Mathematics, 3D Printing, and Computational Thinking Through Work-Based Learning (MPACT)

An Education Innovation and Research (EIR) Grant Evaluation

Technical Report

October 2023

Douglas Gagnon
Ela Joshi
Nicole Arshan
Eliese Rulifson
Elise Levin-Güracar
Tejaswini Tiruke

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The research reported here was supported by the Office of Elementary and Secondary Education (OESE), U.S. Department of Education, through Grant #U411C180070 to SRI International. The federal grant provided $3,926,461, or 90 percent of the total project funds. Additional, generous donors provided 10 percent of project funds. The opinions expressed are those of the authors and do not necessarily represent the official views of, or an endorsement by, OESE, U.S. Department of Education, or our other donors.

Suggested citation: Gagnon, D. J., Joshi, E., Arshan, N., Rulifson, E., Levin-Güracar, E., & Tiruke, T. (2023). Mathematics, 3D Printing, and Computational Thinking Through Work-Based Learning (MPACT): An Education Innovation and Research (EIR) Grant evaluation. Technical Report. SRI International.

Executive Summary

In 2019, SRI International received an Education Innovation and Research (EIR) grant to support the development of the Mathematics, 3D Printing, and Computational Thinking Through Work-Based Learning (MPACT) program to schools in four U.S. states.

Designed, developed, and implemented by TERC, a nonprofit organization dedicated to innovation in science, technology, engineering, and math (STEM) education, MPACT relies on teacher professional development, specialized curriculum and materials, and STEM industry mentors to provide students with project-based experiences implemented across three learning modules. MPACT provides design-and-making projects—including digital fabrication as well as low-tech materials—for teachers and students in grades 4–7. The curriculum includes explicit opportunities to learn mathematics, computational thinking, and spatial reasoning.

In this technical report, we present study findings of MPACT implementation in the 2021–22 school year, the first year in which the program was fully implemented. We describe the extent to which the program was implemented as intended. We also look at the impact of the program on students' socioemotional outcomes and teachers' perceptions of and efficacy in programmatic concepts. We define MPACT Fellows as teachers who participated in the MPACT program. We use a cluster quasi-experimental design that compares students in MPACT Fellows' classrooms to a similar, matched group of students in comparison teachers' classrooms. Additionally, we estimate growth on an assessment of grade-level geometry, computational thinking, and spatial reasoning for grades 4 and 5 MPACT students.

MPACT Fellows implemented MPACT in a year marked by ongoing difficulties brought on by the COVID-19 pandemic, where teachers, students, and families were burdened with challenges to their wellbeing. MPACT was not implemented with full fidelity. Although the professional development itself was delivered with fidelity, only 65 percent of MPACT Fellows implemented all three modules with all of their classes and MPACT Fellows provided fewer opportunities for students to meet with or learn about STEM industry mentors than intended. This lack of program fidelity means that MPACT students in this study did not consistently have the intended level of engagement with the program.

Despite this partial implementation, we do observe an effect of MPACT on MPACT Fellows' outcomes: three of the four factors related to teachers' perceptions of and efficacy in programmatic concepts were meaningfully higher for MPACT Fellows than they were for comparison teachers. Qualitative data from the teacher questionnaire indicates the use of 3D printers to be both a challenge for implementation as well as a source of student engagement. We also find that grades 4 and 5 MPACT students grew nearly a full standard deviation on a measure of geometry, computational thinking, and spatial reasoning. We did not find significant differences in students' socioemotional outcomes—specifically, behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept—between MPACT students and comparison students. This finding is true even when examining only MPACT students whose teachers implemented all three MPACT modules.

The considerable growth of MPACT students on the assessment and the documented program impacts on teachers' perceptions therefore provide limited, suggestive evidence that the program could demonstrate improved student outcomes in ideal conditions if examined over a longer time frame or using different impact measures.

Acknowledgements

Conducting a study of this scale, requiring original data collection, during the COVID-19 pandemic was a complex endeavor. The success of this project, including this technical report and all products and findings resulting from the study, reflects the hard work and dedication of many more contributors than those represented in this author list.

We are indebted to the teachers, administrators, and students who agreed to participate in this independent evaluation and who responded to multiple data collection requests. We thank participating teachers for their meticulous efforts in administering complex data collection activities and coordinating with colleagues to reduce testing burden for students, administrators for supporting teachers in their participation, and students for engaging in these activities.

We are grateful to our partners at TERC, including Jennifer Knudson, Ken Rafanan, Teresa Lara-Meloy, and consultant Harriette Stevens, who provided invaluable support and thought partnership throughout the study. TERC implemented the MPACT program with teachers and contributed to the development of the study design, program logic model, and fidelity measures.

This report is the culmination of nearly three years of evaluation research by a large team at SRI International (SRI). We would like to thank current and former SRI colleagues who contributed in myriad ways to the conception, design, and execution of this study: Andrew Praturlon, Angel Altamirano Jr., Anna Chiang, Christine Korbak, Cris Jimenez, Daniela Torre-Gibney, Elizabeth McBride, Mary McCracken, Meara Algama, Rebecca Griffiths, Rebecca Goetz, Sam Wang, Yesica Lopez, Xavier Fields, and Xin Wei. We also appreciate the contributions of Charles Harding, Bonnee Groover, and Roxanne Jones to the editing and production of this report. We thank Beth Boulay and Anne Wolf from Abt Associates for their support as evaluation technical assistance providers.

The authors assume full responsibility for any errors or omissions.

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Introduction

The Mathematics, 3D Printing, and Computational Thinking Through Work-Based Learning (MPACT) program focuses on increasing science, technology, engineering, and math (STEM)[1] learning opportunities to students in grades 4–7 in rural areas. The program uses a combination of teacher professional development, specialized curriculum and materials, and STEM industry mentors to provide students with project-based experiences that include math, design cycles, and digital fabrication activities.[2] MPACT aims to improve teachers' perceptions of and efficacy in programmatic concepts, and, consequently, student achievement in geometry, computational thinking, and spatial reasoning. Ultimately, MPACT is designed to improve students' career interests and ambitions; here we examine the program's relationships to students' socioemotional outcomes and perceptions of math as proxies for this goal.

In 2018, SRI International (SRI) received an Education Innovation and Research (EIR) grant to evaluate the program. SRI partnered with TERC to develop, pilot, and scale the MPACT program in two phases. In the 2019–20 school year, TERC co-designed the program with teachers, who also piloted the program, while SRI provided formative feedback on the initial program development. From 2020 to 2022, TERC and SRI expanded MPACT to dozens of public schools in four states—California, North Carolina, South Carolina, and West Virginia. A requirement of the grant was for a majority of schools served by the program to be rural.[3] In accordance, over half of the schools were in rural areas.

As part of program activities, TERC staff provided online professional development and ongoing supports for MPACT Fellows.[4] MPACT Fellows implemented the MPACT program in one or more of their classrooms. MPACT Fellows piloted a portion of the program in 2020–21 and implemented the full program in 2021–22.

The EIR grant also supported an independent evaluation to examine both program implementation and the impact of the program on measures of students' socioemotional outcomes, using a cluster quasi-experimental design. Researchers at SRI conducted the independent evaluation, and this technical report presents the results. The report presents the results of MPACT implementation in the 2021–22 school year, the first year in which the program was fully implemented. We first describe the key elements of the MPACT program and its history. Then, we present the research design and outline the data and methods we used. Next, we present the findings on fidelity of program implementation, impact of the program on students' socioemotional outcomes and teachers' perceptions of and efficacy in programmatic

[1] A related term is STEAM, which includes the subjects of science, technology, engineering, arts, and math. In this report, we use STEM because it is the more common term. However, when collecting data from teachers, we used both STEM and STEAM.
[2] Digital fabrication is a design and production process that uses computer-aided design software (e.g., Tinkercad) and 3D printing technology to design, model, and build products.
[3] A majority of schools served by the program must be designated with a locale code of 32, 33, 41, 42, or 43. See https://nces.ed.gov/programs/edge/Geographic/LocaleBoundaries for more information on these locale codes.
[4] We define MPACT Fellows as teachers who participated in the MPACT program.

concepts, and students' achievement on an aligned assessment and their perceptions of math. We close with a brief discussion of findings.

MPACT Background and Program Design

The program developers at TERC designed MPACT to supplement teachers' existing instruction in STEM. The developers drew from principles of project-based learning, math education, and computer science education. In elementary and middle school, 3D modeling can enhance students' learning of volume and surface area in geometry (Battista, 2007, 2012; Francis & Whiteley, 2015). Further, students' spatial reasoning skills, a strong predictor of STEM success (Newcombe, 2010), and math performance can also improve through the integration of physical and digital objects in their learning (Cheng & Mix, 2014; Clements & Sarama, 2011). Researchers have posited for decades that teaching math in a context of use supports learning standards-based math (Greeno & Middle School Mathematics Through Applications Project Group, 1998). Yet math is often not emphasized in project-based curricula.

MPACT also uses 3D digital fabrication to address content standards in computer science. Digital fabrication technology connects abstract digital forms produced by computation and real artifacts produced by converting digital designs to physical objects. Computer science education has expanded to include computational thinking (Barr & Stephenson, 2011; Basu et al., 2016; Wing, 2006), which has been defined as "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (Wing, 2011, p. 20). Computational thinking with a visual orientation complements symbolically oriented programming, just as visually oriented geometry and symbolically oriented algebra are important aspects of math. Both mathematical and computational thinking rely on problem-solving processes (Grover & Pea, 2013; Polya, 1945). MPACT aims to improve students' computational thinking through working with and creating tangible objects.

