Education Research & Development:

Learning From the Field | March 2019

Executive Summary

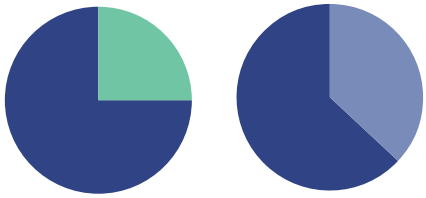
In May 2018, the Bill & Melinda Gates Foundation (BMGF) and the Chan Zuckerberg Initiative (CZI), two philanthropic organizations committed to expanding equity and opportunity in education, came together to seek new approaches from practitioners, researchers, and the public to a set of education challenges with enormous implications for the success of all students – and especially those who have faced early trauma or learning challenges.

The philanthropies issued a Request for Information (RFI) for design concepts for new research and development efforts in three key areas: writing, math, and executive functions. The effort focused on solving immediate, high-leverage challenges in practice by working at the intersection of basic and applied research in these areas. In this report, the two philanthropies are pleased to offer a summary of the more than 400 responses as well as our follow-up conversations with field experts and practitioners.

The RFI sought information for innovative strategies to help address three pressing challenges:

- **Writing:** Preparing all high school graduates for the type of nonfiction writing demanded in college and the workplace by developing the necessary habits, skills, and strategies;
- **Math:** Preparing all students to deeply understand and apply mathematical skills and knowledge and related mindsets;
- **Executive Functions:** Improving the ability of all students to think flexibly, wrestle with multiple ideas, and manage their thoughts and actions.

Percentage of high school seniors scoring at or above proficient



25% Math 37% Reading

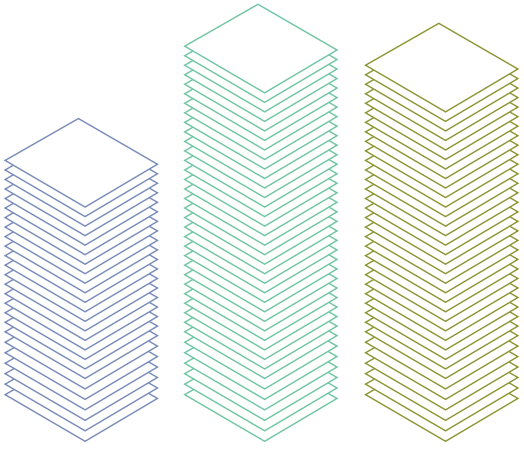
Strength in these three areas matters for every student's success in school, work, and life. Based on 2015 data from the National Assessment of Educational Progress, only 25 percent of high school seniors reach proficiency in math and only 37 percent reach proficiency in reading.[1] Students facing early childhood trauma, poverty, homelessness, or specific learning challenges may be at particular risk of not developing these essential skills.

The RFI invited practitioners, researchers, and the public to help identify where the most important, ambitious, and innovative work is being done to address these challenges across a variety of disciplines, with the goal of channeling those insights quickly and effectively back into the classroom. Respondents could submit information in one area or in multiple areas. The RFI also asked for feedback on the design of the R&D approach itself, including hosting a number of meetings with stakeholders in the field, including teachers and school leaders.

The RFI generated 465 qualified responses from 37 states as well as internationally. (Qualified submissions are those that were complete and addressed the topic.) Of those, 117 addressed writing; 177 addressed mathematics; and 171 addressed executive functions. The responses were approximately balanced across grade spans: elementary, middle, and high school. Examples in this report are cited to demonstrate the nature and variety of submissions, not as an indicator of potential funding.

The two philanthropies share a view that there is enormous unrealized potential for students and that breakthroughs driven by innovation can help students and teachers. The organizations will announce next steps for the responses to the RFI later this year and as yet have made no commitments on funding.

Subject matter breakdown of the 465 qualified responses



117 Writing 177 Math 171 Executive Functions

Writing

The RFI submissions in writing focused on three big areas:

1. Writing for the real world:
These approaches provide students with opportunities to engage in writing that more closely mirror the demands of college and the workplace. These range from a partnership with a science museum to promote real-world science writing to developing a community-based peer coaching model.

2. Getting students more feedback:
Many of these submissions focus on developing students' writing skills or providing feedback to students from a diverse group of readers, including outside experts such as journalists, to complement classroom teachers.

3. Next generation writing environments:
A number of submissions focus on how to put technology at the disposal of teachers to help personalize writing instruction. These range from a tool to capture qualitative data from students' drafts to help teachers see patterns in student writing, to an online learning environment that would make visible students' contributions to peer feedback, so that teachers would know when to coach the class or an individual learner.

