EF+MATH program

Executive Functions, Mathematics, and Equity: A Primer

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1. Introduction

The EF+Math program funds and supports discovery and development that aims to create equitable outcomes in mathematics education in middle childhood (grades 3 - 8). Our mission is to challenge the way people think about how students learn. Students from all backgrounds are equally capable of success in mathematics. However, not all students are given equitable opportunities to build their mathematical abilities, mindsets, and identities. While our goal is universal—that all students are provided equitable opportunities to thrive in mathematics—we fund strategies that support students who have been historically underserved: students learning in under-resourced schools and students of color.

In this primer, we aim to put forward our current views regarding the points of synergy between equity, executive function, and mathematics education and cognition that are relevant to the EF+Math program. The literature shared herein is not exhaustive, but instead is a high-level overview of aspects of these fields that are relevant to the work of EF+Math, with the intention that the information shared stimulates discussion and innovation at this intersection.

We take a strengths-based approach and focus on the foundational skills that all students have and that underlie learning: specifically, the ability to hold and work with information in mind, the ability to focus attention on what a student deems important and ignore what she deems unimportant, and to be flexible in her thinking. These abilities have been referred to as 'executive functions', and are essential assets that every student possesses. Executive functions allow students to have agency over their attention, emotions and behavior to achieve the learning goals they set for themselves. We take the stance that providing students with opportunities to develop their math-relevant executive function skills is about building more equitable opportunities for students to develop agency, and to use that agency to learn anything. We take an equally strong stance that supporting the development of executive functions is not about teaching compliance or ensuring students stay on task. We view executive function skills as a path to student agency, such that students can direct their executive function skills toward learning what they deem important to learn.

Many sources of evidence—including learning science research and teacher expertise—reveal that every child is equipped to excel in mathematics, and yet disparities in mathematics performance still persist. For instance, children's understanding of numbers ('number sense') predicts later math knowledge and can show measurable differences by socioeconomic status (SES) and race as early as preschool (e.g., Bailey, Siegler & Geary, 2014). Early mathematics knowledge is related to long-term educational outcomes, as well as a person's career attainment and health outcomes (e.g., Knuth, Stephens, Blanton & Gardiner, 2016; Rittle-Johnson, Fyfe, Hofer, & Farran, 2016). Given that there are no inherent differences in abilities in students from different races/ethnicities or household income levels, observed performance differences are instead likely driven by differences in *opportunities* to build math abilities given to students from different races/ethnicities or household income levels, with students of color and students in poverty more often held back, offered less challenging math curricula, and held to lower expectations (among other factors) than their peers from higher income households or their white peers (e.g., Carbonara, 2005; Chunn, 1998; Oakes, 1995; Sorhagen, 2013). Thus, a core, and yet addressable, issue in mathematics education is the need to reduce inequalities between students' opportunities to learn and to be given opportunities to be challenged in mathematics (e.g., Byrnes & Wasik, 2009; TNTP, 2018). We will support programs that tackle these challenges head-on.

Despite structural inequities that perpetuate math performance differences, every child possesses foundational assets that enable them to learn what they deem important to learn. One set of skills associated with success in mathematics is executive functioning (EF) ability. EFs are thought to include three separable, yet interacting processes, often referred to as cognitive flexibility, working memory, and inhibitory/attentional control (Miyake et al., 2000):

- ***Cognitive flexibility*** refers to shifting one's attention between or otherwise managing multiple tasks, goals, rules, or perspectives. *An example in mathematics is when a student needs to switch back and forth quickly and easily between solving multiplication and subtraction problems.*

- ***Working memory*** involves holding and working with information in one's mind. *An example in mathematics is when a student is doing algebra and is holding in mind which steps they completed on one side of the equation and the answer they got so they can balance it on the other side.*

- ***Inhibitory/Attentional control*** is the ability to focus on the information or tasks that are important or relevant to you and ignoring or inhibiting distractions or behaviors that are not important or relevant to you. *An* *example in mathematics is ignoring irrelevant details when solving word problems and focusing on the information needed to complete the task.*

While substantial individual differences in EFs exist, all three components of EF on average have been found to be related to performance on mathematics tasks, and to predict mathematics achievement longitudinally (e.g., Bull & Lee, 2014; Cragg & Gilmore, 2014; Ribner, 2019). Teachers have also observed that EFs are important for math learning based on their experience in the classroom (Gilmore & Cragg, 2014). Indeed, one study found that teachers' ratings of students' EF abilities predicted gains in mathematics skills over an 8 month period (Fuhs, Farran, & Nesbitt, 2015), though it's probable that teacher expectations of both mathematics and EF skills may be correlated and thus predictive of math performance.

Mathematics requires all three components of executive function: thinking flexibly, holding and updating important information in working memory (e.g., Fuchs et al., 2008; Raghubar et al., 2010), and inhibiting misconceptions and irrelevant information or rules (e.g., Cragg et al., 2017; Gomez et al., 2015). Here we highlight relevant examples:

- *Cognitive flexibility:* A meta-analysis found that children who had a higher capacity to flexibly shift between different tasks tended to perform better on math achievement measures (Yeniad et al., 2013). Cognitive flexibility has been found to account for more of the variance in math ability when EF components are studied separately, but the relationship is weaker when the other two components (working memory and inhibition) are included, given the overlap between different components of EFs (Cragg et al., 2017).