Finally, we expect MPACT to improve several socioemotional outcomes in students, which serve as a proxy for long-term career ambitions and sense of self in the workplace. Specifically, we expect program to lead to an increase in behavioral engagement in math, in terms of on-task behavior in math activities, class participation, and effort; and to a reduction in behavioral disaffection in math, in terms of withdrawal and ritualistic participation in math activities (Skinner et al., 2009). MPACT also focuses on students' success in math self-efficacy and math self-concept. Math self-efficacy represents a student's conviction to complete a specific task (Schunk, 1991), and math self-concept refers to a student's knowledge and perceptions about themselves in math achievement situations (Wigfield & Karpathian, 1991).

Exhibit 1 displays the logic model for how the MPACT program may lead to students' socioemotional outcomes and abilities in math, computational thinking, and spatial reasoning, as well as increase teachers' perceptions of and efficacy in programmatic concepts. The logic model provides a conceptual framework for understanding the program's inputs, key components, and outputs, and how these aspects relate to the intended outcomes. The first column displays expected program inputs as well as assumptions for implementation. The second column shows the program's three key components: teacher professional development, curriculum and materials, and STEM industry mentors. The last two columns display outputs and the outcomes. In the paragraphs following the logic model, we describe the key programmatic elements of the MPACT program.

Exhibit 1. Logic Model for the Mathematics, 3D Printing, and Computational Thinking Through Work-Based Learning (MPACT) Program

Inputs

Teachers
Grades 4–7 general education or math/CS/STEM/CTE teachers

STEM Industry Mentors
Recruited from workplaces that use 3D printing

Students
3,000 students in K-12 public schools, of which 51% are rural schools

Assumptions

- Teachers and students can meet in person
- Teachers and students have regular access to computers with high-speed internet in addition to curricular materials
- Teachers have time, school leader support, and willingness to implement MPACT modules as designed and participate in PD
- Students have sufficient proficiency in related math and CT concepts to be able to engage with the modules with appropriate teacher scaffolding and/or teachers can differentiate for students with various levels of prior proficiency in math/CT
- Teachers have established classroom management procedures and a culture that allow for project-based learning and engagement with new materials
- MPACT is supplementing, not supplanting, regular math curriculum

Key Components

Curriculum and Materials
- Curriculum Materials: Curriculum guide, teacher notes, PowerPoints, student workbook
  - Covers 3 modules, 12 lesson sequence, differentiated by grade level (4-7); Explicit math content in addition to activities focused on CT/STEM skills; Structured, repeated opportunities for discourse; Culturally relevant; Project-based
- Maker Materials for Digital Fabrication: 3D modeling software (i.e., Tinkercad); maker materials including real objects, 3D printer
- Delivery: Teachers implement all modules (1–3 in 2021–22) for their grade level
- Delivery: Students manipulate real objects, model objects in Tinkercad software, then print models as 3D tangible objects
- Delivery: Teachers address grade level math standards and CT framework through delivery of curriculum

Teacher Professional Development (PD)
- Complete online PD workshops
- Use just in time PD (online meetings, MPACT website, how to videos)
- Curriculum guide with teaching strategies, discussion prompts, and module routines
- Teachers learn to use Tinkercad
- Teachers learn to use 3D printer
- Teachers learn to use program principles, including the design and making cycle

Mentors
- STEM industry mentors (who use 3D printers)
- Teachers provide multiple methods for their students to learn about or interact with mentors (e.g., via email, online workshop, virtual office hours, online videos/PPTs, etc.)

Outputs (Mediators)

Teachers
- **Teacher knowledge and skills.**
- Participate in PD and use at least one form of just in time PD
- Uses the curriculum guide to support MPACT activities
- Facilitate project-based work
- Explicitly connect math, CT, and STEM concepts

Students
- **Engagement.**
- Students engage in MPACT module activities, including math activities, design process activities, and digital fabrication activities
- Engage with mentors to learn about career applications of math/CT
- Experience module activities as culturally relevant

Mentors:
- **Mentor engagement.**
- Mentors interact with students using a variety of methods (e.g., respond to student questions via emails, share information about their work with students via video, PPT, or written bios, conduct workshops or office hours with students, etc.)

Outcomes

Teachers
- Improved perceptions of and/or efficacy in teaching math, CT, spatial reasoning
- Increased efficacy in teaching using the design cycle
- Improved knowledge of how spatial reasoning/CT is used for work
- Improved design thinking and feedback

Students
- Increased geometry and measurement achievement
- Increased proficiency in computational thinking
- Increased spatial reasoning
- Improved behavioral engagement and behavioral disaffection, math self-efficacy, and math self-concept

Context

NGSS/CCSS | Opportunity gaps for historically underserved students and schools in rural areas | Increased demand for STEM Jobs

Note. CS = computer science; STEM = science, technology, engineering, and math; CTE = career and technical education; MPACT = Mathematics, 3D Printing, and Computational Thinking Through Work-Based Learning; PD = professional development; CT = computational thinking; Tinkercad = an online 3D modeling program; PPT = Microsoft PowerPoint; NGSS = Next Generation Science Standards; CCSS = Common Core State Standards.

Context

MPACT addresses gaps in rural students' access to programs centered on STEM principles. TERC developers designed MPACT to align with the Next Generation Science Standards (NGSS), Common Core State Standards (CCSS), and other college- and career-ready state mathematics standards.

Assumptions

The logic model assumes that students and teachers can meet in person for instruction and that they have access to the time, resources, and skills needed to engage with MPACT, including computers with high-speed internet and the MPACT materials. The logic model also assumes teachers have administrative support to implement the curriculum and pedagogical skills to scaffold and differentiate instruction for students with varying levels of proficiency in geometry, computational thinking, and spatial reasoning. Importantly, the MPACT program is intended to supplement, not supplant, students' regular math curriculum.

Inputs

Teachers and Students

The TERC developers designed MPACT to be used by teachers and students in grades 4–7 and in rural schools with high percentages of students from historically underserved backgrounds, because these students are less likely to have equitable opportunities to access to STEM courses and activities (Google & Gallup, 2017).

STEM Industry Mentors

STEM industry mentors can support and guide students through their 3D modeling process and share information about their professions. In doing so, mentors can help improve students' math content learning and influence their perceptions of how math is used in the workplace. Mentors come from a variety of industries, such as a prosthetics design firm or an industrial 3D printing company.

Key Components

Curriculum and Materials

MPACT uses a comprehensive set of curriculum and materials to support project-based learning. Teachers receive a curriculum guide, teacher notes to support instruction, Microsoft PowerPoint slides, a student workbook, a 3D printer, 3D modeling software, and maker materials for all students. The MPACT curriculum is differentiated by grade level for grades 4–7, with each grade having three modules. Each module makes an explicit connection to math content and contains activities focused on computational thinking and STEM skills. In each module, students engage in multi-lesson design cycles in which they collect ideas, make and remake prototypes, design on paper, design in Tinkercad (a free online 3D modeling program), and make a tangible 3D-printed object.[5] Each module increases in complexity as students advance. Students work with Tinkercad software, the 3D printer, and other maker materials (cardboard, tape, scissors, stamps, pipe cleaners, linking cubes, etc.).

The activities students complete in each unit progress in difficulty. In module 1 across all grade-level units, students make a bookmark. In module 2, grade 4 students make a kite from a single piece of paper, grade 5 and 6 students make a soma cube puzzle, and grade 7 students make dice for sighted people and for Blind people.[6] In module 3, grade 4 students make and print a stamp, grade 5 students make a toy on wheels, grade 6 students make a mobile for a community center, and students in grade 7 modify a game to be played by sighted and Blind people.

MPACT is designed for teachers to implement all three modules over one academic year. However, teachers, especially those who teach multiple grade levels, may need time to learn about the program and align program activities with their existing curriculum. Accordingly, during the 2020–21 school year, MPACT Fellows implemented modules 1 and 2 only. In 2021–22, MPACT Fellows implemented all three modules.

Teacher Professional Development

MPACT uses online professional development workshops and just-in-time professional development to help teachers learn digital fabrication (i.e., using Tinkercad and 3D printing), and programmatic concepts including computational thinking, spatial reasoning, and the design cycle. During the 2020–21 and 2021–22 school years, MPACT Fellows received approximately 19 hours of professional development on implementing the MPACT curriculum, which included attending ongoing workshops to develop facility with digital fabrication and the MPACT modules. The COVID-19 pandemic began during Year 1 of implementation; as a result, professional development was delivered virtually using Zoom, rather than in-person, due to travel restrictions and safety concerns. MPACT Fellows who were unable to attend the virtual professional development completed makeup professional development by watching videos asynchronously and answering check-for-understanding questions.

Starting in fall and winter of 2020–21, MPACT Fellows received professional development on using Tinkercad and the 3D printer and on implementing modules 1 and 2. Four facilitators from TERC, who had helped design the MPACT program, led the professional development (two facilitators per workshop). The facilitators had previous experience with curriculum development, the design and implementation of curriculum-based professional development, and STEM education research. Facilitators delivered the professional development outside of regular school hours and over three months (November–January). The professional

[5] In this report, we use the term *design cycle* to capture a set of steps used to solve problems and create a tangible product addressing the issue. Researchers and practitioners sometimes refer to these steps as *maker education* or *making education*.
[6] For details on how math content and MPACT module activities align across grade levels, see Appendix H.

development consisted of 3 three-hour intensive workshops, for a total of nine hours. All MPACT Fellows attended the first workshop to receive an introduction to the MPACT program and to learn information about key program materials, including Tinkercad and the 3D printer. The second and third workshops covered modules 1 and 2 and were differentiated by grade level. During these workshops, MPACT Fellows experienced the modules as students. Throughout all the workshops, facilitators placed MPACT Fellows into breakout groups to engage in small-group activities and facilitated whole-group discussions about key points and takeaways.

