

EQUITABLE AND DYNAMIC APPROACHES TO ASSESSING EXECUTIVE FUNCTIONS IN THE MATHEMATICS CONTEXT

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Executive functions (EFs) are related to mathematics achievement, yet much is still unknown about how or why these relations exist. Improved measurement of EFs in students' math learning is needed to answer such questions equitably. Further, if research is conducted with the goal of informing teaching and learning, the EF assessments should focus on students' strengths and provide data that is useful and understandable to educators and students. In this paper, we explore how interdisciplinary teams of educators, developers, and researchers have assessed EFs in the mathematics context. We present strategies for assessing EFs more equitably and discuss implications for measuring EFs on various partners' activities within the research and development and implementation of mathematics curricula.

Keywords: Cognition; Equity, Inclusion, & Diversity; Assessment

Introduction

Executive functions (EFs) are a set of cognitive processes important for directing our thoughts and actions to what is necessary for achieving our goals. One popular model of EFs categorizes them as three separable, but overlapping functions known as working memory, inhibition, and cognitive flexibility (Miyake et al., 2000). Mathematics requires all three of these cognitive processes: thinking flexibly, holding and updating important information in working memory (e.g. Raghobar et al., 2010), and inhibiting misconceptions and irrelevant information or rules (e.g., Cragg et al., 2017). EFs are related to performance on mathematics tasks, and have been shown to predict mathematics achievement longitudinally (Cragg & Gilmore, 2014; Ribner, 2020). Teachers have also noticed that EFs are important for math learning based on their observations in the classroom (Gilmore & Cragg, 2014). However, there are few educationally-relevant causal studies of these relationships (Clements et al., 2016). We need better theory and measurement of executive functions in mathematics to understand why these relationships exist and whether executive functions should be intentionally targeted through math interventions (Medrano & Prather, 2023; Scerif et al., 2023; Wilkey, 2023; Younger et al., 2023).

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 (Gilmore et al., 2015; Wilkey & Price, 2019). This suggests that the mathematical learning context should be considered when investigating relationships between EFs and mathematics (Gilmore, 2023; Medrano & Prather, 2023; Niebaum & Munakata, 2023). Moreover, a more strengths-based approach to measuring executive functions is needed that reflects the diverse environments in which children are learning (Miller-Cotto et al., 2022). However, there is a large disconnect between research in math education and research in math cognition (Berch, 2016; Bruce et al.,

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2017). Math education researchers have long argued cognitive researchers should better consider the educational context in which math learning occurs (de Freitas & Sinclair, 2015; Verschaffel, Lehtinen, Van Dooren, 2016). Researchers in cognitive science and education often use different terminology to refer to similar constructs, which contributes to the divide across fields, and the gap between research and practice (Berch, 2016). For example, one study found that only 20% of teachers were familiar with the term executive functions (Cragg & Gilmore, 2014). EFs are typically assessed by having children complete cognitive behavioral tasks that measure accuracy and response time, or by having parents or teachers complete a rating scale of a child's everyday functioning, and these different measurement formats are not equivalent or interchangeable (Toplak et al., 2013). There is a building consensus that EF assessments need to account for individual differences and contexts; however, there is a dearth of practical solutions at this time. It therefore remains unclear exactly how or why teachers should assess and support executive functions in the mathematics classroom.

Context and Purpose of this Research

The EF + Math Program was developed to explore the core hypothesis that math intervention approaches which contain support for developing EFs can lead to improved mathematics achievement. EF + Math enlisted a portfolio approach, which entails multiple project teams designing and studying interventions which test this core hypothesis, along with other project teams focused on developing effective and equitable assessments and technologies to support measurement of EFs in mathematics. Each project team is interdisciplinary, with educators, researchers, and developers coming together to mitigate challenges that can arise in bridging research to practice (Uncapher, 2018).