- *Working memory:* Students' ability to hold information in mind can be taxed by many things, including persistent worries about math, known as math anxiety (e.g., Ashcraft & Krause, 2007; Beilock, Gunderson, Ramirez, & Levine, 2010; Lyons, Simms, Begollin, & Richland, 2018; Ramirez, Gunderson, Levine, & Beilock, 2013; Trezise & Reeve, 2017). Math anxiety can be particularly prevalent when gaps in math knowledge exist (e.g., Lee & Bull, 2016). The working memory capacity that could be used to perform math tasks may also be consumed by the monitoring of one's performance and vigilance of external threat detection that can be triggered by 'stereotype threat', a situational context in which individuals are concerned about confirming a negative stereotype about a group to which they belong (e.g., Beilock & Carr, 2005; Tine & Gotlieb, 2013).

- *Inhibitory control:* One study found that children who performed well on an inhibitory control task were more likely to use conceptual heuristics to solve arithmetic problems, perhaps because they were able to inhibit the tendency to use the less efficient procedural algorithm they were initially taught (Robinson & Dubé, 2013). Similarly, children with higher inhibitory control were better at using the most efficient strategy to solve a given math problem (Lemaire & Lecacheur, 2011).

Taken together, these and other related research findings suggest that EFs are important for both learning and doing mathematics.

A hypothesis to be tested is whether students learning in under-resourced schools or from lower SES households may not be provided the same type or frequency of opportunities to develop EFs during math learning, compared to peers from more privileged backgrounds (e.g., Lawson, Hook, & Farah, 2018). We do not take a deficit-based view of these differences, however, because the EF assets of each child develop in context, and optimize to the environments that a student grows up in. In other words, the EF skills developed in one environment are not objectively any better or worse than those developed in another environment. We aim to provide opportunities for all students to develop their EF skills to learn challenging math.

EFs are like any other skill in that they develop with practice (for recent reviews, see Diamond & Ling, 2019; Takacs, & Kassai, 2019). These studies have shown for example that practicing EF skills with adaptive working memory training can increase EF skills, as can curricula designed to engage EFs (e.g., Diamond & Ling, 2019; Takacs, & Kassai, 2019). Note, however, that studies typically show that EF training rarely generalizes (or 'transfers') to improved EFs outside the training context/content (see also Melby-Lervåg, Redick, & Hulme, 2016 for review). This strongly points to the idea that **EFs should be trained in the contexts in which they are to be expressed.** Thus, if we want to support the development of strong math-relevant EFs, we should provide students opportunities to exercise EFs specifically during math learning. In this manner, if EFs improve only in the context of math learning and this leads to improved math outcomes, we will still have accomplished our objective (improving math learning by building EF skills) even if the stronger EF skills do not transfer to other academic domains, like reading or science.

Strong EF+Math proposals will be able to test hypotheses regarding how far EF training might or might not transfer when trained in the context of math learning.

Strong disparities in national student math performance data (NAEP, 2017) persist despite decades of effort across the U.S. to develop and utilize new interventions to improve math learning. One hypothesis that we aim to test is whether this lack of progress stems from math interventions not being designed and developed to respect the realities of teaching and learning in schools that serve students living in poverty and students of color into the design and development process, in an approach we refer to as *Inclusive R&D* (e.g., Fancsalia et al., 2016; Utah's Early Intervention Reading Software Program, 2016-17 K-3 Program Evaluation Results; Protheroe, 2008). A perhaps more powerful approach invites the partnership of teachers who serve students in poverty and students of color. The role of teachers in improving student outcomes is indeed an important contributor (e.g., Desimone et al., 2005; 2011; RAND, 2003; Slavin & Lake, 2008), and instances where researchers co-constructed learning interventions with abundant teacher input produced favorable gains in student performance (e.g., Druin, 1999; Coburn & Penuel, 2016; Penuel et al., 2011). To observe change in math outcomes for students in poverty and students of color, it is necessary to not only include but also to co-design with the people who may know their learning contexts best: their teachers. This is a core component of the EF+Math program, which aims to elevate the voices of educators who serve students we aim to design with and for. We aim to test the hypothesis that when we include in leadership the stakeholders who know and serve students of color and students in poverty, we will discover and develop better, more impactful, and more equitable ways to serve students.

2. Equity in Math Education

EF+Math considers equity and inclusion to be foundational to every aspect of our work. We are committed to ensuring teams design, build, and improve math learning systems that are specifically designed with and for students who have been historically underserved, including students who attend schools in low-income neighborhoods and students of color.

An important body of literature about mathematics and equity has emerged in the past two decades, and includes significant insights from Critical Race Theory scholars in mathematics education. These scholars have elucidated the numerous challenges that may be unique to Black and Latinx learners as well as the gatekeeping nature of mathematics. This roadblock has kept students of color and students from low-income households from gaining access to challenging mathematics (e.g., Davis & Jett, 2019; Martin, 2012). Many scholars argue that White cultural norms are centered as the standard, guiding how mathematics is taught and learned; thus, investigations frequently paint a false narrative that marginalized students are underperforming, unmotivated, or unwilling to assimilate to the majority culture (e.g., Gutierrez, 2008; Ladson-Billings, 2006; Martin, 2008; Martin, Price, & Moore, 2019). This narrative is socially irresponsible since it does not account for the ways educational spaces are problematic for youth that are not included in White dominant cultural norms, and how these problematic spaces further disrupt learning and deny students their whole selves, (e.g., Martin, 2008; Nasir & Shah, 2011) often implying that to do well, they must leave parts of themselves out of the mathematics classroom (Nasir, 2011). Further, Black and Latinx youth are often given fewer opportunities to be challenged in mathematics and then subsequently held to a standard that is typically White centric, evaluating them on a narrow metric of their mathematical thinking (Gutierrez, 2008; Larnell, 2019). Additionally, Black and Latinx youth as well as girls are often stereotyped in U.S. culture as not being ‘good’ at mathematics, which compound the various challenges that systematically prevent students from being challenged in mathematics and from having a math environment that affirms their identities (Nasir, 2011). These challenges should be taken into account when considering equity and mathematics education.