In summer 2021, MPACT Fellows received additional professional development on module 3. This professional development consisted of 2 five-hour workshops, for a total of 10 hours. Because the content of module 3 varies by grade level, the module 3 workshops were differentiated by grade. About half of the MPACT Fellows were unable to attend the virtual, synchronous professional development held in summer. Instead, they viewed a self-guided video of the professional development and answered check-for-understanding questions in fall 2021.

MPACT Fellows also had access to just-in-time supports throughout the school year as needed. These supports included tutorials and videos on the MPACT website and direct support from TERC staff. In both the 2020–21 and 2021–22 school years, MPACT Fellows also received just-in-time professional development such as online support from TERC staff and the community website, which included instructional videos and supplementary activities. Due to the COVID-19 pandemic, facilitators from TERC conducted all just-in-time professional development and supports virtually over Zoom.

STEM Industry Mentors

The COVID-19 pandemic made it difficult to engage classrooms with STEM industry mentors, either in person or through synchronous remote forums. Not only was recruiting mentors a challenge, but facilitating mentor–student engagement on a virtual platform was difficult, especially because many MPACT Fellows were teaching remotely for the first time. Therefore, TERC changed the mentor model to a light-touch, entirely asynchronous experience in which students viewed recorded videos of mentors or read information about their work, rather than connecting with the mentors in an in-person or synchronous, remote workshop.

TERC provided introductory videos, slideshows, and reading materials about mentors and facilitated mentor-led virtual workshops, meetings, and correspondence with students to answer questions about mentors' career fields. MPACT Fellows or TERC staff monitored all interactions for safety.

Outputs

Teacher Knowledge and Skills

MPACT is designed to improve teachers' knowledge and skills in program concepts such as facilitating design-based work, computational thinking, spatial reasoning, and the design cycle.

Student Engagement

MPACT is intended to encourage student participation in all MPACT activities, including a design cycle in which students prototype using real objects, model objects in Tinkercad, create tangible objects with a 3D printer, and engage with mentors to learn about applications to future work.

STEM Industry Mentor Engagement

By engaging with a diverse group of STEM industry mentors, students in the MPACT program can enhance their knowledge of, and interest in, future careers in STEM as well as understand the relevancy of their MPACT learnings to real-world settings. With guidance and supports from TERC, mentors may share information about their careers and their knowledge of MPACT concepts with students through a variety of formats throughout the school year.

Outcomes

Teacher Outcomes

By participating in the MPACT professional development and implementing the program, MPACT Fellows are expected to develop knowledge and skills related to math, computational thinking, and spatial reasoning; improve their ability to facilitate activities using the design cycle; improve their understanding of how spatial reasoning and computational thinking are used in work; and improve their capacity for design thinking and providing feedback on designing thinking. By gaining knowledge and skills in these areas, MPACT Fellows may increase their efficacy to implement curriculum that focus on these strategies and content (Bandura, 1997).

Student Outcomes

MPACT aims to improve student outcomes, including achievement in math—specifically in geometry and measurement, computational thinking, and spatial reasoning. MPACT units are designed to address grade-level content in geometry based on learning progressions relevant to volume and surface area as well as ratio and proportionality. Students also learn computational thinking skills and practices through 3D digital fabrication. Further, the program is designed to help students learn spatial reasoning skills, such as the ability to mentally rotate an object, which are typically not part of state standards but are correlated to math achievement and success in STEM.

MPACT seeks to benefit students' socioemotional outcomes from engaging in project-based learning, including student behavioral engagement, behavioral disaffection, math self-efficacy, and math self-concept. Through MPACT, students engage in activities that help them build problem solving and critical thinking skills. Further, MPACT units aim to grow students' knowledge of industries.

Timeline of Development, Implementation, and Scale

In 2018, SRI received an EIR grant to develop, pilot, and scale the MPACT program. In 2019–20, the TERC developers worked with three grade 5 teachers in rural schools or districts to co-develop and pilot three MPACT modules for grades 5–7 and, later, grade 4. These instructional units addressed math skills such as volume, scaling, ratio, proportionality, and probability, as well as computational thinking and spatial reasoning skills.[7] In the following two years, the MPACT program was expanded to dozens of public schools in four states: California, North Carolina, South Carolina, and West Virginia. In the 2020–21 school year, MPACT Fellows in grades 4–7 received professional development and materials for modules 1–2 for their grade level and had the opportunity to implement these modules in their classrooms. In the 2021–22 school year, MPACT Fellows received professional development and materials for modules 1–3 for their grade level and had the opportunity to implement the full program in their classrooms.

MPACT study activities occurred in two phases. In the first phase (2019−20), TERC co-designed MPACT modules and professional development with teachers, who piloted the program. SRI provided ongoing feedback to TERC on program development. In the second phase (2020−22), TERC implemented the program, with SRI conducting the at-scale impact evaluation during full implementation in 2021–22. Exhibit 2 displays the timeline for study and implementation activities.

The pilot was conducted iteratively, beginning with co-designing MPACT modules in summer 2019 with pilot teachers who provided design advice and input. Additional pilot teachers joined in spring 2020 and implemented MPACT modules in their classrooms. SRI researchers conducted site visits and interviews with these teachers. We provided TERC with feedback from these site visits and interviews at three time points in spring 2020. TERC used the feedback to inform future iterations of the modules.

The at-scale evaluation began with additional recruitment in the summer and fall of 2020. SRI researchers recruited a cohort of MPACT Fellows and a few comparison teachers to participate in the Year 1 implementation efforts. MPACT Fellows received professional development on MPACT modules 1 and 2 and had the opportunity to implement those modules in their classroom. We asked both MPACT Fellows and comparison teachers to participate in the

[7] For this report, we refer to this complete list of topics and skills covered by the MPACT program simply as "math" or "math, computational thinking, and spatial reasoning."

collection of baseline and outcome data, which we used to create factors and refine data collection instruments used in the at-scale impact evaluation in Year 2.

SRI researchers were unable to recruit a sufficiently large comparison group in Year 1 as a result of the COVID-19 pandemic. Further, the study experienced attrition of a few MPACT Fellows and comparison teachers in Year 1. As a result, in the spring and summer of 2021, we recruited additional MPACT Fellows and comparison teachers for Year 2 implementation (the study year). The recruitment of additional MPACT Fellows and comparison teachers ensured we had a treatment and comparison group sample large enough to detect impacts on students and teachers. This report presents results from the 2021–22 school year only.

Exhibit 2. MPACT Grant Timeline

	Phase 1				Phase 2							
	2019–20 School Year (Pilot)				2020–21 School Year (Year 1 Implementation)				2021–22 School Year (Year 2 Implementation/ Study Year)			
	Su 2019	F 2019	W 2019	Sp 2020	Su 2020	F 2020	W 2020	Sp 2021	Su 2021	F 2021	W 2021	Sp 2022
Study Activities												
Pilot Implementation	X	X	X	X								
Recruitment (Year 1)				X	X	X						
Recruitment (Year 2)								X	X			
Baseline Data Collection (Year 2)										X		
Outcome Data Collection (Year 2)												X
Implementation												
MPACT Fellows receive MPACT materials						X				X		
MPACT Fellows participate in Module 1–2 Professional Development						X	X					
MPACT Fellows Implement Modules 1–2 (Year 1)						X	X	X	X			
MPACT Fellows participate in Module 3 Professional Development									X	X	X	
MPACT Fellows Implement Modules 1–3 (Year 2/Study Year)										X	X	X

Note. Su = summer; F = fall; W = winter; Sp = spring. The exhibit displays the timeline of program implementation, including MPACT Fellows' participation in professional development and their implementation of MPACT modules; and the timeline of study activities, including recruitment and data collection.

Research Design

Overview

For the evaluation, SRI researchers used a cluster quasi-experimental design to estimate the impact of MPACT on grade 4–7 students' socioemotional outcomes in the 2021–22 school year. We compared outcomes for students in MPACT Fellows' classrooms to those of students in comparison teachers' classrooms. We also analyzed fidelity of program implementation; impacts on teachers' perceptions of and efficacy in programmatic concepts; and student growth on a measure of geometry, computational thinking, and spatial reasoning for grade 4–5 students.

Before data collection, we registered the analytic design of the confirmatory student impact analysis for four student outcomes—students' behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept—as confirmatory contrasts with the Registry of Efficacy and Effectiveness Studies (Arshan, 2018–23).

Research Questions

The report answers the following research questions:

Confirmatory Student Impact

(1) What is the effect of MPACT on grades 4–7 students' behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept, compared to the comparison condition?

Exploratory Student and Teacher Impact

(2) What is the effect of MPACT on teacher perceptions of teaching math, teacher perceptions of and efficacy in teaching computational thinking, teacher perceptions of spatial reasoning, and teachers' efficacy in teaching using the design cycle, relative to comparison condition?

(3) Did grade 4–5 students grow on a measure of grade-level geometry, computational thinking, and spatial reasoning skills after using MPACT?

(4) To what extent did grades 4–5 students' behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept relate to a measure of grade-level geometry, computational thinking, and spatial reasoning skills after using MPACT?

Implementation

(1) To what extent was MPACT delivered with intended fidelity?

(2) What were the barriers to and facilitators of MPACT implementation?

(3) How did MPACT Fellows' experiences with professional development differ from those of comparison teachers?