Math

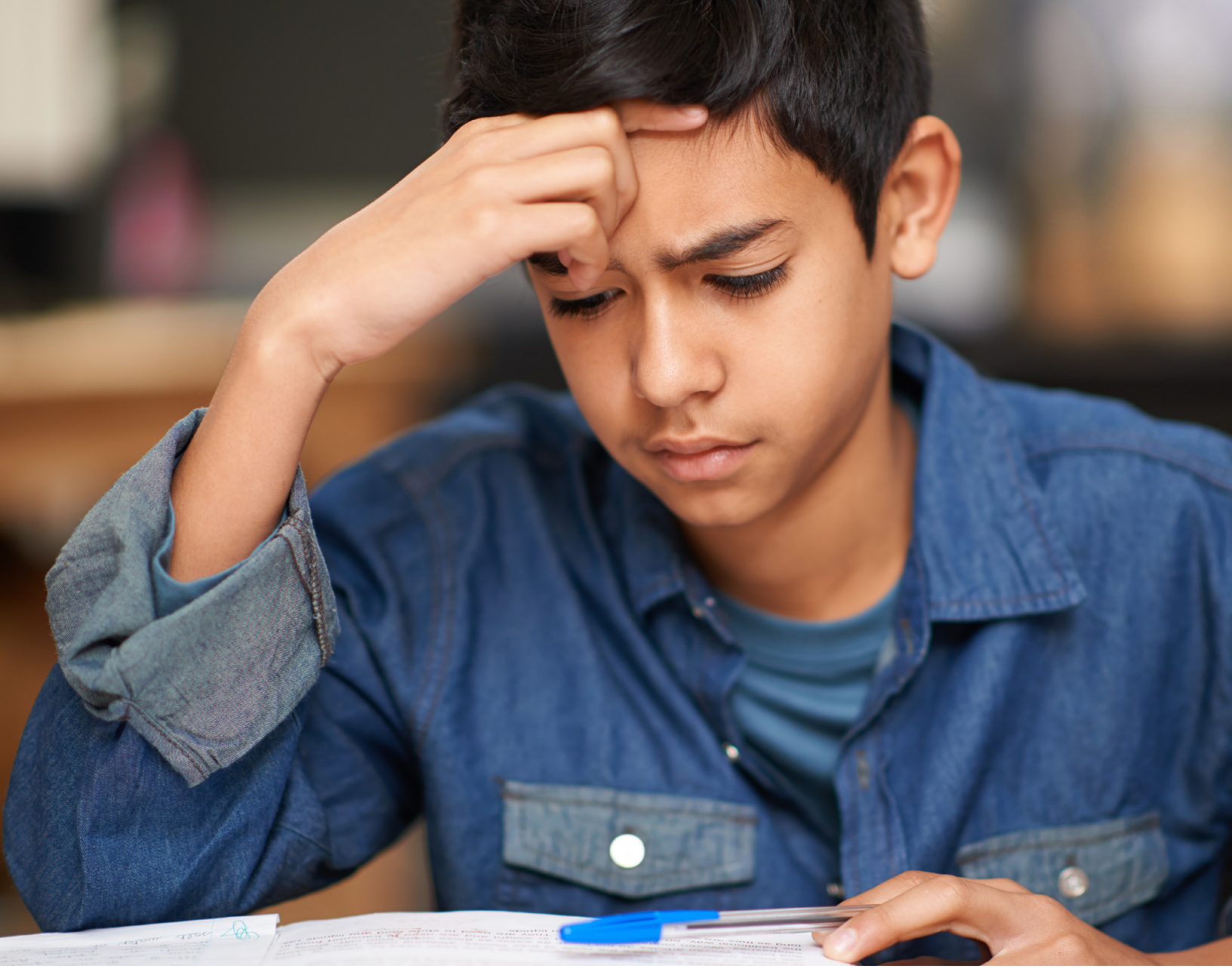
The RFI submissions in mathematics focused on four key topics:

1. Practice and feedback:
These approaches provide students with rich opportunities to engage in deliberate practice and receive actionable feedback that leads to deep mastery of foundational math knowledge and concepts. Many of them employ digital games, intelligent tutoring, and technology-based platforms to tailor learning experiences for individual students.

2. Novel instruction and experiential learning:
These approaches provide students with the opportunity to discuss real-world math problems of interest to them to help develop a positive math identity. One proposal invites students to consider the real-world and ethical implications of math questions.

3. Improved measurement systems:
These solutions propose to narrow the gap between assessment and instruction by providing richer indicators of student progress.

4. Empowered teachers:
These submissions propose using technologies that deliver real-time information on student learning to teachers with recommendations for adjusting instruction. The intent is to support teachers to differentiate their approaches for students with a wide range of proficiency levels, as well as to enable teachers to try new pedagogical strategies.



Executive Functions

The RFI submissions in this area fell into three broad buckets:

1. Measures of executive functions:
There were promising approaches to developing better measures of executive functions across basic and applied research. Such measures are needed to understand which interventions best target individual students' needs and to help teachers make informed judgments. Some submissions offer tools to help teachers understand and support students' development of executive functions, and to provide teachers with professional development in this area.

2. Interventions to build executive functions:
These submissions include ideas for scaling some existing products as well as for basic research. They range from low-cost, targeted strategies that represent the essential "active ingredients" in effective programs to develop students' social, emotional, and cognitive skills, to efforts to build adults' knowledge and development of executive functions, which research has found is strongly associated with children's development of such skills.

3. Tools and techniques to support programs that develop executive functions:
These ideas would support and buttress existing efforts to develop executive functions.

Background on the Request for Information for Advanced Education Research & Development Programs

In universities and research centers across the country, educators and scientists are developing new understanding of how children learn and what it takes to help more of them succeed. Many of those insights, however, have not yet reached the classroom in the form of practices and tools that teachers and students can easily use. That's in part because, unlike such fields as medicine or defense, education has very limited funding or infrastructure to conduct research, particularly directed development research that collapses the boundaries between basic and applied research and is focused on immediate problems of practice.[2]

This lack of infrastructure and dedicated funding is why the Bill & Melinda Gates Foundation (BMGF) and the Chan Zuckerberg Initiative (CZI) are working together to explore innovative ways to accelerate research aimed at solving some of today's most complex and pressing learning challenges. Together, we share the goal of ensuring that every child has the educational opportunities that enable them to develop the skills, knowledge, habits of mind, and agency to realize their full potential and live a healthy, productive, and fulfilling life. Although we each have our own research and development portfolios, our organizations believe that the importance and scope of this work go beyond any one organization.

The education sector currently invests, on a relative basis, less than one tenth of the average research and development spending of other important U.S. industries.[3] Perhaps as a consequence, many previous R&D efforts have fallen short on two major fronts: achieving impact, particularly at scale, and facilitating the flow of new knowledge between practitioners and researchers.[4]

That disconnect is among the reasons why the current rate of academic improvement is too slow to put many more students, particularly Black, Latino, and low-income students of all races, on paths to success after high school.[5] Breaking down the wall between research and practice, and between basic and applied research, offers the potential to dramatically accelerate solutions to problems that stand in the way of delivering better outcomes for millions of students.