To design with these insights, **we encourage teams to consider a *targeted universalism* approach,** where universal goals are defined (e.g., that all students are afforded opportunities to be the powerful math learners they can be), and—recognizing that different students are positioned differently in the structurally unequal education system (e.g., Ewing, 2019; Powell, 1995; Powell, 2007)—require differentiated or targeted strategies to achieve this universal goal.

For the field to understand how new math learning practices, programs, or products can significantly improve students' math performance, it is critical to understand and design for the various ways students experience their schools and classrooms. Addressing inequality as it relates to mathematical outcomes likely requires rethinking the way we do research and development. Confronting how racism and classism operate within learning contexts is a necessary step to first addressing how students can be properly supported in their learning experiences (e.g., Martin, 2008; Gorski, 2019; Joseph & Cobb, 2019). Potential ways we might do this is by ensuring that learning opportunities are made available to all students, consistent with their needs and values; examining how certain policies will differentially impact students from underserved backgrounds potentially through targeted universalism approaches; ensuring that historically marginalized voices are empowered and valued in mathematics research and development; and continually examining how structural racism and classism operates within different learning contexts. Additionally, it is necessary to use equitable design strategies that mitigate the negative effects of social stratification that can play out via segregation, ability tracking, and assignment to special education (e.g., García Coll et al., 1996; Perez-Brena, Rivas-Drake, Toomey, & Umana-Taylor, 2018). These factors tend to affect our most marginalized students when understanding their individual developmental and educational trajectories.

School performance differences arise in part from different or reduced resources provided to students from low-income communities (e.g., Darling-Hammond, 2006; McCrory Calarco, 2018). These different or reduced resources can manifest during early learning (e.g, Byrnes, Wang, & Miller-Cotto, 2019; Byrnes & Wasik, 2009) or later in students' educational experiences. Further, even when there is not a lack of resources, the type or content of resources may be different in under-resourced schools relative to more affluent schools. For example, in mathematics, students from low-income households are more often assigned to practices that emphasize procedural fluency (i.e., 'drill and practice') at the expense of practices that support development of conceptual reasoning (e.g., Wenglinsky, 1998). In addition, even in 'de-tracked' schools, teachers often group students according to perceived abilities in ways that can lessen their opportunities to build conceptual understanding — for example, if a teacher turns appropriately conceptual math activities into procedural activities (Stigler & Hiebert, 2009) and thus lessens the opportunity for underserved students to learn concepts (TNTP, 2018).

Strategies that will enable the field to develop solutions to provide more equitable opportunities requires changes to learning environments to better facilitate student learning for historically marginalized students, including making high quality learning opportunities more available. Our understanding of the goals of math instruction has to become more social and language-based, for example, by emphasizing explanation, justification, argumentation, and discussion (e.g., Gutiérrez, 2013; Lerman, 2000). Students come to classrooms with different experiences with language and mathematics, and instruction is not always sufficiently designed to take advantage of linguistic, social, cultural, and cognitive strengths and differences.

> **"In recent years, there's been a lot of talk about the reasons behind the low performance of many students of color, English learners, and poor students. Rather than examine school policies and teacher practices, some attribute it to a "culture of poverty" or different community values toward education. The reality is that they struggle not because of their race, language, or poverty. They struggle because we don't offer them sufficient opportunities in the classroom to develop the cognitive skills and habits of mind that would prepare them to take on more advanced academic tasks (Jackson, 2011; Boykin and Noguera, 2011). That's the achievement gap in action. The reasons they are not offered more opportunities for rigor are rooted in the education system's legacy of "separate and unequal" (Kozol, 2006; Oakes, 2005)."** (p.29-30, Darling-Hammond, 2015)

Other factors that contribute to inequitable opportunities in math education include teachers' expectations of students across intersections of race, gender, language fluency, immigration status, and household income. Teacher expectations can influence student performance in the classroom (e.g., Ferguson, 2003; Van Den Bergh, Denessen, Hornstra, Voeten & Holland, 2010), and these tend to vary by students' race/ethnicity and income. Sorhagen (2013) found that teacher expectations as early as the first grade can have consequences on student achievement into high school; low early expectations can have especially deleterious effects on students from lower income households. Similarly, since teacher expectations may have a stronger influence on students from lower income households, it will be important to consider how intersectional teacher expectations may affect student development, for instance how race, gender, language and/or immigration status may intersect with teacher expectations of students from low-income households. White teachers may implicitly have lower expectations for their Black students than they do for their White students (e.g., Chunn, 1988), and this may be exacerbated for their students of color from low-income households. Further, White teachers (who comprise ~80% of the U.S. teacher workforce; Department of Education, 2016), may consequently offer less academic support to their Black students as a result of their lower expectations (e.g., Downey & Pribesh, 2004; Rowser, 1994). Of course, these inequitable influences go beyond the teachers' attitudes, mindsets, and beliefs and extend to how resources are allocated for students within and between schools.

Another way instruction may fail some groups of students is when teachers and other adults in the system do not attend to strengths the students bring to learning. In a Funds of Knowledge approach (e.g., Hogg, 2011; Johnson & Johnson, 2016; Rodriguez, 2013), R&D teams seek to understand strengths in students' home community that could be better leveraged in math instruction. This approach does not measure students' knowledge based on mainstream approaches, but instead, acknowledges students' patterns of knowing and learning consistent with their backgrounds and lived experiences. In a culturally responsive pedagogy approach (e.g., Leonard, 2018; Leonard & Brooks, 2010; Morrison, Robinson, & Rose, 2008; Tate, 1995), R&D teams try to find ways that instruction could identify and positively engage aspects of students' identity and culture as assets to build upon. Similar to Fund of Knowledge approaches, this approach builds on diverse students' prior knowledge to develop rich learning experiences that are more relevant to them.