Design Changes Due to the COVID-19 Pandemic

SRI researchers initially began recruitment for the evaluation study in early spring 2020. When the COVID-19 pandemic began, we ceased our initial recruitment plan and redesigned the evaluation study to facilitate recruitment because of ongoing impacts to schools and teachers (e.g., remote instruction, concerns about workplace safety, reports of teacher burnout). We found that administrators were hesitant to ask teachers to participate in an additional activity during the COVID-19 pandemic, and therefore we moved from a school-level recruitment (where all eligible teachers would participate) to a teacher-level recruitment (where individual teachers could opt into participation). We also limited data collection by removing impact measures of student achievement and moving to a pre–post measure in the treatment group only. This design change had several benefits. First, we lessened the time and effort requested of comparison teachers. Additionally, we were able to develop an aligned measure of student achievement that would give us a near-proximal measure of student growth. Such a measure, given in the comparison condition, might have risked over-alignment. Additionally, by eliminating state assessments as an outcome measure, we were able to move into multiple states, expanding our pool of eligible schools without increasing the project budget.

Recruitment and Study Eligibility

Recruitment occurred in summer through early fall of 2020 and late spring through summer of 2021. Our power estimates indicated we should aim to have MPACT Fellows in roughly 33 schools, and comparison teachers in another 33 schools, in the 2021–22 school year to achieve a minimum detectable effect size of 0.2. In 2020, we recruited an initial cohort of MPACT Fellows and comparison teachers; MPACT Fellows would participate in the two years of implementation and the one-year study (2020–2021 and 2021–22), and comparison teachers would participate in just the study. Teachers were able to participate in the group of their choice; nearly all chose to participate as MPACT Fellows instead of as comparison teachers.

In summer 2021, all comparison teachers recruited in the 2020–21 recruitment cycle were given the option to participate as MPACT Fellows in the 2021–22 school year. However, only one of these teachers became an MPACT Fellow in 2021–22, and they withdrew before the conclusion of the study. As a result, the study engaged in a second round of recruitment in summer 2021 to ensure a sufficiently large group of comparison teachers in the study year (2021–22). In summer 2021, we recruited additional MPACT Fellows and comparison teachers to join for the 2021–22 school year to ensure enough teachers in each group for a well-powered impact estimate. In the summer 2021 recruitment cycle, we included a delayed treatment incentive, wherein comparison teachers were given the option to receive MPACT materials and professional development in summer 2022, after the study's conclusion.

To minimize contamination and cross-over, we only allowed teachers in the same treatment condition within the same school. That is, when more than one study teacher was in the same school, they were all of the same treatment condition. As a result, while recruitment into the study took place at the teacher level, treatment assignment was at the school level.

During each recruitment cycle, our recruitment strategy included:

- Contacting all district superintendents and principals in the target states to provide information about the MPACT program and study.
- Advertising for participation in the study by posting on social media, including a targeted Twitter campaign and posts on relevant social media pages.
- Leveraging study teachers' networks to share about the MPACT program and study to additional educators across the four target states.
- Hosting information sessions about the study.

SRI researchers began recruitment in California, despite losing initial partnerships that had been intended to facilitate recruitment. Challenges with recruiting during the COVID-19 pandemic led us to expand recruitment to North Carolina, as TERC had contacts with teachers in these states. We then expanded to South Carolina and West Virginia, as these states had high proportions of schools in rural areas, were in the same time zone as North Carolina, and covered similar math topics across grade levels. Thus, including these states improved cross-state alignment in implementation.

All public school districts in California, North Carolina, South Carolina, and West Virginia that included at least one regular (non-shared time) vocational elementary or middle school were eligible for participation (school type was determined by Common Core of Data classification). As this project was funded under the rural priority for EIR, we enrolled participants such that at least 51 percent of schools served were rural (defined by the grant as those having a National Center for Education Statistics [NCES] locale code of 32, 33, 41, 42, or 43).

To be eligible for participation, teachers were required to teach at least one grade 4–7 science, technology, engineering, math, or another STEM-related course. Teachers also were required to teach the same group of students for the full duration of the school year. Before professional development and data collection began, teachers completed a consent form to provide their permission to participate in the study. Principals were also informed of teachers' interest in the study and were given the opportunity to either show their support of teachers' participation or opt teachers out of participating by completing a short form. Schools were provided with $1,000 to compensate for any time or resources necessary to facilitate study participation (e.g., time to complete research applications, communicate with teachers, work with an IT support).

Treatment and Comparison Conditions

Assignment of teachers as MPACT Fellows or as comparison teachers was nonrandom. During each recruitment cycle, teachers received information on requirements for participation as MPACT Fellows and as comparison teachers.

In the study year (the 2021–22 school year) SRI researchers asked MPACT Fellows to[8]:

- Participate in all professional development sessions or watch online makeup tutorials
- Implement MPACT 1–3 modules and collect data in classes using science, technology, engineering, math, or other STEM-related curriculum, or other classes, at their discretion

MPACT Fellows received:

- Approximately three days of online professional development
- One classroom 3D printer
- Access to MPACT modules
- Necessary maker materials for their students
- A classroom library of STEM books
- Just-in-time professional development from TERC staff to facilitate implementation (e.g., printer troubleshooting, mentor communications)
- An annual stipend of $850 for completing evaluation activities.

SRI researchers asked comparison teachers to collect data in the study year (2021–22 school year) from science, math, other STEM-related classes, or any other classes in which they would implement MPACT in the following year (when they received MPACT in a "delayed treatment" capacity. During the study year, comparison teachers continued in business-as-usual instruction. That is, comparison teachers did not receive MPACT professional development or access to MPACT curriculum or materials, which are only accessible with login credentials for the MPACT website.

As an incentive for their participation in the study, comparison teachers received:

- The opportunity to receive MPACT professional development, curriculum, and materials in summer 2022 (i.e., delayed treatment)
- An annual stipend of $150 each year for completion of evaluation activities
- A classroom library of STEM books

Both MPACT Fellows and comparison teachers were provided with a classroom library of 20–25 books related to STEM careers. Providing a classroom library to both study conditions allowed SRI researchers to control for access to information about STEM, ensuring that any measured effect of MPACT would not be able to be replicated by a simpler intervention that merely provided information about STEM to students. That is, if MPACT had an impact on students' socioemotional outcomes, it would be due to other facets of the program beyond this simple classroom library intervention.

[8] MPACT Fellows who had participated in the prior year (2020–21 school year) received an additional three days of professional development and annual stipend. They were only asked to implement modules 1–2 in their classrooms in that school year.

Samples

To answer the confirmatory student impact research question, SRI researchers constructed an intent-to-treat analytic sample using MPACT Fellows' and comparison teachers' students in the 2021–22 school year. That is, we constructed an analytic sample using the students of all MPACT Fellows in the 2021–22 school year, regardless of the Fellow's level of implementation. The confirmatory student impact sample included students who had baseline and outcome data on all outcome measures from the student survey. The teacher impact sample included teachers who had baseline and outcome data on all outcome measures from the teacher questionnaire and who were included in the confirmatory student impact sample. The student assessment sample included students of MPACT Fellows in the confirmatory sample who were in grades 4 and 5 and who had complete baseline and outcome data on the student assessment. We considered an assessment complete if the student answered at least one question on the assessment.

For any covariate with missing data, we used missing dummy imputation to retain the observation by categorizing the data into a new category called "skipped question" or "unknown" for the covariate and creating a binary variable to indicate whether missing data were set to this new value. (Puma et al., 2009).[9]

Below, we describe statistics for our analytic sample.

The teacher impact sample consisted of a total of 79 teachers (43 MPACT Fellows and 36 comparison teachers) who completed baseline and outcome data collection. These teachers came from 57 schools (29 MPACT schools and 28 comparison schools). The confirmatory student impact sample included 2,319 students (1,235 MPACT students and 1,084 comparison students) who completed both baseline and outcome data collection. These students were taught by the 79 teachers in the teacher impact sample and were enrolled in the 57 schools. The student assessment sample consists of 737 students (320 grade 4 students, 403 grade 5 students, 9 grade 6 students, and 5 grade 7 students).

School Sample

Exhibit 3 shows important characteristics of schools in the sample, both overall and by school type (i.e., MPACT school or comparison school).

[9] For additional details on covariates, see Exhibit 3, Exhibit 4, Exhibit 5 and Appendix A.

Exhibit 3. MPACT Study School Sample

School-Level Characteristic	MPACT	Comparison	Overall
School type			
Middle school	44.8%	46.4%	45.6%
Elementary school	55.2%	53.6%	54.4%
STEM school			
STEM	34.5%	32.1%	33.3%
Not STEM	65.5%	67.9%	66.7%
Urbanicity			
Rural	82.8%	57.1%	70.2%
Non-rural	17.2%	42.9%	29.8%
FRPL quartile			
Q1 (lowest rates of FRPL)	20.7%	17.9%	19.3%
Q2	20.7%	25.0%	22.8%
Q3	6.9%	7.1%	7.0%
Q4 (highest rates of FRPL)	51.7%	50.0%	50.9%
Title I status			
Title I	72.4%	75.0%	73.7%
Not Title I	27.6%	25.0%	26.3%
Total number of schools	**29**	**28**	**57**

Note. STEM = science, technology, engineering, and math; FRPL = free or reduced-price lunch; Q = quartile. For detailed definitions of each variable, see Appendix A.

Teacher Sample

Exhibit 4 shows important characteristics for the teacher impact sample, both overall and by teacher type (i.e., MPACT Fellow or comparison teacher).

