to benefit from these interventions, even if the effects on the overall student population are weaker.[92]

One recent study found the impact of growth mindset interventions on students' math grades is greater when their teacher also has a growth mindset. In a nationally representative double-blind clinical trial that included 8,775 9th-grade students and their 223 math teachers, David Yeager and colleagues tested the effectiveness of a growth mindset intervention on students' mindsets and math grades.[93] All students in the intervention group had significantly lower fixed-mindset beliefs at the end of the intervention.

However, when their math grades were examined later in the year, only the intervention students who were taught by a math teacher who espoused a growth mindset exhibited significant improvements to their math grades. The study found no differences between intervention and control group students whose teachers espoused a fixed mindset. The authors concluded that these findings suggest a "mindset-plus-supportive-context hypothesis."[94] Although they observed an immediate effect of the intervention on students' mindsets, they found that students also needed to be in a classroom context where their teacher shared these growth mindset beliefs—and likely reinforced them through classroom discourse and practices—in order for the intervention to result in improvements in their subsequent math grades.

As the Yeager study suggests, teachers can cultivate and reinforce students' growth mindset orientations through their classroom practices. For instance, teachers can do the following:

- **Learn More About What It Means to Have a Growth Mindset.** A teacher's personal beliefs about the nature of intelligence and ability matter to the students in their classrooms. Not all teachers have had sufficient—or, in some cases, any—training in mindset theory, and many hold fixed beliefs about their students' and their own mathematical abilities that can transfer into their classroom practice.[95] Even teachers who are familiar with the term "growth mindset" may harbor misconceptions about its meaning. For instance, they may reduce growth mindset to a "generic optimism that ability will always improve" or mistakenly associate a growth mindset with successful students and a fixed mindset with unsuccessful students.[96] For many teachers, developing and deepening their understanding of mindset theory is a foundational step toward the establishment of a classroom context that encourages students' growth mindsets. Furthermore, evidence suggests that teachers' familiarity with mindset beliefs may equip them to notice when students express a fixed mindset, allowing those teachers to intervene with practices that promote a growth mindset.[97]

- **Provide Students With Explicit Instruction About the Malleable Nature of Human Intelligence and Ability.** Growth mindset interventions have been shown to promote student achievement. While most intervention studies focus on interventions delivered by researchers, one randomized-controlled study of a teacher-delivered growth mindset intervention for their students found positive effects on student grades, particularly in classrooms where teachers reported a fixed mindset orientation prior to the intervention.[98] This finding suggests that teachers can cultivate growth mindsets by providing age-appropriate explanations of how the human brain works, emphasizing its ability to develop new neural connections as a product of experience, and framing effort and practice as key to learning.

- **Adopt Teaching Practices That Reinforce a Growth Mindset Orientation.** The student mindset changes supported through explicit instruction on growth mindset may be difficult to sustain without concurrent shifts in classroom practice.[99] Certain teaching practices can inadvertently contradict growth mindset messaging.[100] For example, grouping students by ability for collaborative work may convey to students the idea that math ability is a fixed trait.[101] Rather than placing the onus on students to adopt and sustain a growth mindset orientation in the face of mixed messages, teachers can work toward creating a classroom environment that reinforces growth mindset beliefs in all aspects of instruction. Furthermore, they should equip students with strategies that help them learn and grow in response to failure and that normalize the performance ups and downs that may precede mastery.

  Researchers have synthesized the literature on growth mindset to identify math teaching practices that are informed by and reinforce a growth mindset orientation.[102] These include:

  - establishing and reinforcing classroom norms that communicate the belief that all students can learn and succeed in math, that the goal is learning rather than performing, and that mistakes represent opportunities for learning;
  - avoiding the use of fixed labels to describe student ability (e.g., "high" and "low" students);
  - using mixed ability–level groupings that provide all students access to mathematically rich tasks;

- providing specific, process-based praise that focuses on how students engage in mathematical thinking rather than the correctness of their solutions; and
- adopting formative assessment structures that provide students feedback on their progress toward specific learning goals and that allow students multiple opportunities to demonstrate their mastery of material after they receive support (e.g., through assessment retakes or test corrections).[103]