EF+Math will support approaches that can create contexts where students of color and students in poverty are provided equitable opportunities to learn challenging math. These opportunities can come in many forms, including classroom instruction or high quality learning tools in their schools and classrooms. We support approaches that give teachers the support they need to help students reach the potential they are capable of.

2.1 Opportunities, Mathematics Learning, and Cognitive Development

Many different scholarly traditions have examined relationships among opportunities to learn, mathematics learning, and cognitive development. Important scholarly traditions exist in educational neuroscience, cognitive development, cognitive psychology and mathematics education research.

Educational neuroscience research reveals that, in general, all children are born with relatively similar neural machinery that enables deep mathematical processing, but how that machinery develops depends on the environments students are exposed to. Environmental factors that are linked to different or fewer opportunities to build school-aligned math skills include less access to high quality math instruction, teachers who are less well prepared to teach mathematics, and inequitable access to informal mathematics learning opportunities. Indeed, strong mathematics performance is often related to having a teacher with more years of expertise, student hours spent focused on math learning, access to tutoring (e.g., Byrnes & Miller, 2007; Byrnes & Miller-Cotto, 2016), exposure to school-aligned mathematical language in the home (e.g., Hanner, Braham, Elliot, & Libertus, 2019), and the quality of ways students are supported to study mathematical examples and practice problems when learning mathematics (e.g,. Booth, McGinn, Young, & Barbieri, 2015). Unfortunately, mathematics instruction for students in under-resourced schools often emphasizes disconnected concepts, mathematics vocabulary out of context, following steps, and answers over explanation (e.g., Anyon, 1980; Ladson-Billings, 1997; Lubienski, 2002; Means & Knapp, 1991), with few opportunities to build on prior knowledge and map this knowledge on to new material.

The fields of developmental psychology and mathematics education have investigated the processes of learning mathematics in ways that complement educational neuroscience. One example, grounded in a constructivist perspective on knowing and learning, considers a three part mental structure known as a *schema* (von Glasersfeld, 1995) and accommodation of those structures to more advanced concepts via a perturbation (Piaget, 1985). The first part of the schema consists of a learner recognizing a certain situation. This recognition is based on previously recorded, similar experiences and prior knowledge. From this "recognition template" the learner then sets a goal which activates the second part of the schema, a mental activity in order to accomplish the goal set. The third part of the schema is the result the learner expects from the set goal based on prior knowledge and similar experienced activities. If the outcome of the third part of the schema is different from the goal set and prior experiences and knowledge, a perturbation or disequilibrium can occur for the learner (Piaget, 1985). This perturbation then allows for the learner to create equilibrium through accommodation of new information, which can then lead to new learning. However, if the perturbation is too far beyond the learner's prior knowledge and the learner cannot make a connection to newer concepts, the learner is likely to give up, and no new learning will occur. From this perspective, prior knowledge is key to advancing learning as it is where a learner starts their journey and is needed as a stepping stone towards more advanced concepts. In addition to the constructivist perspective to knowing and learning, Understanding

Mathematics and Science Matters (Romberg, Carpenter, & Dremock, 2005) and Foundations for the Future in Mathematics Education (Lesh, Hamilton, & Kaput, 2007) are examples of handbooks contributing to general insights and developmental perspectives shaping mathematics education.

Relatedly, cognitive psychology reveals that while prior knowledge is an important predictor in mathematics learning, prior knowledge does not operate in isolation. Prior knowledge interacts with other cognitive processes, including working memory and other aspects of executive function. More specifically, prior knowledge helps guide selective attention to information relevant to the task at hand (e.g., Amso & Scerif, 2015). However, prior knowledge can also hinder learning when the to-be-learned information is incongruent with students' existing concepts (e.g., Shing & Brod, 2016). A caution when framing student knowledge as "misconceptions" is that this can lead to ill-considered efforts to suppress student knowledge; alternative epistemologies see students as having many pieces of knowledge, and the educators' role is to help students achieve greater coherence and systemicity between their experience in the world and mathematical concepts (e.g., Smith, diSessa & Roschelle, 1993). For a better understanding of how cognitive psychologists have studied mathematics, please refer to the Acquisition of Complex Arithmetic Skills and Higher-Order Mathematics Concepts (Geary, Berch, Ochsendorf, & Koepke, 2017) and Children's Logical and Mathematical Cognition: Progress in Cognitive Development Research (Brainerd, 2012) handbooks on mathematical cognition.