The project teams established their approaches to answering the core hypothesis of the EF + Math Program through collaborative discussions, which allowed for the designed interventions and assessments, and their theories of action to be situated not only within the research base, but within the needs of real classroom contexts, educators, and diverse student populations. However, this inclusive approach to research and development raises tensions about the relationships between researchers' assessment of cognitive constructs and the ways that data informs educator practice and student learning (Uncapher, et al., 2022). We elevate one of those tensions in relation to our focus on executive functions in the mathematics contexts: to what extent is the assessment of EF in the mathematics contexts useful, and for which partners? Each project team encountered this tension in their work, and addressed it through different approaches, based on their conceptualizations of EFs in mathematics contexts and the ways that EF supports were incorporated into their interventions. In this paper, we ask, "how have project teams navigated the needs of researchers, developers, educators, and students in assessing EFs in math contexts? How can EFs be assessed in ways that inform both educational practice and mechanistic cognitive research questions?"

Conceptual Framework: Inclusive Research And Development

We examine this research question through the lens of inclusive research & development (iR&D; EF + Math, 2023). The IR&D model is part of the larger movement toward educational participatory research methodologies and partnerships (Amiel & Reeves, 2008; Vaughn & Jaquez, 2020). In these methodologies and partnership models, researchers, developers, and educators are positioned as collaborative partners and actively work to deconstruct hierarchies of power.

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However, even in iR&D-driven projects, tensions can arise regarding the role and purpose of conducting research on interventions, especially given the relations different team members may have to the data. For example, researchers collect and analyze data to provide findings to developers and educators, as well as answering more generalizable research questions. Developers use data to inform future development of the interventions, including improving data collection mechanisms or structures to share data findings and implications with teachers and students within the intervention itself. Finally, teachers collect and use data to inform the supports they provide students, future adaptations of curricular materials, and other implications for practice; teachers also provide valuable context and interpretations of data to support researchers and developers in their work. Equity not only means that these different purposes and goals for engaging in research can cause project teams to take a particular approach to their assessment strategies, such as this paper's focus on EFs in math. Equitable approaches to assessment center the lived realities, needs, and assets of students, particularly students of color.

Data and Methods

The research questions and related findings presented in this paper are part of a set of larger, ongoing research studies. Each project team has conducted several cycles of inclusive R&D. Across these cycles, project teams created and updated study design documents, research plans, and measurement plans. For this analysis, our data sources included these documents, as well as notes taken during conversations about measurement and data collection with project teams throughout the inclusive R&D cycles. We have conducted initial analyses of the project team documents and conversation notes; as the teams' are actively engaged in inclusive R&D cycles, future analyses will include additional data sources and updated themes. To answer our research questions, we first identified sections of text that referred to the measurement or assessment of EFs. Within these sections, we coded for the "how" a project team assessed EFs and the "why" for their decisions. We looked for shifts across time for each project team to identify key moments for analysis. Finally, we looked to see how the methods for assessing or the justification for those methods were in response to researcher, teacher, or developer needs and uses of data. The themes presented in this paper represent two types of equitable EF assessments developed and refined through inclusive R&D.

Results: Equitable Approaches to Assessing EFs in Mathematics Contexts

Defining EFs within Mathematical Activity

Assessments do not always provide discipline-specific approaches to measuring EFs; given research on the role of context (Medrano & Prather, 2023; Niebaum & Munakata, 2023), it is essential for researchers to continue developing assessments that capture EFs in mathematics. Measuring EFs in the mathematics context can be approached by capturing in-the-moment data on student activity while actively doing mathematics. The Project teams worked to develop new assessments involving technological features and varied data sources to define EFs in the mathematical context more equitably and in ways that honor students' epistemic diversity.