- **Collect Data on Students' Perceptions of Their Teacher's Growth Mindset Orientation.** Unfortunately, even when teachers espouse a growth mindset orientation, they may inadvertently communicate a fixed-mindset orientation through their language and practices.[104] A new vein of research has begun to examine how college students' beliefs about their STEM teacher's mindset influence their learning experiences.[105] In one study, students' perceptions of their professor's mindset orientation predicted their subsequent sense of belonging, classroom engagement, interest in STEM, and course grades.[106] While a comparable study has not yet been conducted in the K–12 context, researchers hypothesize that younger students' perceptions of their teacher's mindset may influence their learning experiences, given the importance of student perceptions in other contexts.[107] Collecting data on student perceptions of the teacher's mindset orientation can help the teacher identify disconnects in their own beliefs and practices as well as inform continuous improvement.

# The Importance of High-Quality Instruction

*Students' opportunities to learn and succeed in math maximize when teachers couple positive classroom learning conditions with high-quality instruction, high expectations, and strong supports for all students.*

As detailed in the previous sections, teachers have the capacity to implement concrete practices that can support student engagement with math. Classroom learning conditions that allow students to feel emotionally safe, supported, and able to succeed establish the necessary preconditions for deep engagement in academic learning opportunities. However, these developmentally enabling classroom conditions must be coupled with high-quality math instruction for students to achieve to their potential and thrive as mathematical thinkers, learners, and doers. Indeed, classroom conditions appear to lay the groundwork for students to engage with, make meaning of, and benefit from well-designed math learning experiences.

Developmentally enabling classroom conditions must be coupled with high-quality math instruction for students to achieve to their potential and thrive as mathematical thinkers, learners, and doers.

Teacher instructional practices matter for student learning, with multiple studies finding that teacher instructional practices have a stronger relationship with student math achievement than other factors. For example, in the Fernández et al. nationally representative study of nearly 20,000 9th-graders, described previously, researchers identified teachers' self-reported usage of "reform-oriented pedagogy" as a strong predictor of students' mathematics identity.[108] By reform-oriented pedagogy, the study referred to instruction that develops students' problem-solving skills, explores connections between math ideas, teaches students to effectively explain their mathematical thinking, and teaches students the logical structure of math.

Although teachers' relational practices were also positively associated with student identity, teachers' usage of reform-oriented pedagogy was also a *direct* predictor of students' math achievement, whereas the relationship between teachers' relational practices and achievement was mediated by students' mathematics identity. This finding suggests that reform-oriented classroom instruction helps students come to view themselves as competent doers of math at the same time as it develops the skills and knowledge that will allow them to demonstrate mastery of core math content. In another study, researchers found a statistically significant relationship between teachers' implementation of ambitious and inquiry-oriented instruction and student performance on a low-stakes math assessment. The relationship between classroom emotional support and student performance in this study was, in contrast, not statistically significant.[109]

High-quality math instruction requires students to move beyond the memorization and reproduction of algorithmic problem-solving methods. Instead, it involves "ambitious learning goals that are grounded in the expectation that all students will develop high-level thinking, reasoning, and problem-solving skills."[110]

This means that, in addition to procedural fluency, math instruction should support all learners in developing deep conceptual understanding that enables them to draw connections between different areas of math, model their mathematical thinking, strategically select methods that suit different contexts, and reason adaptively to solve challenging and authentic problems.[111] These practices bring students' classroom activities more in line with the actual practices of working mathematicians and communicate the expectation that all students can engage with math at a high level. Indeed, students show greater growth in math achievement when they view their teacher as academically challenging, with an especially strong relationship between challenge and academic growth in classrooms with more African American students.[112]

Teachers, supported by well-designed curricular materials,[113] can promote students' mathematical growth and development through high-quality instruction. For instance, mathematical instructional quality can be bolstered when teachers do the following:

- **Emphasize Conceptual Understanding.** Due to the traditional—and in many cases, ongoing—emphasis in U.S. classrooms on rote learning and algorithmic problem-solving, many students experience mathematics as a series of disconnected procedures. As a result, they may see little relationship among the concepts they encounter over the course of the school year, let alone across grade levels. Instead, contemporary research suggests that teaching for conceptual understanding—i.e., emphasizing the "why" rather than just the "how" of mathematical content and making connections between different areas of math and problem-solving procedures—can promote greater mathematical fluency, support the retention of new facts and methods, and enhance students' ability to apply their math learning to novel situations.[114] Researchers suggest the following practices as means of supporting students' conceptual understanding:
  - "discussing the mathematical meaning underlying procedures,
  - asking questions about how various solution strategies are similar to and/or different from one another,
  - considering the ways in which mathematical problems build on each other or are special (or general) cases of each other,
  - attending to the relationships among mathematical ideas, and
  - reminding students about the main point of the lesson and how this point fits within the current sequence of lessons and ideas."[115]

  Others highlight the practice of modeling mathematical concepts with multiple forms of representation—e.g., using an array, area, or set model in addition to the standard algorithm when teaching multidigit multiplication—as another strategy that can reinforce and deepen students' conceptual understanding (both within and across mathematical domains) while also improving their ability to creatively problem-solve.[116]
- **Give Students Opportunities to Grapple With Mathematically Challenging Content.** Mathematics education researchers hypothesize that the process of "struggling to make sense of mathematics" can contribute to student learning.[117] When teachers give students instructional tasks that ask them

only to replicate mathematical procedures that have been explicitly demonstrated, students miss out on opportunities to develop their conceptual understanding and apply their learning to novel situations. Tasks that are within reach for students but that also offer opportunities to grapple with mathematical ideas that are "not yet well formed" can push students toward mastery, within their zone of proximal development.[118]

These opportunities can also help students learn to creatively flex their skills and knowledge. Importantly, a classroom environment that encourages a growth mindset can help students interpret this type of struggle in developmentally positive ways. (See The Importance of a Growth Mindset.) To provide students at all levels of understanding with this opportunity, teachers can use tasks that have a "low floor and high ceiling," including multistep problems that progressively grow more complicated.[119] These types of tasks lower barriers to engagement by allowing all students to access success *and* to push their mathematical thinking. They also tend to be more engaging and interesting for students.[120]

- **Create Opportunities for Well-Structured Collaborative Learning.** Although U.S. math classrooms historically prioritized independent problem-solving over collaborative work, emerging research identifies a positive link between engagement in collaborative problem-solving and student math achievement,[121] particularly for Black and Hispanic students.[122] In one example, a study of kindergarten math learning found a positive association between the frequency of interactive group activities and math achievement, with significant effects across students from different socioeconomic and racial/ethnic backgrounds.[123] Further evidence suggests that struggling students may benefit more from mixed ability–level groupings than from being grouped with students who similarly struggle.[124]

  However, absent established norms for collaborative work, researchers find that students may value their peers' contributions to group discussion differently based on their social positioning[125] or membership in a stereotyped identity group.[126] Practices such as modeling positive forms of group engagement, assigning unique roles and responsibilities, and designing open-ended tasks that allow students to demonstrate their competence in different ways may help students get the most out of opportunities to reason and discuss mathematical ideas in collaboration with their peers.[127]

- **Offer Instructional Tasks That Allow for Multiple Means of Solving.** Tasks that require students to "impose meaning and structure, make decisions about what to do and how to do it, and interpret the reasonableness of their actions and solutions" better mirror the ways they will apply mathematical ideas to real-world problems in the workforce.[128] Approaching math in this way has the potential to be far more cognitively stimulating and enriching than tasks whereby teachers focus on the one "correct" approach to solving a problem.[129] One experimental study found that students who were prompted to create multiple solutions reported greater interest in math than their peers who were prompted to provide a single solution.[130] Furthermore, embracing multiple means of solving classroom problems opens the door for students to compare different solution methods. Research conducted in algebra classrooms found that the practice of comparing solution methods can prompt reflection on the efficiency and accuracy of different strategies and deepen students' conceptual understanding, most notably for students who already have sufficient baseline knowledge of algebraic methods.[131]