Research in mathematics education has clarified what high quality instruction looks like. A starting point for defining high quality instruction has been codified in standards and policy documents. For example, the Common Core State Standards (National Governors Association Center for Best Practices, 2010) describe school mathematics as including both mathematical practices and mathematics content. The National Council of Teachers of Mathematics, in Principles to Action (2014), describes attributes of high quality math instruction including that which "engages students in meaningful learning through individual and collaborative experiences that promote their ability to make sense of mathematical ideas and reason mathematically" (p. 5). Jo Boaler (2008; 2015) wrote a series of well-known books that highlight some of the common weaknesses of typical math instruction in low-income schools, such as a premium on speed and accuracy over mathematical strategies and explanations. Scholars such as Deborah Ball and Heather Hill (2004, 2005) have defined the mathematical quality of instruction. Further, concepts like the level of cognitive demand have proven to be important. Frameworks like the TRU framework (2007), and others express this along with other dimensions of high quality instruction. There has also been much scholarship on the nature of teacher professional development in mathematics, including work on such concepts as Mathematical Knowledge for Teaching (Ball 1991; 2000). It is also important to conceptualize high quality instruction as grounded in an analysis of the long term learning trajectories for students; for example, in the grade levels for the EF+Math program (grades 3–8), the strand of development that includes rational number, multiplicative reasoning, proportional reasoning, and linear functions is known to be difficult for students and central to their eventual proficiency. The existing literature on high quality instructional materials in math education is very large; a good starting place for a newcomer would be the NCTM Compendium handbook (2017) or one of the other high quality handbooks of mathematics education research.

Additional research has found that the likelihood of a student benefiting from higher quality instruction or exposure to certain academic content depends on factors such as prior educational experiences (leading to greater prior knowledge), and parents' level of education or socioeconomic status as well as whether well qualified teachers are working in schools that serve low-income communities. Opportunities and student assets are often heavily dependent on factors that occur earlier in time, such as the assignment to a gender, a students' race/ethnicity, or a students' parental/guardian level of education (e.g., Byrnes & Miller, 2007). Thus, it is necessary to examine interventions not only as they relate to performance but also how student characteristics, or assets, may alter the effectiveness of these interventions.

3. Executive Function in Education

EF+Math aims to fund and support teams that can achieve dramatic improvements in middle years math achievement by providing opportunities for students to exercise their EF skills while learning math. In this section, we briefly summarize evidence linking EF skills to growth in math achievement and introduce evidence that points to why leveraging EFs may be a promising way to create more equitable opportunities for students to develop agency over their math learning.

Decades of research reveal that every student possesses the core capacities that give agency over their learning; these core capacities include the ability to focus on what a student thinks is important while ignoring what is not, the ability to work with and hold important information, thoughts, or rules in mind, and the ability to flexibly shift between thoughts, rules, and tasks. These skills are collectively referred to as executive functions (EFs) in clinical and cognitive psychology research. Teachers consider these cognitive skills, important for learning, although they likely use different terminology to describe them (Gilmore & Cragg, 2014). It is notable that EF research has often (though not always) described a deficit framework—focusing on perceived needs or problems with student EFs—and public discourse has often (inaccurately) framed EFs as fixed, unchangeable factors that some students have and others do not. The EF+Math team is led by a team of researchers and educators who have studied EF, math, and educational equity for decades, and our position is that EFs are core assets that every student has, they are like any other skill in that they can improve with practice and exercise, and that they are critical paths to student agency. By 'critical paths to student agency' we mean that all students have goals that are meaningful to them, and their core EF assets allow them to achieve those goals. From this perspective, building EFs is not about teaching students how to be compliant or to pursue goals defined by the adults in their school and life, but rather how to hone their unique capacities to have agency over their own learning, in school and in life (e.g., Lee & Shute, 2010). This is a core perspective that all funded EF+Math teams will design, develop, and iterate their programs around.

Before discussing the academic research on EFs, it is critical to acknowledge that much of it has over-represented students from so-called ‘WEIRD’ backgrounds: Western, educated, industrialized, rich and democratic (Henrich & Heine, 2010). Thus, the existing literature over-represents this narrow population, and a great deal of further research is needed to better understand the role of culture, language, socioeconomic contexts, and other factors in the individual mosaic of development of EFs (e.g., Howard et al., 2019; Lewis et al., 2009). *EF+Math will support research that extends our understanding of EFs by including student populations who have typically been under-represented in EF discovery work, particularly students learning in under-resourced schools and Black and Latinx students.*

Research also reveals that all people, in general, are born with similar executive function neural machinery, and how that machinery develops depends on the environments they are exposed to. Environments of high poverty, high adversity, chronic stress, high residential mobility, and irregular family routines may provide fewer opportunities to build EFs, resulting in children not demonstrating their greatest EF potential (e.g., Lawson et al., 2018; Raver & Blair, 2014). Children’s cognitive development arises from an interaction of biological, social and environmental factors. Some research suggests that poverty can change children’s brain development (e.g., Hair, Hanson, Wolfe, & Pollak, 2015), and higher socioeconomic status (SES) households are often associated with higher executive function performance and mathematics performance (e.g., Fitzpatrick, McKinnon, Blair, & Willoughby, 2014). We acknowledge that racism is due to a combination of environmental and systemic factors, however, one area ripe for intervention may be at the school level. It is our intention to address racism in part by ensuring that students have high quality learning opportunities, that we change conditions to support high quality enactment of these opportunities, and that we support students to take advantage of them (e.g., Byrnes & Miller, 2007; Byrnes, Wang, Miller-Cotto, 2019; Darling-Hammond, 2015). In these ways, we aim to support students in building powerful math and EF skills.

We now turn to relevant findings from EF research, keeping top of mind that the samples and therefore findings are not equally representative of the full demographics of U.S. students. EFs have been shown to be related to academic achievement and to improve due to a number of factors, including the normal course of development (e.g., Bull & Lee, 2014), formal education (e.g., Brod et al., 2017), and more. Importantly, executive functions in early childhood (~3-5 year-olds) may be best explained by a single underlying factor (Hughes & Ensor, 2011; Wiebe et al., 2011). This single EF factor is thought to grow and differentiate over childhood, maturing into at least three factors that can be observed as early as middle childhood (~8-13 years old) (e.g., Hartung et al., in press; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003). For students in middle childhood and older, neuroimaging evidence further supports that the three components of

EF engage overlapping, but separable neural networks, similar to the networks engaged by adults (Engelhardt et al., 2019).