One project team's intervention focused on the role of EFs in middle school students' collaborative problem solving practices (Kuchynka, et al., 2023). They developed a qualitative coding scheme that identifies what EFs look like in student talk or student actions during problem solving (Renninger, et al., 2023). This assessment strategy leverages qualitative data

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sources, such as transcripts or observations. Researchers are still able to conduct analyses on the relationships between EFs and math learning; such a coding scheme is also supportive of teacher use to develop an understanding of what EFs look like, noticing of when students are engaging their EFs, and cultivating awareness of how teaching practices or curricular materials can create opportunities for students to engage their EFs within a task.

Another team conceptualized EFs within the context of rational number learning, with an embodied cognition approach driving their intervention design and implementation. Their team developed a rational number knowledge assessment that requires students to engage their EFs to shift across strategies, filter information, and manipulate quantities flexibly. Administering this assessment allowed teachers to focus on assessing mathematical task performance and gathering rational number knowledge evidence, while still providing researchers with relevant and useful data on EFs.

Measuring EF Fluctuations and Communicating Findings Effectively

Traditional measures of EFs often provide static snapshots of student performance on EF tasks. In reality, students' engagement of EFs on a given day or within a task is dependent on a variety of factors, including social and cultural contexts, affective factors, and personal differences. Equitable assessments of EFs should be more flexible and dynamic to mirror this reality and disrupt static labeling practices common in schooling. Approaches to measuring student EFs can include more regular assessments, but also involve the communication of assessment data back to students and teachers to inform adaptations of teachers' practice, as well as supports for developing student agency.

One team has focused on the development and iteration of a machine-learning assessment tool that collects "in the moment" data on students' engagement of EFs and other metacognitive processes (Zhang, et al., 2022). This tool provides an asset-based approach to understanding the variability in students' EFs within problem solving tasks; the assessment aims to promote more accurate understandings of what students are able to do. This team's technology takes in large amounts of qualitative data and presents summaries of data trends to educators through a dashboard view. The teachers are able to view key information about students and classes, as well as implications for their pedagogy, use of particular materials, or scaffolds that may be high leverage supports for students based on their EFs needs that day.

Another project team is developing an app that can quickly and easily assess daily fluctuations in students' EFs (Ghil, et al., 2022). They are developing an adaptive technology that can optimize the EF assessment items students should complete each day; this capacity will allow researchers to model EF trends using minimal data and limiting teacher burden (Katsumba, et al., 2023). Additionally, this team has worked to develop a dashboard that displays these fluctuations to students and educators in positive, asset-based ways. The dashboard, which was co-designed with students themselves, presents data in understandable amounts, and includes recommendations for students to enact agency over their learning based on their data for the day.

Implications and Conclusions

The project teams have continued to iterate upon their approaches to assessing EFs as part of inclusive research and development processes. As the approaches are implemented in additional educational environments, new information is collected regarding their effectiveness and applicability. Further, researcher, educator, and developer goals for understanding EFs in math

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contexts will continue to evolve as part of the broader fields of math education and math cognition. The EF + MathProgram and its project teams will continue to explore the question, “to what extent is the assessment of EF in the mathematics context useful, and for whom?”

In collaborative partnerships, each party may require or prioritize different data sources or varied granularity to be able to achieve their own goals. Navigating these tensions and creating strategies for assessment in inclusive R&D cycles is non-trivial activities. By documenting the strategies developed by EF + Math’s project teams, we hope to encourage continued conversation and exploration of the role of assessment and measurement in iR&D activities. We envision a future for mathematics education where multiple partners are able to effectively collaborate to design and test solutions that address the challenges educators face in their mathematics classrooms in order to support all students in achieving their full potential as brilliant mathematicians.