By supporting research on problems of immediate use to society, our two organizations hope to spur directed development research of immediate, compelling usefulness to the field.

We take as our models such productive initiatives as the Defense Advanced Research Projects Agency, a government initiative which has brought

Our goal is to collapse the boundaries between basic and applied research to better tackle difficult problems of immediate, pressing need.

together teams of the brightest minds to iterate on basic research challenges and has led to such breakthroughs as the Internet and GPS, and in the private sector, Bell Labs, which led to the development of radio astronomy, the laser, and several major operating systems and programming languages. These efforts break down the traditional distinction between basic and applied research.[6] Basic research seeks to create new knowledge, while applied research takes existing knowledge and finds new applications for it. While this can lead to incremental improvements, our goal is to collapse the boundaries between basic and applied research to better tackle difficult problems of immediate, pressing need.

Based on successful public and private sector R&D efforts outside of education, it is clear that education requires research programs that:

- Bring together diverse, interdisciplinary teams that include educators, developers, and others from education research, human development, learning measurement, technology, neuroscience, and other fields to work collaboratively on innovative solutions to real-world problems.
- Connect funded projects to each other and to the field in an ongoing way, so that research is deeply informed by practice.
- Work with a program manager who can continually share information and expertise across individual projects, with the goal of creating solutions that integrate the most promising results from across the program. In this R&D model the program manager is an active participant in program execution and development, working closely with team members to ensure coordinated efforts and to provide nimble direction as lessons are learned by the overall team.

In May, our two organizations issued an RFI to help learn from others about how we might best design a jointly funded R&D program that would pilot this approach in education and to help refine our perspective on potential R&D topics.

The RFI sought information for innovative strategies to help address three pressing problems of practice:

- Preparing all high school graduates for the type of nonfiction writing demanded in college and the workplace by developing the necessary habits, skills, and strategies;
- Preparing all students to deeply understand and apply mathematical skills and knowledge and related mindsets; and
- Improving the ability of all students to think flexibly, wrestle with multiple ideas, and regulate their thoughts and actions (a set of competencies known as executive functions).

Strength in these three areas matters for every student's success in school, work, and life. Students facing early childhood trauma, poverty, homelessness, specific learning challenges, or in under-resourced schools may be at special risk of not developing these essential skills.

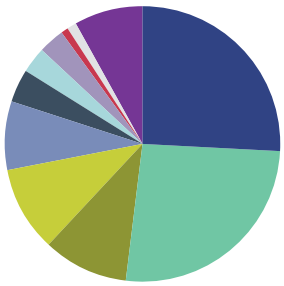
The RFI invited practitioners and researchers to help us identify where the most important, ambitious, and innovative work is being done across a variety of disciplines. Respondents could submit information in one area or in multiple areas. We also hosted a number of meetings with stakeholders in the field, including teachers and school leaders, to ask for feedback on the RFI program areas as well as on the design of the R&D approach itself.

We are encouraged by the results. We received 465 qualified RFI responses from 37 states as well as internationally. (We define qualified submissions as those that were both complete and addressed the topic.) Of those, 117 addressed writing; 177 addressed mathematics; and 171 addressed executive functions. The responses were approximately balanced across grade spans: elementary, middle, and high school.

Of the organizations responding to the RFI, 88 percent had a primary focus on education and 12 percent on another field. More than 7 in 10 of those responding had no prior funding from either BMGF or CZI. The respondents represented a diverse array of organizations. While respondents could fit into more than one category, based on their primary identification: 26 percent were nonprofits; 26 percent were universities; 10 percent were corporations; 10 percent were edtech developers; 8 percent were educators; 4 percent were schools; 3 percent were research institutions; 3 percent were state or local education agencies; 1 percent were professional development organizations; 1 percent were publishers; and 8 percent were other. One in five organizations were minority owned or led.

In this brief we share some of the underlying rationale for exploring research and development in each area, along with highlights of what we learned from the RFI feedback in each program area and in general. The ideas and examples described are illustrative; they are meant to give readers a sense of the breadth of submissions rather than being a complete and comprehensive analysis.

The RFI respondents represented a diverse array of organizations.



- 26% nonprofits
- 26% universities
- 10% corporations
- 10% edtech developers
- 8% educators
- 4% schools
- 3% research institutions
- 3% education agencies
- 1% professional dev
- 1% publishers
- 8% other

Writing

Developing the Requisite Habits, Skills, and Strategies

Why a focus on improving writing:
Success in college, work, and life depends upon communicating and expressing ideas effectively through writing. Employers cite skills related to writing as essential for their employees, including making clear and persuasive arguments, writing in different genres, and thinking critically and creatively about solutions.[7] Strong writing skills help individuals advocate for themselves, whether applying to college or asking for a raise. These skills also allow individuals to advance their positions in the marketplace of ideas.

Yet most high school graduates are not prepared for the writing demands of college or the workplace. Only 27 percent of high school seniors are proficient in writing, based on the National Assessment of Educational Progress (NAEP), sometimes called the Nation's Report Card.[8] Fewer than 15 percent of Black, Hispanic, and low-income students score at the proficient level.[9] This lack of writing proficiency negatively affects students' future success.

The major challenges and opportunities for teaching writing:

The following challenges were identified by experts in the field and affirmed in focus groups with educators.