The individual mosaic of a student's core set of assets is a critical component in their ongoing development, and one aspect of that development is that the individual differences in children's EFs have been found to predict growth in math ability over time (e.g., Fuhs, Nesbitt, Farran, & Dong, 2014). This finding has spurred hypotheses that EFs play foundational roles in math learning. Interestingly, this influence is not a one-way street, in that measures of math performance are also predictive of EF skills longitudinally (e.g., Clements et.al., 2016), suggesting that EFs and math knowledge interact in a reciprocal manner over development (e.g., Merkley et al., 2018; Miller-Cotto & Byrnes, in press). In other words, strong EFs may help children learn more from math instruction, and likewise acquiring and practicing mathematics skills may in turn build stronger EF skills. Indeed, a recent study found an interaction between kindergarten students' EF performance and how much they benefited from math instruction in kindergarten, as indicated by how much their math scores improved (Ribner, in press), in that children with higher EF skills showed more growth in math performance compared to children with lower EF skills. Similarly, another analysis of longitudinal data showed that kindergarten students with stronger EF skills were more likely to show greater gains in future math scores in third grade (Morgan et al., 2019), suggesting that higher EF skills may propel academic performance (e.g., Younger, et al., 2019).

> **"Given that both math and EF skills improve with practice, this type of reciprocal ratcheting-up of both skills is to be expected."** (p. 22, Zelazo et.al., 2017)

In sum, a large body of research shows that EFs are related to math achievement and thus EFs may be a promising leverage point to help students learn more from math instruction. Further work is needed to investigate whether and how EFs can be intentionally practiced in the math classroom to increase students' math learning and performance. We turn next to this topic of the causal relationship between EFs and math learning.

3.1 Can EF practice improve mathematics outcomes?

Despite a preponderance of strong correlational relationships observed between EF skills and math skills, correlation does not confer causation, and indeed EF interventions have shown mixed success at generalizing improvements to mathematics outcomes (e.g., Strobach & Karbach, 2016). While many EF interventions have had positive effects on EFs, these improvements have not always generalized to increases in math achievement (for reviews see Diamond & Ling, 2019; Takacs, & Kassai, 2019). More research is needed to determine whether and how EF interventions can improve mathematical outcomes. Insights may be found in studies that investigate direct relationships between EFs and math. For instance, studies have found that EFs measured during a numerical task are more strongly related to math achievement than EFs measured during tasks that do not explicitly include math-related information (e.g., Gilmore et al., 2015; Wilkey & Price, 2019). This points to a testable hypothesis: *that students should practice engaging EFs while learning and doing math*. Indeed, often the most successful EF interventions are those that build EFs in the contexts in which they are intended to be expressed (Clements et al., 2016; Strobach & Karbach, 2016). EF interventions that are integrated with the curricula and implemented by teachers have shown promising results (e.g., Mackey et al., 2017; Wright et al., 2019).

EF+Math will fund R&D that can reveal how EF skills can be deployed in math classrooms to increase students' math learning and performance.

Spending time in school is associated with increases in executive function skills (e.g., Finch, 2019; Brod et.al., 2017), suggesting that the classroom is a great place to build EFs. For example, one study found that children from low SES families showed more growth in working memory over the first two years of school compared to their peers from higher SES families. This suggests that improved EF could help improve equity in educational performance (e.g., Lawson et.al., 2018; Zelazo et.al. 2017). Students who start school with high EF seem to avoid the academic risks that can be associated with low SES, suggesting that EF skills may serve as a "protective factor" (e.g., Masten et al. 2012; Obradović 2010) (see Figure 1 below). Furthermore, the largest benefits from executive function interventions have typically been seen in children who may have had fewer opportunities to intentionally practice EF skills (e.g., Diamond & Ling, in press). For example, a randomized controlled trial of a preschool curriculum designed to increase EFs showed that children in the intervention group showed higher math performance on average than those in the control group following the intervention. Importantly, children in the intervention group who were in high poverty schools showed greater improvements on EFs compared to children in schools with more resources (Blair & Raver, 2014). Students have diverse skills and needs and do not all respond to interventions in the same way.

We acknowledge, however, that moving research from a controlled study environment to the classroom is not straightforward, nor is moving from a small number of classrooms to a large number of classrooms, and intervention design should be informed by classroom contexts in addition to the findings from cognitive science research (e.g, Brown, 1992; Coburn & Penuel, 2016; Penuel et

ARE EXECUTIVE FUNCTIONS IMPORTANT FOR MATH?