References

- Amiel, T., & Reeves, T. C. (2008). Design-Based Research and Educational Technology: Rethinking Technology and the Research Agenda. *Journal of Educational Technology & Society*, 11(4), 29–40. <https://www.jstor.org/stable/10.2307/jeductechsoci.11.4.29>
- Berch, D. B. (2016). Disciplinary Differences Between Cognitive Psychology and Mathematics Education: A Developmental Disconnection Syndrome Reflections. *Journal of Numerical Cognition*, 2(1), 20–41. <https://doi.org/10.5964/jnc.v2i1.10>
- Bruce, C. D., Davis, B., Sinclair, N., McGarvey, L., Hallowell, D., Drefs, M., Francis, K., Hawes, Z., Moss, J., Mulligan, J., Okamoto, Y., Whiteley, W., & Woolcott, G. (2017). Understanding gaps in research networks: using “spatial reasoning” as a window into the importance of networked educational research. *Educational Studies in Mathematics*, 95(2), 143–161. <https://doi.org/10.1007/s10649-016-9743-2>
- Clements, D. H., Sarama, J., & Germeroth, C. (2016). Learning executive function and early mathematics: Directions of causal relations. *Early Childhood Research Quarterly*, 36, 79–90. <https://doi.org/10.1016/j.ecresq.2015.12.009>
- Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. In *Trends in Neuroscience and Education* (Vol. 3, Issue 2, pp. 63–68). <https://doi.org/10.1016/j.tine.2013.12.001>
- Cragg, L., Keeble, S., Richardson, S., Roome, H. E., & Gilmore, C. (2017). Direct and indirect influences of executive functions on mathematics achievement. *Cognition*, 162, 12–26. <https://doi.org/10.1016/j.cognition.2017.01.014>
- de Freitas, E., & Sinclair, N. (2015). The cognitive labour of mathematics dis/ability: Neurocognitive approaches to number sense. *International Journal of Educational Research*, 1–9. <https://doi.org/10.1016/j.ijer.2015.10.008>
- EF+Math Program. (2023). Strengthening executive function skills to improve mathematics learning: Evidence of promise from EF+Math's inclusive R&D approach. <https://hdl.handle.net/20.500.14099/13>
- Ghil, E., Gomez, M., Chen, Y., Rodriguez, C., Mester, R. E., Barbour, D. L., Ramani, G. B., Seitz, A. R., & Jaeggi, S. M. (2022, April 27-May 1). Developing and implementing equitable and game-like EF and math tasks for children [Presentation]. Annual Convention of the Western Psychological Association.
- Gilmore, C., & Cragg, L. (2014). Teachers’ understanding of the role of executive functions in mathematics learning. *Mind, Brain, and Education*, 8(3), 132–136. <https://doi.org/10.1111/mbe.12050>
- Gilmore, C., Keeble, S., Richardson, S., & Cragg, L. (2015). The role of cognitive inhibition in different components of arithmetic. *Zdm*, 2010. <https://doi.org/10.1007/s11858-014-0659-y>
- Kasumba, R., Marticorena, D.C.P., Pahor, A., Ramani, G., Goffney, I., Jaeggi, S.M., Seitz, A., AGardener, J.R., & Barbour, D.L. (2023). Distributional latent variable models with an application in active cognitive testing. *PsyArXiv*. <https://doi.org/10.48550/arXiv.2312.09316>
- Kuchynka, S., Rosenberg-Lee, M., & Renniger, K.A. (2023). Fostering equity, executive functions, and math conceptual understanding: A multi-year intervention with Black and Latinx middle school students [Symposium]. *Association of Psychological Science Conference*, Washington, D.C.
- Kosko, K. W., Caniglia, J., Courtney, S., Zolfaghari, M., & Morris, G. A., (2024). *Proceedings of the forty-sixth annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Kent State University.