- **Provide Culturally Relevant and Empowering Learning Experiences.** Teachers can design classroom experiences that leverage students' cultural and linguistic backgrounds and experiences as assets that can support, extend, and solidify their math learning. Researchers and practitioners often refer to this approach as "culturally responsive teaching."[132] In the math classroom, culturally responsive teaching can involve:
  - linking mathematical language and concepts to familiar ideas and activities;
  - incorporating culturally responsive interactional techniques in instruction (e.g., choral responses, storytelling, movement);
  - creating opportunities for students to apply mathematical reasoning and problem-solving to community-based or social justice issues;
  - increasing classroom collaboration;
  - building relationships with student families; and
  - when possible, facilitating multilingual engagement to support students as they process higher-level math.[133]

  By weaving ideas, activities, and interactional styles that are familiar to students from their life outside of school, teachers can create learning experiences that make math feel more welcoming, engaging, and relevant for their students. A recent research synthesis of 35 studies of culturally responsive teaching in math learning environments reported several associations between culturally responsive instructional practices and student outcomes. These included increases in student interest, enjoyment, and confidence in math; persistence in problem-solving; and positive attitudes toward math.[134]

- **Include Timely Evidence-Based Interventions.** While strong instruction coupled with positive classroom learning conditions lays a groundwork for math learning, there always will be students who require additional support to access grade-level content. Teachers can use formative assessment data to identify knowledge gaps and areas where students need additional skills development so that they can deploy timely and targeted interventions that will help students succeed and thrive in their math classrooms. The What Works Clearinghouse identifies several intervention strategies, supported by strong research evidence, that can bridge skills gaps for students and support students with disabilities.[135] These include providing systematic instruction that:
  - incrementally and intentionally "builds student knowledge over time toward an identified learning outcome(s)";
  - teaches "clear and concise mathematical language" and supports students' mathematical language usage;
  - uses "well-chosen … concrete and semi-concrete representations"—including, in particular, number lines—"to support students' learning of mathematical concepts and procedures";
  - provides specific instruction on word problems that supports students' "capacity to apply mathematical ideas"; and
  - incorporates timed activities that help students build their arithmetic fluency.[136]

# Conclusion

Both developmentally and cognitively, students benefit from learning math in classrooms that provide them with supportive relationships, a strong sense of belonging within the classroom and broader mathematics community, and a firm conviction in their capacity to grow their mathematical abilities through experience and practice. In such classrooms, students are better situated to benefit from high-quality math instruction. When experienced together, these four positive classroom conditions have the potential to promote math learning experiences that are characterized not by fear, but instead by the excitement of discovering mathematical relationships and grappling with challenging and meaningful problems in the context of a supportive classroom community.

Math teachers, although they have great influence over the classroom environment, cannot accomplish this shift alone. Other groups that play an important role are the following:

- **Teacher preparation programs** can explicitly teach preservice math educators about the importance of positive classroom conditions and equip them with the skills and knowledge to establish these conditions in their own classrooms.
- **School and district leaders** can support in-service math teachers using multiple approaches. They can provide access to and create time for professional learning that helps teachers refine their practices in line with the research and/or initiate observation-feedback cycles with the same intent. They can use math-specific classroom observation and feedback tools—such as the Mathematical Quality of Instruction (MQI) or Teaching for Robust Understanding (TRU) frameworks—to provide math teachers with formative feedback or adopt survey tools designed to help teachers and schools assess classroom climate and learning conditions—such as those offered by the Project for Education Research That Scales (PERTS), Kelvin, and Panorama Education. Furthermore, district and school leaders can select curricular materials that facilitate the delivery of high-quality, cognitively challenging math instruction, reinforce a growth mindset orientation toward math learning, and support each student's identity development as someone who can "do" math.
- **The research community** can support teachers by developing and refining data tools that support teachers' ability to assess and reflect on student perceptions of the classroom environment with greater objectivity and that provide guidance on how to refine their practices in line with the newest research. By pulling together in the same direction, educational practitioners and researchers alike can move the needle toward more positive math learning experiences and outcomes for all students.

Positive learning conditions show promise for helping all students achieve their full potential in math. Notably, student groups that have been historically marginalized in math education—namely, female students, students of color, and students experiencing poverty—may stand to benefit most from a transition toward more developmentally nurturing classroom environments.[137]

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