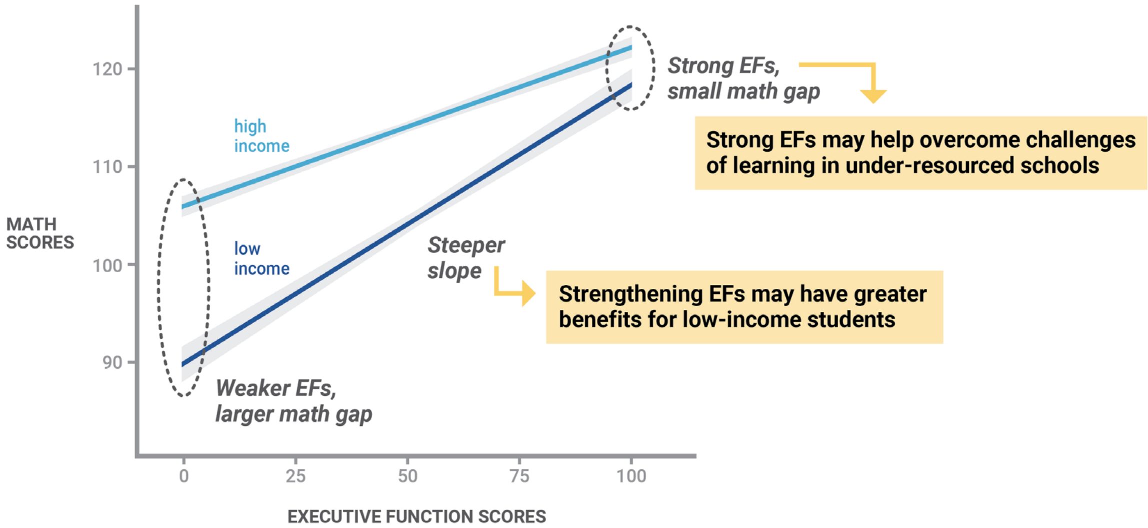

Figure 1. *The 'math gap' between children from low income households and children from high income households is reduced when children from both groups demonstrate strong EFs. This suggests that stronger EFs may serve as a buffer to challenges that may be posed to children learning in under-resourced schools (data drawn from ECLS:K, 2011).*

al., 2011). Educators' expertise is critical to design and implement interventions that are feasible for classrooms at scale. Multidisciplinary research is needed to develop and assess ways of increasing both EFs and mathematics skills through math instruction. In sum, the promise of leveraging EFs to advance math instruction has not yet been realized. The EF+Math program aims to build on existing evidence showing a relationship between EF and math by developing, iterating, and improving innovative interventions side-by-side with educators to increase opportunities for students to achieve math proficiency and subsequent agency over their own learning goals.

4. Mathematical Proficiency – Conceptual Understanding and Complex Problem Solving

With regard to mathematics content, the EF+Math program is firmly committed to enabling students in under-resourced schools to not only score higher on mathematics tests, but also to attain improved mathematical mindsets, identities, and proficiency. Proficiency implies not only a higher score on the “basics” but also developing the quality of mathematical knowledge that opens broader opportunities in life. Proficiency implies, for example, that a student can make sense of problems, apply mathematics and communicate with others about mathematics in situations they haven’t encountered before — whereas “the basics” often consists of getting the right answer quickly on familiar tasks.

For EF+Math proposals, merely aiming to increase mathematics scores is not enough; we seek proposals that conceptualize proficiency broadly and have a compelling mechanism to enable students to achieve it.

Two aspects of mathematical proficiency are particularly important to the EF+Math program: conceptual understanding and complex problem solving (multi-step problem solving). They are important because they are strongly associated with the proficient level and because the field has evolved such that they are clearly addressable in instructional activities and measurable on assessments. By conceptual understanding, we mean an articulation of mathematical relationships gained from learning (e.g., Crooks & Alibali, 2014). Therefore conceptual understanding is defined as knowledge of those relationships that govern the mathematical concept and of the interrelations of the units of knowledge involved in the mathematical concept (e.g., Rittle-Johnson et al., 2001). Skemp (1976) referred to this as relational versus instrumental understanding. Relational understanding is not only knowing what method to use when solving a problem and why that method worked, but also the ability to adapt that method to new problems posed. Conceptual understanding focuses on reasoning & justification, using and connecting multiple representations, problem solving, and problem posing (e.g., Lyke & Young, 2006; Silver, 1994, 1997; NCTM, 2014). For example, a person with conceptual understanding of unit rate can express the connection between (a) a small multiplicative coordination of a “this per that” where there is just one “that” and (b) a bigger multiplicative coordination where there is more than one “that” — in particular they can explain how iterating the smaller coordination leads to the latter coordination. The student can unpack how the thing we phenomenologically experience as “the same speed” has a mathematical sameness when understood as being related through the same unit rate. They can also connect the representation of rate in graph to representation in symbols or in a table.

By multi-step problem solving, we mean problems that include, as part of the solution process, multiple steps to be completed and use of one or more than one operation. An example of a multi-step problem from the Engage NY curriculum (New York State Education Department, 2014) is: Uniforms are sold in packages of 8. The store’s 127 employees will each be given 3 uniforms. How many packages will the store need to order? When solving this problem, the student has to take multiple steps using different operations to determine the answer. One way of performing these steps is to first determine the amount of uniforms needed by using the operation of multiplication and then using that product with the operation of division to determine the number of packages of uniforms needed. Multi-step problems often require composing solutions, not just choosing which algorithm to apply. They often require flexibility, as initial strategies sometimes do not work out. Often multi-step problems require moving across representations, for example, drawing a picture that clarifies a situation and then connecting the picture to a symbolic mathematical expression.

4.1 Realities of Conceptual Foundations in Middle Years Mathematics

Many students in middle childhood are not given quality opportunities to build a conceptual understanding of math and the ability to solve multi-step problems, often because classroom instruction and textbooks focus on procedures (e.g., RAND Study; Qin & Opfer, 2018). This causes problems as students attempt to build cumulative knowledge on weak foundations (e.g., Siegler, 2015) and disproportionately affects Black, Latinx, and low-income students (e.g., Schoenfeld, 2002), due to the structural (and not student) reasons described above. For example, Booth et al. (2014) demonstrated the risk of poor conceptual understanding and early misconceptions which can (1) be difficult for students to let go of and (2) can interfere with learning unless interventions are developed specifically to overcome the common errors. Unfortunately, there is often no safety net for students who have conceptual gaps due to insufficient time to both cover grade-level standards and revisit foundations.