Exhibit 4. MPACT Study Teacher Sample

Teacher-Level Characteristic	MPACT	Comparison	Overall
Subject area			
Self-contained	16.3%	33.3%	24.1%
STEM	48.8%	16.7%	34.2%
Math	25.6%	33.3%	29.1%
Science only	4.7%	8.3%	6.3%
Other subject	4.7%	8.3%	6.3%
STEM teacher			
STEM	48.8%	16.7%	34.2%
Not STEM	51.2%	83.3%	65.8%
Experience level			
Novice (< 4 years)	23.3%	38.9%	30.4%
Experienced (4+ years)	76.7%	61.1%	69.6%
Classroom type			
Self-contained	16.3%	33.3%	24.1%
Not self-contained	83.7%	66.7%	76.0%
Grade level taught			
Teaches grade 4	36.4%	44.4%	40.0%
Teaches grade 5	43.2%	41.7%	42.5%
Teaches grade 6	34.1%	25.0%	30.0%
Teaches grade 7	31.8%	22.2%	27.5%
Total number of teachers	**43**	**36**	**79**

Note. STEM = science, technology, engineering, and math. For detailed definitions on each variable, see Appendix A.

Student Sample

Exhibit 5 shows important characteristics for the confirmatory student impact sample, both overall and by treatment status.

Exhibit 5. MPACT Study Student Sample

Student-Level Characteristic	MPACT	Comparison	Overall
Grade			
Grade 4	26.5%	25.2%	25.9%
Grade 5	33.1%	29.2%	31.3%
Grade 6	16.1%	22.3%	19.0%
Grade 7	24.3%	23.3%	23.8%
Unknown grade	0.0%	0.0%	0.0%
Race/ethnicity			
American Indian or Alaska Native; Asian or Asian American; Middle Eastern or North African; Native Hawaiian or Pacific Islander; Self-described as a race/ethnicity not listed on survey; Chose not to share; Not sure; Skipped question	33.7%	28.7%	26.8%
Black or African American	15.0%	17.3%	16.0%
Latino/a, Latinx, Hispanic, or Spanish origin	19.8%	14.9%	17.5%
Two or more races	8.7%	9.0%	8.8%
White	31.7%	30.4%	31.1%
Gender			
Female	44.9%	45.8%	45.3%
Male	44.5%	44.4%	44.4%
Self-described as a gender not listed on survey; Chose not to share; Not sure; Skipped question	10.6%	9.9%	10.3%
Home language			
English only	67.9%	69.7%	68.7%
At least one language other than English	31.4%	29.2%	30.4%
Unable to determine or skipped question	0.2%	0.4%	0.3%
Family engagement with school			
Never or hardly ever	16.9%	15.0%	16.0%
Once every few weeks	13.4%	10.5%	12.0%
About once a week	16.5%	15.6%	16.1%
Two or three times a week	17.5%	20.8%	19.0%
Every day	35.3%	37.6%	36.4%
Skipped question	0.4%	0.5%	0.4%
Class subject			
Self-contained class	6.5%	8.1%	7.2%
STEM	34.6%	23.9%	29.6%
Math	32.4%	46.5%	39.0%
Science	14.0%	19.5%	16.6%
Other subject	12.6%	2.0%	7.6%
Total number of students	**1,235**	**1,084**	**2,319**

Note. STEM = science, technology, engineering, and math. The exhibit displays statistics on student characteristics collected from the student survey and teacher questionnaire. SRI researchers aggregated item-level data on students' self-reported race/ethnicity, gender, and home language to create variables for the purposes of this study. For details on how we aggregated variables and for definitions on each variable, see Appendix A. The exhibit displays statistics for variables used in the study. For detailed, item-level statistics on students' self-reported race/ethnicity, gender, and home language, see Appendix B.

Data and Methods

SRI researchers collected data from multiple sources, including program implementation data, a student survey, a teacher questionnaire, and a student assessment. We used a variety of descriptive and quasi-experimental methods to understand implementation and assess outcomes.

Fidelity of Program Implementation

SRI researchers worked with TERC staff to determine three key program implementation components. Next, we collaboratively developed indicators from which to assess whether each of these components was implemented with fidelity, at both the individual and program levels. These three components of implementation fidelity reflect the three key components of the MPACT program delivery: teacher professional development, curriculum and materials, and connection to STEM industry mentors (see Exhibit 1). Embedded within these key components is the extent to which the professional development supports the three outputs: teacher knowledge and skills, student engagement, and mentor engagement.

Fidelity of Implementation Indicators

In the logic model (see Exhibit 1), SRI researchers and TERC staff defined each key component of the program using specific criteria. For each criterion, we designed an indicator to capture the extent to which the criterion was adequately implemented. For each indicator, we identified an individual, teacher-level threshold. We also identified a program-level threshold for each indicator to assess adequate implementation of a given component. We defined a component as implemented with fidelity if the program-level threshold for the indicator was met for each criterion. We describe each implementation fidelity indicator and the teacher and program-level thresholds below (see Appendix C for details on each indicator).

Teacher Professional Development. MPACT Fellows received ongoing professional development and supports from TERC to implement the MPACT curriculum. The indicators for teacher professional development captured the extent to which MPACT Fellows participated in professional development, understood key components of the program, and felt comfortable with implementing program tools. To meet implementation fidelity for the teacher professional development component, the program-level threshold had to be met for each of the following six indicators:

- MPACT Fellows participate in online professional development events.
- MPACT Fellows use just-in-time professional development.
- MPACT Fellows review the curriculum guide, including all lesson plans and teacher notes, in the curriculum guide during the professional development and understand the goals of the module.
- MPACT Fellows understand how to use and troubleshoot Tinkercad.

- MPACT Fellows understand how to use and troubleshoot 3D printers.
- MPACT Fellows understand the steps of the design cycle.

Curriculum and Materials. Program participation requires MPACT Fellows to use MPACT and its curriculum and materials with students. The implementation fidelity indicators for curriculum and materials capture the extent to which MPACT Fellows are able to access MPACT materials and the extent to which they implement the program with students. To meet implementation fidelity for the curriculum and materials component, the program-level threshold had to be met for each of the following five indicators:

- MPACT Fellows can access the MPACT curriculum (e.g., teacher notes, PowerPoints, student workbook).
- MPACT Fellows receive all MPACT maker materials (e.g., 3D printer, blocks, linking cubes) in time to implement MPACT as planned and in enough quantity.
- MPACT Fellows implement MPACT modules for their grade level.
- MPACT Fellows report that students manipulate, model, and print 3D objects.
- MPACT Fellows address math standards through implementation.

Mentors. Finally, MPACT Fellows were asked to engage students with STEM industry mentors. The implementation fidelity indicators capture the extent to which MPACT Fellows were aware of opportunities to engage their students with mentors and the extent to which engaged students in these opportunities. To meet fidelity of implementation for the mentor component, the program-level threshold had to be met for each of the following two indicators:

- Students have the opportunity to engage with STEM industry mentors.
- Students engage with mentors.

Data

SRI researchers collected program implementation data from TERC and through an additional questionnaire that SRI administered. TERC staff collected and shared MPACT Fellows' attendance data for the summer 2021 professional development workshops on module 3. Because about half of the MPACT Fellows were unable to attend the live professional development in summer, SRI researchers collected data on MPACT Fellows' completion of makeup professional development. After MPACT Fellows' completed their self-directed, online professional development modules, we asked them to complete a brief questionnaire that checked their understanding of the professional development. We collected the remainder of program implementation data, including MPACT Fellows' participation in professional development activities outside of the workshops, use of curriculum and materials, and engagement with mentors, through the baseline and outcome teacher questionnaires.

Analysis

To analyze the fidelity of program implementation, SRI researchers first determined whether each MPACT Fellow met the teacher-level threshold for a given indicator. Next, we calculated the percentage of MPACT Fellows who met the program-level threshold for adequate implementation. If the percentage was greater than or equal to the program-level threshold, we considered the indicator to be met. We repeated this process for each indicator. Finally, we determined whether a given component was met. We considered a given component to be met if all indicators in the component were met with fidelity.

The sample we used to assess implementation fidelity consisted of MPACT Fellows in the teacher impact sample. These teachers had complete baseline and outcome data on all four teacher factors and had complete baseline and outcome data for all four student factors for their students. MPACT Fellows who did not respond to an item on the teacher questionnaire that was required to assess an indicator were considered as not having met the teacher-level threshold for that indicator.

Students' Socioemotional Outcomes and Perceptions of Math

Data

SRI researchers administered a student survey in fall 2021 (baseline) to both MPACT and comparison students, again to both groups in spring 2022 (outcome). To ensure alignment with the What Works Clearinghouse (WWC) standards, we reviewed the WWC Review Protocol for student outcomes allowed to be measured by self-report. We narrowed these outcomes to constructs aligned to the MPACT logic model and identified validated instruments (reliabilities ranging from α = 0.61 to 0.83) with evidence of reliability and validity in primary or secondary grades (Griggs et al., 2013; Midgley et al., 2000; Schulz, 2005; Skinner et al., 2009). The final survey included four constructs: behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept. Behavioral engagement captures students' on-task behavior, class participation, and effort, while behavioral disaffection captures a lack of behavioral engagement (e.g., lack of effort, lack of participation) as well as withdrawal and ritualistic participation (Skinner et al., 2009). Math self-efficacy represents students' conviction to complete a specific task (Schunk, 1991), and math self-concept refers to students' knowledge and perceptions about themselves in math achievement situations (Wigfield & Karpathian, 1991).

Each construct constitutes a single factor as defined by the validated instrument and contains five to six survey items. All four factors were on a five-point Likert scale with 1 equal to strongly disagree, 2 equal to disagree, 3 equal to neither agree nor disagree, 4 equal to agree, and 5 equal to strongly agree. SRI researchers made minor adaptations to survey items to make them more grade-appropriate or to tailor items to math learning. Across all four constructs, alpha values for the four factors ranged from 0.70 to 0.87 in both fall 2021 and spring 2022. (See Appendix D for more information on the instruments used to measure each construct and a comparison of the measure of reliability from the original validation effort to the measure from the current study.)

In addition to measuring these constructs, the spring student survey included both closed and open-ended questions to understand students' perceptions of how MPACT may connect with math, have real-life application, or influence careers related to math.