Writing for the real world:
Both college and the workplace employ a broad range of writing formats that they use flexibly based on audience and purpose. In these real-world settings, writers typically choose the writing topic, seek out information about that topic, evaluate the quality of what they find, present that learning to an audience in a compelling and appropriate format (ranging from memos to lab reports to multimedia presentations), and then make revisions based on audience and expert feedback. Unfortunately, school instruction is sometimes aligned to state assessments that prioritize certain formats, such as the five-paragraph essay, over other writing skills, particularly in schools serving predominantly low-income students and students of color.[10] Isolated grammar rules and exercises, while popular, are ineffective; research shows that knowing these rules does not transfer to success in broader writing.[11] Research suggests that teaching multiple forms of writing that are realistic and effective ways of communicating outside the classroom can enable students to develop a broader range of real-world writing skills.[12]

Increasing student agency and identity as writers:
Student motivation and engagement matters. Research has found that providing students with some choice to select their own questions for inquiry within a broad topic and to evaluate sources and construct an argument drawing on a host of real-world research skills is most effective. For example, within a study of World War II, one student might choose to write about the Normandy invasion, while another seeks to understand how the U.S. fought for freedom abroad while championing segregation at home. Students can also be given choices in how to present what they've learned, from writing a literary analysis of a text based on an essential question to a literary critique.
When students have the opportunity to wrestle with ideas and to write to convince an audience about something of importance to them, they build their confidence as writers and their ability to transfer their writing skills to contexts outside of school.[13] Building on students' existing background knowledge and experiences, and connecting topics and issues to ideas of relevance to them, while coaching students on which forms of writing are best suited to which purposes, can increase students' sense of purpose and agency.[14]

Relatedly, culturally responsive teaching that honors and respects students' diverse backgrounds builds students' identity and self-efficacy as writers.[15]
When students interact with literature that reflects their communities, they often are more likely to see themselves as participants in a broader writing community.[16] Creating culturally responsive writing classrooms requires providing sufficient training for teachers and access to rich resources to support this approach to teaching writing.

Creating real world audiences for student writing:
Research suggests that students' identity, motivation, and self-efficacy as writers all benefit when students write for an authentic audience, in a format they choose, to accomplish specific goals they have set for themselves, and when they can adjust and revise their writing over time based on reader feedback.[17]
Attitudes improve when writing has a purpose that extends beyond the school, and when students

Culturally responsive teaching that honors and respects students' diverse backgrounds builds students' identity and self-efficacy as writers.

can use writing to form social connections and to build membership in groups or communities they care about.[18] This requires providing avenues for meaningful revision of writing based on self-reflection and feedback from peers, community members, and others, not just the teacher.

Providing more opportunities for practice and feedback:
Writing is time-consuming to produce and to evaluate, which currently prevents many students from engaging in sufficient practice or receiving sufficient feedback on their writing to develop fluency. Most middle and high school English teachers, for example, have student loads of 90-150 students per day. With each essay assignment creating a lot of work for the teacher per revision, teachers may feel constrained by the lack of time, and choose to limit the number of essays they would otherwise assign. Because teachers use a wide range of rubrics to evaluate writing, students also may be confused about what excellence looks like and teachers may strain to understand where students struggle from subject to subject or grade to grade. Peer review, while helpful to students in reflecting on their own practice, can be challenging in the classroom because students at different levels of writing may benefit from different feedback approaches.[19]

Building teacher capacity to teach writing:
Despite the importance of writing, most teachers currently are not provided enough training to teach

writing, particularly non-ELA teachers.[20] Even pre-service methods classes for English language arts teachers typically focus on reading and literature, rather than on writing. Teachers in other subjects are typically not required to take courses in writing instruction. Additional support in writing instruction is something teachers want: Teachers, especially those in schools serving large percentages of low-income students, frequently cite writing instruction as an area where they need a moderate or high level of additional professional learning.[21]

Teachers need the time and capacity to support students' success in writing. This includes help to create culturally aware learning environments, to build students' self-efficacy and identity as writers through writing that matters, and to create opportunities for students' active participation in selecting the topics they write about within the content of a course, as well as the creation of more authentic writing assignments that engage readers outside the classroom.

Promising approaches identified through the RFI:

There were 117 qualified RFI submissions for writing. We grouped the submissions into three different approaches to improving writing instruction, based on the challenges and opportunities described above: writing for the real world, giving writers more feedback, and next generation writing environments.

Writing for the real world:

What these approaches have in common is that they give students significant agency in the selection of the content they write about, with a focus on real-world scenarios and audiences, which allows for writing across the content areas.

- One proposal would pair a science museum with a network of schools to develop students' writing in science. During the summer, students would work with science journalists to learn the basics of writing about science (such as interviewing,

assessing facts, and using language to describe phenomena). Reporters would mentor students and teachers to create mini-apprenticeships around science journalism.

- Another submission supports students in becoming more effective writers by using their voices to advocate for social justice issues. The community-based center uses a peer coaching model to empower students to develop each other's skills as writers and connects young writers with audiences in their neighborhoods. Early research has shown that the project has a positive impact on writing scores on state tests, as well as on participants' sense of agency and their feelings of efficacy as learners and communicators. The team would like to partner with university-based researchers to further research and scale its work.
- To help students learn to critically assess the validity of evidence when using primary source material, one submission proposes creating a robust digital library of informational texts to guide students learning to write arguments based on multiple, real-world sources. Teachers could create prompts that require students to evaluate evidence and craft a compelling argument using these informational texts.
- Another submission similarly helps middle and high school students develop research and argumentative writing by selecting a social justice issue of personal interest. Students learn to voice strong opinions, cite hard evidence, anticipate counterarguments, and develop presentations. The team proposes creating a digitized curriculum based on this approach with a focus on formative feedback and explicitly integrating social and emotional learning.
- Another proposal currently prepares pre-service secondary school teachers to help students write in response to real-world issues in appropriate genres. The team proposes using technology to archive and curate these materials and to create online professional learning communities so that teachers could study, discuss, and improve upon the examples through collaboration.

Another submission supports students in becoming more effective writers by using their voices to advocate for social justice issues they care about.