In time, this lack of understanding can lead to a negative cycle of adverse math experiences, higher anxiety and poorer math performance (e.g., Lee, Ng, & Bull, 2017; Tresize & Reeve, 2017). For example, when students struggle to understand math, they may see it as more disconnected and arbitrary, which decreases their desire to learn it. Additionally, mathematics instruction for low-SES students of color is often characterized by disconnected concepts, mathematical vocabulary that is out of context, an emphasis on following specific steps to solve a problem, and a focus on students' answers instead of their explanations (e.g., Battey & Franke, 2015; Anyon, 1980; Ladson-Billings, 1997; Lubienski, 2002; Means & Knapp, 1991). Too often, the coursework offered to students of color is far below the level of rigor needed to support mathematical achievement; nearly 90% of the time, in the 1000+ classrooms in a recent large TNTP study, students who focused on the classwork they had been assigned met grade level standards only 17% of the time (e.g., TNTP, 2018).

Assessments using measures of student performance on standardized tests have demonstrated that students with conceptual understanding are able to score well on both conceptual and procedural questions, reaching higher levels of achievement than their peers whose math classes focused mostly on procedural fluency (e.g., MET study 2010; Hiebert & Grouws, 2007). More importantly, high quality instruction can remediate students' gaps in conceptual understanding (e.g., Schoenfeld, 2002). For example, mathematics instruction emphasizing reasoning, problem solving, and understanding led to improvements on Grade 8 NAEP scores in middle school students from poor communities (e.g., Silver & Lane, 1995).

4.2 Building Conceptual Foundations in Middle Years Mathematics

Research has uncovered specific approaches that seem most effective to improve mathematics learning, conceptual understanding, and ultimately mathematical proficiency (e.g., Booth et al., 2017; Sweller, 2012), including self-explanation, problem-based productive struggle, and interactive visual representations (e.g., Rittle-Johnson & Koedinger, 2009; Booth et al., 2013, Booth & Koedinger, 2008). Productive struggle is defined as effortful practice that builds useful, lasting understanding (e.g., Heibert & Grouws, 2007). Experiencing productive struggle is a sign that students are doing challenging work at high standards, activating growth in their Zone of Proximal Development (ZPD) (e.g., Vygotsky, 1978). Teachers enacting this practice provide opportunities for students to struggle with conceptual ideas (as opposed to reinforcing learner dependency by doing the thinking work for them) (e.g., Hammond, 2015; Schoenfeld, 2014).

> **“Effective mathematics teaching uses students’ struggles as valuable opportunities to deepen their understanding of mathematics. Students come to realize that they are capable of doing well in mathematics with effort and perseverance in reasoning, sense making, and problem solving.”**
> (p. 52, NCTM, 2014)

The type of task provided has also shown to make a difference when promoting conceptual foundations for complex problem solving. High cognitive demand tasks often focus on reasoning and problem-solving, and have multiple methods of solution (e.g., Charalambous & Praetorius; 2018). They may be open-ended problems, with not only multiple methods of solution but indeed multiple possible solutions. These rich tasks have multiple “ways in” or points of access, so that all students are positioned to engage with meaningful content (Schoenfeld, 2014). A similar construct is the idea of “group-worthy tasks”, which situates high-cognitive-demand tasks within collaborative learning experiences (e.g., Hiebert et. al., 2005; Smith & Stein, 2011; Stein & Lane, 1996).

In general, the field of mathematics education research has investigated the characteristics of high quality mathematics materials at length. For example, the TIMSS studies famously uncovered the problem with materials that are “a mile wide and an inch deep” (Schmidt, 2004, para. 8). Good quality mathematics materials are highly coherent, are based on individual differences in learning progressions that can respect the cumulativity of mathematics, and provide a depth and intensity of coverage of each concept (e.g., Smith & Stein, 2011; NCTM, 2014; Van de Walle, 2015). In general, good places to learn about what the field already knows about high quality instructional materials in mathematics include the reports of the International Congress of Mathematics in Education conference (an ‘olympics’ of worldwide mathematics education research that occurs every four years) the Psychology in Mathematics Education conference, the journals JRME and ZDM, and the high quality research handbooks available in the field. Of particular note, there is significant and deep scholarship on student learning of most foundational school mathematics concepts (for example, how students learn “place value”), and designers of EF+Math approaches would be well-advised to read these for insights on the concepts they will be covering. For further insights, we suggest referring to Principles to Actions from the National Council of Teachers of Mathematics for additional reading (e.g., Leinwand, Huinker, & Brahier, 2014; NCTM, 2014). Related to mathematics education and equity, a recent resource on Critical Race Theory in mathematics education (Davis & Jett, 2019) is a good place to learn more about how mathematics education when serving Black students.

Concluding Remarks

In this primer, we introduced ideas from bodies of work on equity, executive functions, and mathematics to spur ideation at the intersection of these fields. It is important to note that we do not take an equity lens on the work but rather value equity as the backbone of our work. The EF+Math program seeks to catalyze breakthroughs that can emerge when researchers, developers, and educators work together to design, develop, implement, and improve solutions that support students of color and students living in poverty to become the powerful mathematical thinkers they are equipped to be. We take an *Inclusive R&D* approach that puts educator leadership at the center of this approach. We will support research that designs approaches to learning mathematics in contexts where students, regardless of their backgrounds or experiences, are provided equitable support to learn mathematics. We will fund research and development that elucidates our understanding of EFs by including historically marginalized students and their teachers in this R&D work, while creating learning systems that are designed with the students we aim to serve and within the contexts they learn. Funded projects will aim to increase students' mathematical learning and performance broadly defined, and will also support students in achieving the mathematical learning goals they set out to fulfill.

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