Analysis

Propensity Score Weighting. Propensity score techniques are quasi-experimental approaches developed to approximate findings from randomized controlled trials (Becker & Ichino, 2002). They are suitable for observational studies with cohort designs to reduce selection bias in estimating treatment or intervention effects when randomized controlled trials are not feasible or ethical (Rosenbaum & Rubin, 1983, 1984, 1985).

SRI researchers used propensity score weighting to test the difference between the MPACT Fellows and comparison groups on student outcome measures. The propensity score is the predicted probability of being an MPACT Fellow based on a set of potentially confounding covariates (e.g., students' demographic characteristics and baseline scores), using logistic regression. Propensity scoring attempts to equalize the mean values of potentially confounding observed covariates in the two groups being compared, ensuring differences in outcomes are not the result of differences in the mean values of those covariates. We selected weighting over other approaches, such as matching, because it retains all sample members in the analysis and does not reduce sample size.

We adjusted the impact analysis for confounds using inverse propensity score estimators, as recommended by Rosenbaum and Rubin (1983). Specifically, for MPACT and comparison students, the weight for MPACT students was set at 1.0 and the weight for comparison students was equal to $p_i/(1 - p_i)$, where p_i is the propensity score for the *i*th comparison student. The weighting created balance between MPACT students and comparison students on observed covariates and thus estimated the effect on student outcome measures. We used all covariates in the model to create weights such that baseline equivalence was achieved between MPACT Fellows and comparison teachers (i.e., weighted standardized differences of 0.05 or below for baseline outcome measures and 0.25 or below for other prioritized variables) across groups. The sections below specify the models and procedures we used for creating the analytical group of comparison students.

To generate the propensity score to use in our weighted regression analysis, we fit the following pooled logit model as shown in Equation 1:

$$\ln\left(\frac{p_i}{1 - p_i}\right) = \beta_0 + \beta' X_{i,t0} + \gamma' Z_t + \pi' G_i + \pi' Q_i + e_t \quad (1)$$

where the log odds of being an MPACT student for individual student i is a function of a vector of each of the baseline outcomes of interest $X_{i,to}$; a vector of student demographic variables and teacher- and school-level covariates, Z_t; a vector of dummy variables representing grade fixed effects, G_i; and a vector of dummy variables representing state fixed effects, Q_i. The intercept is represented by β_0. The error term is represented by e_t.

Using the estimated propensity score for each observation, we generated the following weights using Equation 2:

$$\text{For } D_{it} = 1: \quad w_{i,\,\text{ATT}} = 1 \tag{2}$$

$$\text{For } D_{it} = 0: \quad w_{i,\,\text{ATT}} = \frac{\hat{p}_{it}}{1 - \hat{p}_{it}}$$

where MPACT students (D_{it} = 1) receive a weight (w_i) of 1, and comparison student observations (D_{it} = 0) receive a weight of their propensity score ($\hat{p}_{it}$) divided by 1 minus their propensity score. Thus, comparison students with similar baseline characteristics to MPACT students received relatively high weights, whereas comparison students with dissimilar characteristics to MPACT students received relatively low weights.

Estimating Impact. The confirmatory student impact sample includes students who had complete baseline and outcome data on all four factors. We considered a factor complete if a student provided responses for at least 80 percent of items in the factor. We estimate the impact of assignment to receive the MPACT program on each outcome, using an intent-to-treat ordinary least squares (OLS) weighted regression (and applying the inverse propensity score weights described above). The predicted outcome measure on student *i* taught in school *j* is given as:

$$y_{ijk} = \beta_0 + X_{ij}\beta_1 + \beta_2 Prior_{ij} + \beta_3 Treatment_j + \beta_4 T_j + S_j\beta_5 + e_{ij} \tag{3}$$

This equation estimates the impact of assignment to participate in MPACT on a given student socioemotional outcome (y_{ijk}). We estimated the model four times, once for each socioemotional outcome (behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept) The model includes controls for y_{ijk} baseline student-, teacher-, and school-level characteristics, represented by X_{ij}, T_j, and S_j, respectively. $Prior_{ij}$ is a measure of a given socioemotional outcome, measured at baseline. Teacher assignment as MPACT Fellows was at the school level, and β_3 provides an estimate of the effect of school assignment to MPACT on student outcomes (the intent-to-treat effect). The error term is represented by e_{ij}. We used cluster-robust standard errors to account for nesting of students within schools. For detailed information on variable definitions, see Appendix A. For a complete list of the covariates included in each model, see Appendix E. In addition to examining impacts on students' socioemotional outcomes, we examined variation in impacts by student-, teacher-, and school-level subgroups by running the model for each subgroup variable specified in Appendix E.

Descriptive Analysis of Students' Perceptions of Math. We also examine students' perceptions of how MPACT connects with math, has real-life application, or relates to careers in math. First, we analyzed descriptive statistics for closed-response items that asked students about their perceptions of MPACT. Next, we conducted a qualitative analysis of open-ended survey items asking students to explain connections they made between MPACT and math. We analyzed student survey open responses using codes developed a priori, including 3D designs, objects, and printer; connecting math learning to other subjects or classes; connecting math learning to future jobs or responsibilities; and connecting math learning to other interests and activities. We added other codes after engaging with the data, including specific math topics.

Student Achievement

Data

SRI researchers administered grade 4 and grade 5 student assessments in MPACT classrooms in fall 2021 (baseline) and again in spring 2022 (outcome).[10] These SRI-developed assessments measured students' knowledge of MPACT-aligned geometry, computational thinking, and spatial reasoning. The development of the assessments followed an evidence-centered design process (Mislevy & Haertel, 2006; Mislevy & Riconscente, 2006). In this process, a set of focal knowledge, skills and ability statements were developed. These statements were aligned with the learning goals of the curriculum. A team separate from those who developed the MPACT curriculum developed tasks and scoring guides aligned to these learning goals. This ensured that while there was alignment with the curriculum through the use of shared goals, there was not over-alignment as the assessment did not draw directly from the curriculum.

We matched baseline and outcome scores to create the confirmatory student impact sample. Student assessment items were either multiple choice items or numeric-entry items in which students performed a calculation and typed in their response. Thus, we were able to automate the scoring of student responses. Each grade-level assessment contained items that ranged in difficulty and produced a spread of student scores (as intended) with no evidence of floor or ceiling effects. Expert reviews and cognitive interviews with students indicated the items on the assessments were aligned to the desired learning goals and students were interacting with the items as intended. Reliability for each assessment was high (grade 4 Cronbach's $\alpha = 0.49–0.75$; grade 5 Cronbach's $\alpha = 0.81–0.84$), and difficulty scores of items matched expectations.

Analysis

To account for differences in scales between the grade 4 and grade 5 assessments and to adjust for grade level, SRI researchers converted students' scores to z-scores measured in standard deviations, standardized within grade. We then used OLS regression to test for significant

[10] We also include in the sample grade 6 and 7 students who were enrolled in classes with grades 4 and 5 students. Grade 6 and 7 students represent less than 2 percent of the assessment sample.

differences between baseline and outcome assessment scores measured in z-scores. The assessment sample includes students in the confirmatory impact sample who were in grade 4 or 5 and who responded to at least one question on both the baseline and outcome assessment. The predicted outcome measure on student i in school j is given as:

$$y_{ij} = \beta_0 + X_i\beta_1 + \beta_2 Spring + e_{\text{ij}} \qquad (4)$$

The model predicts the continuous student outcome of a measure of grade-level geometry, computational thinking, and spatial reasoning skills (y_{ij}). X_i is a dummy variable for grade 5 (and grade 4 otherwise). β_2 provides an estimate of the increase in student assessment score. The error term is represented by e_{ij}. We also explored variation by student-, teacher-, and school-level subgroups by running the model for each subgroup variable specified in Appendix E.

In addition, we estimated the relationship between students' growth on the assessment and their growth on each of the four student survey factors. For these analyses, we limited the sample to a matched sample of students in both the student survey analysis and student achievement analyses (i.e., grades 4 and 5 students with both baseline and outcome data on all student survey factors and the student assessment). We then calculated continuous variables for students' growth on the assessment and on each of the four socioemotional outcomes as a simple difference between students' outcome and baseline values. Note that students' growth on the assessment and on each of the four factors measuring students' socioemotional outcomes are measured on different scales, as described above. Student growth on the assessment is measured in standard deviations, and student growth on a given socioemotional outcome is measured in Likert-scale points ranging from 1 to 5.

We used an OLS regression model to estimate the correlation between students' assessment scores and their socioemotional outcomes related to math. Assessment growth for student i was regressed on students' growth for a given survey factor as follows:

$$y_{ij} = \beta_0 + Grade_i\beta_1 + \beta_2 Z_{ij} + \beta_3 X_{ij} + \beta_4 T_j + S_j\beta_5 + e_{\text{ij}} \qquad (5)$$

This equation predicts students' growth from baseline to outcome on a continuous measure of grade-level geometry, computational thinking, and spatial reasoning skill (y_{ij}). $Grade_i$ is a dummy variable for grade 5 (and grade 4 otherwise). Z_{ij} is a continuous variable representing students' growth on a given survey factor. X_{ij}, T_j, and S_j are vectors of student, teacher, and school covariates, respectively. We included controls identical to those used in the analysis of the student survey. The error term is represented by e_{ij}. The coefficient of interest is β_2, which provides an estimate of the relationship between students' gain on a given survey item and their gain on the assessment.