Giving writers more feedback:

These submissions focus on bringing in engaged readers beyond the teacher to provide students with feedback in adjusting and revising their writing. They give students the chance to repeatedly write through successes and failures in communicating with an authentic audience. Submissions included the use of peer-review platforms and scaffolded online writing communities to help students give and receive feedback on writing in progress.

- One proposal would expand upon a program that brings recent journalism graduates into the classroom to work alongside English language arts and social studies teachers as readers and mentors. These mentors coach middle and high school students on how to use Skype to connect with experts to write about topics of personal interest to them. In teams of four, students research, interview, take notes and photographs, write stories, peer edit, and publish online using journalism strategies.
- Another proposal would enable students to upload real-world projects to an online platform where they could give and receive feedback from peers and creative industry professionals, including through videoconferencing.

Next generation writing environments:
A number of submissions focus on how to put technology at the disposal of teachers to help personalize writing instruction.

- One submission creates an online learning environment where students practice giving each other criterion-informed feedback and use that feedback to revise their writing. The platform makes visible students' contributions to peer learning—in the form of reviewer comments and writers' revision plans—so that instructors can determine where they need to coach the class or individual learners. The team's current and future R&D efforts focus on refining methods for measuring and displaying the repetition, frequency, intensity, and quality of peer feedback; developing analytics; and tracking revision decisions in real-time.
- One proposal would build a tool to capture qualitative data from students' "messy drafts," converting words and sentences into patterns that could provide additional insights for teachers into how their students craft arguments or narratives.
- Another submission describes a demonstration project that uses technology to make it easier for teachers to tailor instruction based on student performance, with the goal of deploying a writing assessment tool online that would generate teacher professional development.

We received a number of responses that focused on automated scoring tools to improve the efficiency of measurement and feedback during the writing revision process.

Gap Areas:

We received many submissions from university researchers focused on aspects of good writing and on student engagement, but these submissions largely did not address the constraints and pressures K-12 teachers face in delivering effective writing instruction. In contrast, many contributions from teacher trainers or professional development organizations in the K-12 space focused on creating the time and space to teach writing better by tackling inefficiencies in the system—document organization, workflows for record-keeping and classroom management, or alignment to standards—but did not actually focus on writing instruction itself. For example, we received a number of responses that focused on automated scoring tools to improve the efficiency of measurement and feedback during the writing revision process, but we did not see any responses around better understanding the progression of writing skills that could help inform teaching practice.

Math

Improving Mathematical Understanding, Application, and Related Mindsets

Why improve mathematics:

Proficiency in mathematics is critical for students to pursue a wide range of post-secondary careers, particularly in science, technology, engineering, and mathematics. Some familiarity with analytic methods is useful in life: for example, to interpret claims from others either as a citizen or at work. Increasingly, jobs require workers to solve complex and rapidly changing problems and to synthesize large amounts of data. Many other jobs require enough data fluency to be able to decide on the value of the analyses done by others. Yet today the majority of students are not proficient on grade-level math standards by middle school. And high schools struggle to support students to reach grade-level standards and to stay on track. These gaps create barriers to graduation and postsecondary pathways early in life. Only one-quarter of high school seniors are proficient in math based on the 2015 NAEP, and that figure drops to 12 percent for Hispanic students, 10 percent for American Indian students, and 7 percent for Black students.[22]

While efforts to improve the teaching and learning of mathematics—through higher standards, well-designed curricula, teacher professional development, and targeted student interventions—have led to incremental improvements in many states and districts over the past 15 years, Black, Latino, and low-income students often remain significantly underserved by today's approaches.[23]

The major challenges and opportunities for improving mathematics:

The following challenges were identified by experts in the field and affirmed in conversations with educators.

Facilitating deep understanding, fluency, and engagement in mathematics:

Research suggests that in many cases, math education under-emphasizes the building of problem-solving skills in favor of assignments and lessons that focus on procedures and rote calculation.[24] As a result, many students lack a deep conceptual understanding of math and its uses, and struggle to apply concepts in non-routine situations. Students of color and those from low-income backgrounds are less likely to have access to grade-appropriate assignments that ask them to think deeply about

rigorous content.[25] Too often, the feedback students receive from current math assessments—typically in the form of scores and grades—does not show students why they got a problem wrong or how to approach similar problems in the future.[26] This is true of the feedback provided by many technology tools and platforms, which often focus on right and wrong answers or multiple-choice items that cannot reveal students' thinking. Although mastery of foundational concepts is critical for student success in higher-level mathematics, students often do not have enough opportunities for authentic math practice and conversation around complex math thinking and use.[27] As a result, their misconceptions often go unidentified and unaddressed.

These problems are reinforced by challenges in the learning environment. Students enter math classrooms with widely varying levels of knowledge and skill, yet individualized instruction is challenging with only one teacher and large class sizes. Instruction that is too hard or too easy can result in students feeling left behind or disengaged—feeling that "I am not good at math," or "math is really boring," when the problem is in the learning environment, not with the domain or the individual. Traditional math classrooms also do not provide enough opportunities for students to talk or write about mathematics, including explaining their thinking, asking clarifying questions, and discussing different approaches or applications.[28] Though math is often taught as a solitary activity, research suggests group work at the right time can result in deeper learning because it allows students to tackle more complex problems with their peers and to explain their reasoning to others.[29] While math is interconnected with science, literacy, and many other disciplines, students generally lack opportunities to make connections between subjects or to integrate concepts.