- Medrano, J., & Prather, R. W. (2023). Rethinking Executive Functions in Mathematical Cognition. *Journal of Cognition and Development, 24*(2), 280–295. <https://doi.org/10.1080/15248372.2023.2172414>
- Miller-Cotto, D., Smith, L. V, Wang, A. H., & Ribner, A. D. (2022). Changing the conversation: A culturally responsive perspective on executive functions, minoritized children and their families. In *Infant and Child Development* (Vol. 31, Issue 1, pp. 1–12). <https://doi.org/10.1002/icd.2286>
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “Frontal Lobe” tasks: a latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. <https://doi.org/10.1006/cogp.1999.0734>
- Raghubar, K. P., Barnes, M. a., & Hecht, S. a. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences, 20*(2), 110–122. <https://doi.org/10.1016/j.lindif.2009.10.005>
- Renninger, K. A.,Boehim, R., De Dios, M. C., Hogan, M.R., Kyaw, M. H., Michels, A.G., Nakayama, M., Torres, P.E., & Werneck de Souza Dias, H. (2023, August). Exploring collaboration and executive functions in open-ended problem-solving in mathematics. [Paper Presentation] *20th Biennial EARLI Conference for Research on Learning and Instruction*, Thessaloniki, Greece.
- Ribner, A. (2020). Executive function facilitates learning from math instruction. *Learning and Instruction, 65*(2016), 2017. <https://doi.org/10.1016/j.learninstruc.2019.101251>
- Scerif, G., Blakey, E., Gattas, S., & Hawes, Z. (2023). Making the Executive ‘ Function ’ for the Foundations of Mathematics : the Need for Explicit Theories of Change for Early Interventions. *Educational Psychology Review, 1*–27. <https://doi.org/10.1007/s10648-023-09824-3>
- Toplak, M. E., West, R. F., & Stanovich, K. E. (2013). Practitioner Review: Do performance-based measures and ratings of executive function assess the same construct? *Journal of Child Psychology and Psychiatry and Allied Disciplines, 54*(2), 131–143. <https://doi.org/10.1111/jcpp.12001>
- Uncapher, M. R. (2018). From the science of learning (and development) to learning engineering. *Applied Developmental Science, 0*(0), 1–4. <https://doi.org/10.1080/10888691.2017.1421437>
- Uncapher, M., Baker, R., Liu, Y., Prather, R., Ramani, G., & Smith, A. (2022, September 24). Creating tools for equitable research and development [Moderated Discussion]. Society for Research on Educational Effectiveness Conference. Arlington, VA.
- Vaughn, L. M., & Jacquez, F. (2020). Participatory research methods: Choice points in the research process. *Journal of Participatory Research Methods, 1*(1). <https://doi.org/10.35844/001c.13244>
- Verschaffel, L., Lehtinen, E., & Van Dooren, W. (2016). Neuroscientific studies of mathematical thinking and learning: a critical look from a mathematics education viewpoint. *ZDM - Mathematics Education, 48*(3), 385–391. <https://doi.org/10.1007/s11858-016-0781-0>
- Wilkey, E. D. (2023). The Domain-Specificity of Domain-Generality: Attention, Executive Function, and Academic Skills. *Mind, Brain, and Education, 17*(4), 349–361. <https://doi.org/10.1111/mbe.12373>
- Wilkey, E. D., & Price, G. R. (2018). Attention to number: The convergence of numerical magnitude processing, attention, and mathematics in the inferior frontal gyrus. *Human Brain Mapping, September*, 1–16. <https://doi.org/10.1002/hbm.24422>
- Younger, J. W., O’Laughlin, K. D., Anguera, J. A., Bunge, S. A., Ferrer, E. E., Hoefft, F., McCandliss, B. D., Mishra, J., Rosenberg-Lee, M., Gazzaley, A., & Uncapher, M. R. (2023). Better together: novel methods for measuring and modeling development of executive function diversity while accounting for unity. *Frontiers in Human Neuroscience, 17*(July). <https://doi.org/10.3389/fnhum.2023.1195013>
- Zhang, J., Andres, J. M. A. L., Hutt, S., Baker, R. S., Ocumpaugh, J., Nasiar, N., Mills, C., Brooks, J., Sethuraman, S., & Young, T. (2022). Using Machine Learning to Detect SMART Model Cognitive Operations in Mathematical Problem-Solving Process. *Journal of Educational Data Mining, 14*(3), 76–108. <https://doi.org/10.5281/zenodo.7304763>

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