Teacher Perceptions and Efficacy

Data

SRI researchers administered a teacher questionnaire in fall 2021 (baseline) and again in spring 2022. The teacher questionnaire contains four constructs to measure impacts on teachers' perceptions of and/or efficacy in programmatic concepts, namely, in teaching math, computational thinking, spatial reasoning, and the design cycle. The questionnaire also collected data on MPACT Fellows' attitudes toward, perceptions of, and experiences with MPACT professional development; frequency of program implementation; experience with planning for and implementing MPACT, such as supports for and barriers to implementation; and perceptions of the usefulness of materials and supports. In addition, the questionnaire collected data on MPACT Fellows' and comparison teachers' classes, their experiences with professional development during the 2021–22 school year, and demographic information.

To measure teacher outcomes, SRI researchers reviewed literature on teaching math, computational thinking, spatial reasoning, and the design cycle. To ensure key constructs were measured and to maintain a reasonable length of the questionnaire, we combined, adapted, or wrote items derived from or informed by existing question banks and previous literature. Each construct contains a single factor measured used self-reported data. During Year 1 implementation (2020–21), we examined the internal consistency of factors and removed poorly performing items to improve reliability. We described each factor below.

We measured teachers' perceptions of teaching math using a four-item factor capturing the value teachers ascribe to the importance of teaching math and to their enjoyment and attitudes toward teaching math, drawing from work by Frenzel et al. (2009) and Russo et al. (2019). We measured teachers' perceptions of and efficacy in teaching computational thinking using a four-item factor capturing teachers' perceptions of the extent to which computational thinking skills are malleable as well as their comfort with skills and activities related to teaching computational thinking, drawing from work by Yadav et al. (2014). We also measured teachers' perceptions of spatial reasoning using a four-item factor capturing teachers' beliefs about the importance of students' learning spatial reasoning, drawing from work by Pollitt et al. (2020) and Burte et al. (2020). Finally, to measure teachers' efficacy in teaching using the design cycle, we used a three-item factor capturing teachers' comfort with skills and activities related to using the design cycle in their teaching, drawing from Foster (2021). For additional details on each teacher questionnaire factor, see Appendix F.

Analysis

Estimating Impact. SRI researchers used an intent-to-treat OLS regression model to estimate the relationship between treatment status and each outcome. The teacher impact sample included teachers who were included in the confirmatory student impact sample and who had complete baseline and outcome data on all four factors. We considered a factor to be complete if a teacher provided responses for at least 80 percent of items in the factor. We created factors using exploratory factor analysis. Final factors had alphas greater than or equal to 0.7. The predicted outcome measure on teacher j in school k is given as:

$$y_{jk} = \beta_0 + \beta_1 Prior_j + \beta_2 Treatment_j + \beta_3 T_j + S_k \beta_4 + e_j \qquad (6)$$

This equation predicts the continuous outcomes of teachers' perceptions of and efficacy in math, computational thinking, spatial reasoning, and design cycle, (y_{jk}), accounting for pretreatment teacher- and school-level characteristics, represented by T_j and S_k, respectively. $Prior_j$ is a measure of each factor at baseline, measured before the intervention. Treatment is at the school level, and β_2 provides an estimate of the effect of school assignment to participate in MPACT on teacher outcomes (the intent-to-treat effect). T_j and S_k represent teacher and school variates, respectively. The error term is represented by e_j. We used Huber-White standard errors to account for heteroskedasticity. For detailed information on variable definitions, see Appendix A. For a complete list of the covariates included in each model, see Appendix E. We also explored variation by student-, teacher-, and school-level subgroups by running the model for each subgroup variable specified in Appendix E. Results for subgroup analyses are available upon request.

Descriptive Analysis of Teachers' Perceptions of Program. To further examine differences in MPACT Fellows' and comparison teachers' experiences with professional development and to examine MPACT Fellows' experiences with implementation, as well as their perceptions of program supports, we calculated descriptive frequencies of teachers' responses to relevant items on the questionnaire.

Additionally, we conducted a qualitative analysis of open-ended items on the teacher questionnaire. We compiled open-response data into common categories, such as collaboration with other teachers, alignment of the program with school curricula, use of program tools, and student participation. We identified these codes based on our Year 1 implementation data and used them for the initial round of coding. We then collaboratively identified and refined codes across open-response items and coded each response (Creswell, 2007).

Findings

In this section, we describe our findings on the fidelity of program implementation, impact of the program on students' socioemotional outcomes, students' achievement on an aligned assessment and their perceptions of math concepts and design tools, and MPACT Fellows' perceptions of and efficacy in programmatic concepts and overall perceptions of the program.

Program Implementation

The MPACT program was not implemented as fully intended; however, MPACT Fellows met 100 percent of indicators in component 1 and 80 percent of indicators in component 2. We present detailed findings on the implementation of the three components: teacher professional development, MPACT curriculum and materials, and connections to STEM industry mentors. Exhibit 6 shows whether each component was met. For details on the extent to which each indicator was met, see Appendix G.

Exhibit 6. Fidelity of Program Implementation: Component-Level Results

Component	Description	Number of Indicators Met	Threshold for Component to Be Considered Met	Component Met?
1	Teacher professional development	6/6	6/6 indicators	Yes
2	Curriculum and materials	4/5	5/5 indicators	No
3	Mentors	0/2	2/2 indicators	No

Note. The sample includes 43 MPACT Fellows. For indicator-level results, see Appendix G.

Component 1: Teacher Professional Development

SRI researchers used six indicators to measure implementation fidelity of teacher professional development in MPACT: MPACT Fellows' participation in online professional development, just-in-time professional development, review of materials, use of Tinkercad, understanding of 3D printers, and exposure to the design cycle. The MPACT program met all six indicators in Component 1 (see Exhibit 6). A majority of MPACT Fellows participated in professional development activities, engaged in lesson materials, and reported understanding how to use Tinkercad and the steps to the design cycle (88%–97%). Additionally, a majority of MPACT Fellows reported understanding how to use the 3D printer and having resources to troubleshoot issues with the printer (79%).

Component 2: Curriculum and Materials

We used five indicators to measure the implementation fidelity of curriculum and materials in MPACT: MPACT Fellows accessing MPACT materials, receiving MPACT materials, implementing MPACT modules, reporting that students manipulate real objects and model objects in Tinkercad, and addressing math standards through implementation. The MPACT program met four of the five indicators in Component 2 (see Exhibit 6). A majority of MPACT Fellows were able to access the MPACT materials, received materials both on time and in enough quantity, reported that their students manipulated real objects and modeled objects in Tinkercad, and addressed math standards (90%–95%). However, only 49 percent of MPACT Fellows reported implementing MPACT modules 1–3 in all classes, below the threshold of 75 percent. Nevertheless, about 85 percent of MPACT Fellows implemented at least two modules in all classes, with modules 1–2 implemented most frequently. At the student level, over half of students engaged in all three modules (55%) and about another third engaged in two modules (37%).

Component 3: Connection to STEM Industry Mentors

We used two indicators to measure the implementation fidelity of connection to STEM industry mentors in MPACT: MPACT Fellows' awareness of opportunities for students to engage with STEM industry mentors who use digital fabrication in their work, and students' engagement with mentors. The MPACT program did not meet any indicators in Component 3 (see Exhibit 6). About 56 percent of MPACT Fellows reported being aware of at least three opportunities for their students to engage with mentors, below the threshold of 70 percent. Additionally, 60 percent of MPACT Fellows reported that most or all their students engaged with mentors through these opportunities, below the threshold of 75 percent.

Impact on Students' Socioemotional Outcomes

In this section, we present impact analyses on four outcome measures from the student survey: students' behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept. Exhibit 7 and Exhibit 8 provide baseline and outcome data for the survey factors for MPACT and comparison students. Baseline data include the unadjusted mean and standard deviation for each factor, the difference between MPACT Fellows' and comparison teachers' unadjusted means, and the standardized difference, prior to weighting. Outcome data include the unadjusted means and standard deviation. All four factors were on a Likert scale of 1 through 5, with 1 equal to strongly disagree, 2 equal to disagree, 3 equal to neither agree nor disagree, 4 equal to agree, and 5 equal to strongly agree.

Exhibit 7. Baseline Descriptives for Confirmatory Student Impact Sample, by Treatment Status

	MPACT Students		Comparison Students			Baseline Equivalence	
	Unweighted Mean	Unweighted SD	Unweighted Mean	Weighted Mean	Unweighted SD	Cohen's d (Unweighted)	Cohen's d (Weighted)
Behavioral engagement in math	4.2	0.6	4.3	4.2	0.6	-0.05	0.01
Behavioral disaffection in math	3.6	0.8	3.7	3.6	0.8	-0.13	0.00
Math self-efficacy	3.9	0.8	4.0	3.9	0.8	-0.11	0.00
Math self-concept	3.3	0.9	3.4	3.3	0.9	-0.08	0.03

Note. SD = standard deviation. The confirmatory student impact analytic sample includes 1,235 MPACT students in 29 schools and 1,084 comparison students in 28 schools. Exhibit presents unadjusted, unweighted means, standard deviations, and cohen's d values that are not adjusted using model covariates or weights for baseline measures. Weighted means adjust means using weights.The baseline equivalence columns present Cohen's d values, calcualted using both the unweighted and weighted values.

Exhibit 8. Outcome Descriptives for Confirmatory Student Impact Sample, by Treatment Status

	MPACT Students		Comparison Students	
	Mean	SD	Mean	SD
Behavioral engagement in math	4.2	0.6	4.1	0.6
Behavioral disaffection in math	3.5	0.8	3.5	0.8
Math self-efficacy	3.9	0.8	4.0	0.8
Math self-concept	3.4	0.9	3.4	1.0

Note. SD = standard deviation. The confirmatory student impact analytic sample includes 1,235 MPACT students in 29 schools and 1,084 comparison students in 28 schools. Exhibit presents unadjusted, unweighted means and standard deviations that are not adjusted using model covariates or weights for outcome measures.