Motivating students to put in persistent effort toward mastery:

Students learn concepts more deeply and are more engaged when they are encouraged to fail and try again.[30] They benefit from opportunities to explore multiple ways to approach problems or to see math in real contexts.[31] Yet traditional math education often falls short of providing these opportunities for exploration. Instead, instruction may prioritize teaching a particular method of how to solve a problem rather than giving opportunities to apply a variety of tools and fluencies already mastered to make meaning for themselves. As a result, many students do not enjoy learning math.[32]

Helping students develop an identity as math learners:

Many students experience high anxiety and a lack of confidence when it comes to doing math. This is often fueled by a belief that students' (and adults') math abilities are fixed and cannot be improved through effort.[33] Similarly, fixed teacher mindsets can pass onto students, contributing to their lack of confidence and identity as math learners.[34] Providing opportunities to explore math concepts in interesting ways—such as with manipulatives, visuals, games, interactive activities, or in real-world settings with meaning to the local community—can help engage students and develop their identity as math learners.[35] Developing students' inclination to see math as a sensible, useful, and worthwhile subject, coupled with a belief in their own efficacy to do math, is important to developing math proficiency.

Providing teachers with the supports, skills, and beliefs to reach all students:

Teachers need access to sufficient math education and training, including professional development on how students learn math, how to anticipate student thought processes and misconceptions, how to implement complex and non-routine problem solving in the classroom effectively, and how to link math concepts and skills to motivating examples and practice.[36] However, professional development often focuses on generic content knowledge that lacks direct classroom or community application or follow through. In addition, teachers often receive inadequate support to deploy new solutions, such as new curricula or personalized learning platforms, making it hard to integrate them into the classroom.

End-of-year, large-scale assessments alone do not provide teachers with the fine-grained data needed to understand and continuously monitor student thinking.[37] Teachers need access to formative assessments that provide the type of highly specific, real-time data that enable them to address misconceptions and common learning needs as they occur. There also are few effective assessments to measure non-academic skills that can influence math learning and performance.

Teachers need the time and flexibility to try new approaches for differentiating instruction, based on a robust knowledge of mathematics and of learning theory. These changes can be supported by assessments that provide teachers with timely, multidimensional, and actionable information about their students' math understanding in order to inform instruction; math standards that are easy to interpret and that facilitate depth and breadth of understanding; and access to evidence-based approaches for selecting curricula and other high-quality instructional

materials that are informed by teachers. Courseware developers face a tension between creating solutions that cover a breadth of topics across the curriculum or going deeper on common problem areas (such as fractions or algebra) to address key learning challenges. There's also pressure to build out content and feedback features quickly without compromising on quality. Cost, resources, platform capabilities, and a lack of research on efficacy in different contexts all pose significant barriers to developing high-quality courses at scale.

Promising approaches identified through the RFI:

There were 177 qualified submissions to the math RFI. We grouped the submissions into four broad categories: improving practice and feedback; novel instruction and experiential learning; improved measurement systems; and empowered teachers.

Practice and feedback:

The proposed approaches provide students with rich opportunities to engage in deliberate practice and provide actionable feedback that leads to deep mastery of foundational math knowledge and concepts. They include digital games that enable students to practice the application of concepts in novel situations.

- One gaming solution mixes mini video games, digital sandboxes, printed textbooks, traditional storytelling, and printed exercises to offer highly visual, emotional, and playful tools for learning mathematics. The features can be adapted from tablets to smartboards to partially analog configurations.
- Another proposed solution would use intelligent tutoring and technology-based, personalized learning platforms to identify student misconceptions, provide students with actionable feedback, and support individualized opportunities for learning and practice. Another proposes an intelligent learning companion that would ask students to teach a simulated digital peer, while tracking students' mathematical understanding.
- Another example uses a personalized learning platform to analyze student diagnostics in minutes, enabling teachers to quickly understand whether a particular explanation or intervention is working and what set of strategies would help individual students or groups of students navigate a curriculum, but it has not yet been expanded to mathematics. By providing rapid information to both teachers and students and their families on student progress, these approaches could help students make the connection between effort and growing proficiency in math.

Novel instruction and experiential learning:

These approaches provide students with repeated opportunities for math literacy and discourse about real-world problems to engage students in problems of interest to them and to help develop a positive math identity.

- One submission proposes using a series of lessons based on the game of chess to help at-risk preschoolers improve their early math skills so they are ready for kindergarten. Another solution for middle and high school students asks students to apply math concepts to solve real-world problems and aims to transform math classrooms into arenas for civic discourse. Questions such as "What are some consequences of increasing the minimum wage?" help students appreciate the importance of math and develop the skills and mindsets needed to analyze complex problems rationally, respectfully, and from a variety of perspectives.
- Another solution focuses on reducing math anxiety among Black and Latino students by "taking math out of the bubble" and connecting it to other content areas and topics of personal interest to students. For example, students rewrite math problems from existing curricula based on story problems that are of interest in their own lives. They work collaboratively to apply math knowledge and skills to choose-your-own adventure scenarios. These community-based learning strategies, currently in use in only a few pilot sites, are meant to foster a positive culture around mathematics.

Improving measurement systems:
These solutions propose to narrow the gap between assessment and instruction by using richer indicators of student progress.

One potential solution focuses on reducing math anxiety among Black and Latino students by "taking math out of the bubble" and connecting it to other content areas and topics of personal interest to students.

- One solution would digitally collect students' answers to math problems and then use artificial intelligence to quickly detect patterns and classify responses along a learning progression for the teacher. This would use classroom assignments to provide teachers with the type of highly specific, real-time data they need to address misconceptions and common learning needs as they occur.
- Another management tool uses student data to provide personalized intervention recommendations. The platform helps schools implement evidence-based practices and leverages student data to understand and problem-solve student learning needs.

Numerous solutions focused directly on supporting students, but relatively few focused specifically on supporting teachers.

- A third submission would design, develop, and study a new model that can provide relevant, personalized academic guidance and counseling to Algebra 1 learners, by using artificial intelligence to detect and predict learning styles associated with different personality traits.

Empowered teachers:

The common thread in these submissions is the intent to support teachers to differentiate their approaches for students with a wide range of proficiency levels and to free up teachers' time to try new strategies.

- One submission would help teachers support more active math learning in their classrooms by expanding the use of STEM tournaments. Teachers in these classrooms can pose open- and closed-ended questions, connect synchronously to other classes in real-time, and share information and knowledge about student progress to support teacher learning.
- Another submission would use student response data from digital math talks to provide insights for teachers of where students are along a learning progression, as well as real-time suggestions for instruction. The data could be aggregated and analyzed across classrooms, so that students would be de-identified, for use by online professional learning communities of educators.

Gap Areas:

Despite the large number of promising solutions and approaches, there were also challenges not specifically addressed through the submissions. Numerous solutions focused directly on supporting students, but relatively few focused specifically on supporting teachers. Though respondents did cite teacher supports as a challenge, as described above, few solutions directly tackled this. For example, few submissions directly addressed ensuring that teachers have robust knowledge of mathematics and of learning theory, nor did they focus on ensuring that teacher and student supports account for environmental and systemic factors that impact marginalized groups.

Executive Functions

Measuring and Improving Executive Functions

Why improve executive functions:

Student success in academics and in future careers is intimately tied to their ability to wrestle with multiple ideas at once, think flexibly, hold complex information in mind, filter out distractions, and manage actions, thoughts, and emotions. These skills describe what researchers call "executive functions," a set of skills that a robust body of evidence has found to predict better academic performance, higher income levels, better physical health, and fewer drug-related problems and criminal convictions in adulthood.[38] Research has clearly established that students' executive function skills predict school readiness and academic achievement, even after accounting for intelligence and prior knowledge.[39] Thus executive functions form the foundational building blocks for learning.

Executive functions develop and change over time, can respond to intervention, and can be measured.[40] Yet, despite the strength of basic research, there is much to be done to understand and improve students' progress in developing executive functions, as well as to understand the precise relationships between different aspects of executive functions and real-world outcomes. For instance, research shows that these skills emerge in early childhood and build the foundation for more complex problem solving, reflection, planning, creativity, and task management skills that students will need throughout life.[41] Psychological and physical stress can impede the development of these skills. Children who have experienced trauma or adversity—such as violence, neglect, chronic hunger, or homelessness—can be buffered from the effects of stress by building their executive function skills, but they also may have less opportunity to practice these skills.[42] The field has not yet identified precise, context-appropriate, effective, and scalable ways to track progress or the types of interventions that can improve executive functions in the general student population or for children with stress- or adversity-related challenges.

In addition, researchers do not fully understand all the various ways in which executive functions may develop and how these developmental trajectories may influence or be influenced by real-world contexts for different groups of children as they mature to adulthood. For example, practitioners lack targeted strategies and tools to intervene efficiently with adolescents who lag in developing these skills and may therefore be at risk of having less positive life outcomes as adults.

The major challenges and opportunities for improving executive functions:

The following challenges were identified by experts in the field and affirmed in conversations with educators.

Providing educators, parents, and students with a clear understanding of executive functions:
A critical foundational challenge to improving executive functions is that the term is not well communicated by researchers and is thus not universally well understood by educators, parents, or students. Executive functioning is defined in the research community as the cognitive processes that allow us to allocate our attention in service of our goals. Researchers generally, although not universally, agree that it includes three or four main skills: our ability to hold information in mind ("working memory"), to flexibly shift between multiple tasks or goals ("cognitive flexibility"), and to control our attention and ignore distractions or competing goals ("inhibitory control" or "attentional control").[43] In labs, these executive functions are often tested in a low-stakes way, when emotions aren't really a factor ("cold" contexts). In more emotional, social, or high pressure ("hot") contexts, executive functions allow us to flexibly manage our emotions and motivation in order to stay engaged in goal-directed behavior.

Deepening the understanding of executive functioning by teachers, parents, and students can help students harness these skills to learn more effectively; inform how educators structure learning experiences and environments to help students practice and build these skills; and actively support students who may face challenges to executive functioning that contribute to learning or behavioral difficulties. A better understanding of how these skills develop over time could also provide parents and caregivers with clear, actionable recommendations on how to build executive functioning at home and in informal learning environments.

Developing valid, reliable measures that could inform understanding of how executive functions develop over time and opportunities for improvement:
While executive functions are measurable, there is a lack of valid and reliable measures that can make visible a student's capacity to use these skills. Without such measures, practitioners have limited ability to determine precisely how the various executive function skills relate to learning specific subjects and how those relationships unfold throughout childhood and adolescence. Without such measures, it's also difficult to design interventions that help develop executive functions and then determine their effectiveness. In particular, while research has shown that specific programs can develop executive functions, these programs do not always lead to improved use of these skills in other contexts or to improved real-world outcomes.[44]

Developing basic models of how specific executive functions relate to math, reading, writing, and other content areas:
While research suggests that better executive functioning can contribute to better academic and life outcomes overall, it offers little guidance to educators on how best to create learning environments that enable students to practice and develop these skills, or how to support students who have executive function challenges.

The development of educational curricula, tools, and technologies is similarly constrained by the lack of strong models, methods, and interventions from basic research. Closing the gap between basic and applied research in this area could yield significant advances in students' development of these foundational and critical skills.

Promising approaches identified through the request for information

There were 171 qualified submissions to the executive functions RFI. We grouped the submissions into three broad categories: measures of executive functions; interventions to build executive functions; and tools and techniques to support programs that develop executive functions.

Measures of executive functions:
There were promising approaches to developing better measures of executive functions across basic and applied research and advanced development.

- An applied research submission proposes to create a state-of-the art tool—based on advances in precision medicine—to enable families and teachers to securely gather more robust information about children's executive functioning, and for those learnings to be de-identified to advance the field's understanding of how executive functioning develops over childhood.
- Another submission proposes to convene a multidisciplinary team of practitioners, researchers, developers, and designers to create a tablet-based measurement-and-intervention platform that would train teachers to better identify, assess, and develop students' executive functions. The platform would help teachers target developmentally appropriate applications of these skills, quickly assess students' executive functions during regular classroom activities, and help pinpoint areas for further teacher training.
- Another submission proposes a multi-disciplinary team of psychologists, social psychologists, cognitive neuroscientists, and empirical economists to: (1) *map how teaching about executive functions relates to the development of social and emotional skills;* (2) i*dentify individual differences in responsiveness to such teaching; and* (3) *chart the effects of such teaching on the developmental trajectory of executive functions. This basic research proposal would use longitudinal data to identify "profiles of change" that*

could enable interventions to be tailored for individual students. Although the submission did not suggest a specific intervention or set of measures, its sophisticated models could advance the field and accelerate R&D efforts.

Interventions to build executive functions:
We received more submissions in this category than in any other. The most promising approaches fell across basic, applied, and advanced development research but also included the expansion or scaling of some existing products.

- A basic research idea submitted jointly by two universities would explore three interesting questions: (1) *Does providing students with the chance to practice building executive functions in relatively low-stakes environments, such as by playing games, prove more effective at transferring these skills to real-world academic performance than by teaching such skills directly?* (2) *What are the most effective and durable interventions to improve executive functions?* (3) *Are approaches that combine direct teaching with practicing executive functions in low-stakes environments most beneficial in developing the ability to apply these skills to academic tasks?*
- An applied research submission, also from two universities, would develop "kernels of practice": low-cost, targeted strategies that represent the essential "active ingredients" in effective programs to develop social, emotional, and cognitive skills. By design, these kernels are behavioral "nudges" that target a specific daily behavior and can be taught quickly. The researchers hypothesize that such kernels would be more potent and feasible to implement than full-scale programs, potentially increasing initial uptake, impact, and sustainability over time. Because the development of executive functions is particularly sensitive to the negative effects of stress and trauma, such kernels might be particularly relevant for at-risk students who encounter many more external stressors than other children, yet are often in under-resourced settings that make it difficult to implement social, emotional, and academic development programs at scale.
- An interesting advanced development submission would boost adults' knowledge and development of executive functions, which research has found is strongly related to children's development of such skills. The submission proposes to bring together

an interdisciplinary team of practitioners, researchers, families, technology experts, and policymakers to develop a mobile-first education platform for parents and early caregivers. The platform would translate ongoing research about executive functioning into interactive media and "just-in-time" competency building activities for adults, so that they can better teach, measure, and practice these skills themselves. An artificial intelligence-based "smart tutor" would create personalized professional learning that could serve as a backbone for both adult and early childhood education about executive functions.

- Other submissions propose: expanding existing programs that integrate the development of executive functions and social-emotional skills by incorporating play and academic learning; and bringing together the fields of gaming, entertainment, education, and research to deliver programming that builds children's executive functions through innovative digital games that build upon an existing game as a model.

Tools and techniques to support programs that develop executive functions:

Promising approaches in this category included applied research and advanced development.

- One interesting submission builds on two key findings from research: motivation to learn and curiosity strongly predict educational success, and testing students on information they've recently studied helps them do better at retaining that information over time. The first idea would be to ask students questions that stimulate their curiosity (and engage reward-motivation systems in the brain) and then teach them additional, unrelated information while their brains are in that heightened, learning-oriented state. Research suggests this could lead to better learning and retention of complex material. The second idea would allow students to film real-world learning experiences (such as through smartphones) and then use snapshots from those films to provide targeted tests they could complete in a few minutes, asking them to recall details from their learning. The hypothesis is that this process will result in better retention of information over time. It is based on brain imaging research that shows when people recall a specific detail from a learning event, it reactivates a fuller pattern of brain activity that was engaged during the learning event.

Gap Areas:

There were several important areas that were not explicitly addressed or were only sparsely addressed. For instance, there were relatively few submissions that addressed measurement issues. This was particularly true for basic research submissions, where much work needs to be done to help understand executive functions across the lifespan in order to generate valid, reliable, and repeatable measures and interventions. In particular, it is critical to understand how executive functions dynamically fluctuate across learning experiences and across the school day, but no submissions directly addressed how to measure such dynamic fluctuations with authentic embedded assessments. It is also critical to address privacy and ethical concerns related to the development and use of measures of executive functions, and only a few submissions discussed this topic. None of the programmatic interventions addressed the notion that executive functions fluctuate within individuals over time, as influenced by a variety of factors, including: nutrition, circadian rhythms, sleep levels, social and emotional interactions with peers and adults, feelings of belonging and safety, and feelings of self-efficacy both in specific academic subjects and overall. It will be important to consider these fluctuations in order to design programs that harness and build executive functions in every student. Only a few of the submissions strongly considered individual differences in executive functions and how to both measure and address those in designing strategies for students with varying strengths and needs. None of the ideas addressed how to improve the executive functions of teachers themselves. Given the impressive advances being made in neuropsychology, brain science, and technology, the tools and techniques area holds untapped promise for advancing a broad range of solutions to developing and measuring executive functions that were not fully explored in the submissions we received.

It is critical to address privacy and ethical concerns related to the development and use of measures of executive functions.

Opportunities Going Forward

We were tremendously inspired and encouraged by the responses to the RFI, as well as by the overall feedback from the field. The Bill & Melinda Gates Foundation and the Chan Zuckerberg Initiative are looking forward to continuing to collaborate with teachers, school leaders, families, researchers, edtech developers and publishers, universities, professional development organizations, and others on important work in these disciplines.

This summary of the RFI submissions is not intended to imply funding decisions at this point. Rather, we encourage you to share your ideas or responses to the themes and gaps that we have identified and to send those thoughts to us at EducationRD@gatesfoundation.org or EducationRD@chanzuckerberg.com.

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