Exhibit 9 presents the estimated effects of MPACT instruction on MPACT students' behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept. We calculated the effect size as Hedges' g (i.e., the covariate-adjusted mean difference minus the treatment coefficient divided by the unadjusted pooled within-group standard deviation). The impact estimate is the unstandardized regression coefficient for MPACT students and is measured in Likert-scale points. We find that assignment to participate in the MPACT program (intent to treat) did not have a statistically significant impact on any of the four socioemotional outcomes measured for students. Similarly, we find that receipt of all three modules in the MPACT program (treatment on the treated) did not have a statistically significant impact on any of the four socioemotional outcomes measured for students.

When examining variation by student subgroups, we find that MPACT did not have a statistically significant impact on the vast majority of the four socioemotional outcomes measured in the majority of student subgroups, outside of significant results we would expect by chance. These results are available upon request.

Exhibit 9. Impact Estimates of MPACT Instruction by Student Socioemotional Outcome

	Predicted Outcome, MPACT Students	Predicted Outcome, Comparison Students	Impact Estimate	Standard Error	Test Statistic	*p* Value	Effect Size
Behavioral engagement in math	4.00	3.96	0.04	0.04	0.99	0.33	0.07
Behavioral disaffection in math	3.55	3.48	0.07	0.04	1.62	0.11	0.08
Math self-efficacy	3.96	3.93	0.03	0.05	0.62	0.54	0.04
Math self-concept	3.38	3.40	-0.02	0.05	-0.44	0.66	-0.02

Note. This exhibit shows results from intent-to-treat OLS weighted regression models applying inverse propensity score weights. The models estimate the relationship between students' assignment to an MPACT Fellow and each student factor. Factors are in Likert-scale points ranging from 1 to 5. The sample includes 2,319 students (1,235 MPACT students and 1,084 comparison students). Models include student-, teacher-, and school-level covariates. For details on model covariates, see Appendix E. The impact estimate is the unstandardized regression coefficient for the intervention indicator, namely, students' assignment to an MPACT Fellow. The test statistic is the t-statistic from the student's t-test. P values are those associated with the impact estimate and test statistic. The effect size is reported in terms of Hedges' g, based on the adjusted means and the unadjusted standard deviation. No estimates were statistically significant at the $p = 0.05$ level.

Descriptive Analysis of Students' Perceptions of Math

Next, SRI researchers examined how students perceived math as part of MPACT activities. In this section, we present descriptive analyses on questions addressing student perceptions of the integration of math into MPACT projects. Most MPACT students in the sample (90%) reported they recalled completing an MPACT project. Among the students in this subset:

- 70 percent agreed the MPACT project showed them one way math could be used in real life.
- 80 percent agreed the MPACT project helped them learn about careers that use math.
- 90 percent agreed they used math during the MPACT project.

Students also had the opportunity to answer an open-response question about how MPACT showed math could be used in real life. Of the 65 percent of students (n = 1,146) who responded to the question, over half described specific math topics (e.g., measurement, geometry) in their response (59%), about one fifth wrote about making 3D objects or using the 3D printer (22%), and about a tenth wrote about connections to future jobs (10%). We describe findings for each of these themes below.

> "The bookmark project showed how you have to adjust the width, length, and height. It uses math because you have to know how tall and long it is, which means you have to find it out." - Student

Most often, students mentioned a math topic (59%), with the most common topic being measurement (e.g., "I learned to measure"). A few students also explained features of the math topic. For instance, when describing measurement, one student wrote, "The bookmark project showed how you have to adjust the width, length, and height. It uses math because you have to know how tall and long it is, which means you have to find it out." Few students connected the math topic to a real-world object or activity. One student who made this connection wrote, "You need to use L x W x H and area and volume. Like if you were going to buy a TV, you need the same as the TV frame." Detailed results are available upon request.

> "It showed me how math can be used in real life by showing me that kites can be a part of math." - Student

Most students who wrote about making 3D objects referred to 3D objects they were exposed to in the MPACT curriculum either through projects or videos. For instance, one student wrote, "It can be used to create body parts and help with area and perimeter to build houses and buildings." Another stated, "It showed me how math can be used in real life by showing me that kites can be a part of math." Some students reflected on learning the importance of accuracy when doing mathematics. For example, when describing what they learned, one student wrote, "The 3D printing project taught me how math

> “The 3D printing project taught me how math can be used in real life by finding the correct dimensions that need to make the print come out right.” - Student

can be used in real life by finding the correct dimensions that need to make the print come out right.” Another stated, “Well, it showed me the volume and how much is needed and you have to get the right angles or you could mess the whole thing up.” Finally, when writing about connecting their math learning to their future jobs, most students gave examples of how math is necessary in the real-life jobs. For example, one student wrote, “Many jobs need math. If you are a designer, any designer, like a fashion designer or an interior designer, you will need math to measure things and put them in the right place. Many of the building jobs need math also, a teacher may need to learn math before becoming one, to help the students.”

> “Many jobs need math. If you are a designer, any designer, like a fashion designer or an interior designer, you will need math to measure things and put them in the right place. Many of the building jobs need math also, a teacher may need to learn math before becoming one, to help the students.” - Student

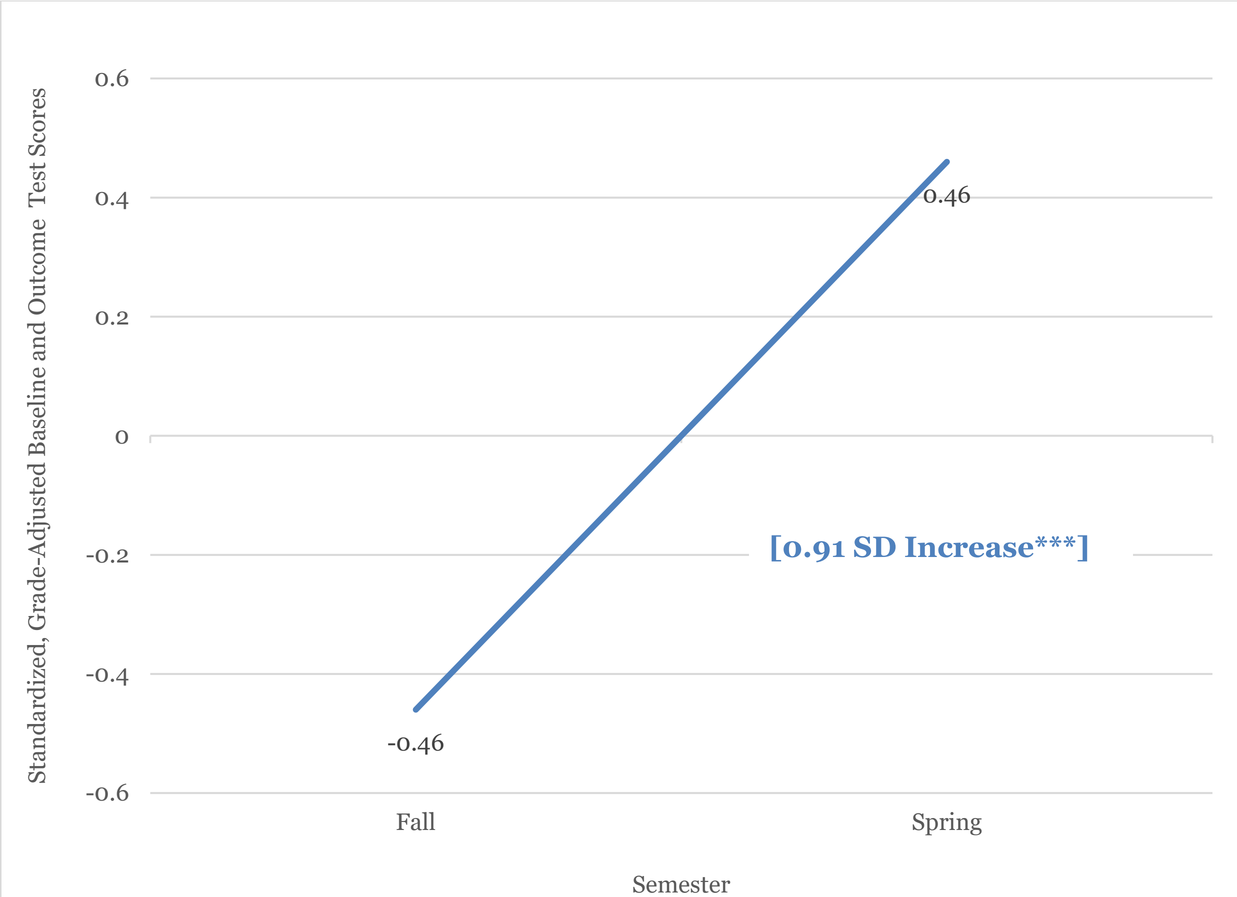
If students referenced a specific industry, most often it was construction. Further, many students referenced the usefulness of measurement skills. As one student described, “This project showed me how math can be used in real life, because-for example if you want to build a building you need certain measure like the height and length.”

Student Achievement

In this section, we present findings on student achievement for MPACT students in grades 4 and 5 on an assessment measuring students’ knowledge of MPACT-aligned geometry, computational thinking, and spatial reasoning.

Exhibit 10 shows growth in student achievement. We presented effect sizes in standard deviations, as we converted grades 4 and 5 students’ scores to *z*-scores and analyzed them using a pooled sample. We found statistically significant growth on a measure of grade-level geometry, computational thinking, and spatial reasoning skills ($p < 0.001$) across students. As shown in Exhibit 10, MPACT students improved from baseline to outcome by an average effect size of 0.91 standard deviations, roughly equal to a 19-percentage-point higher score on the post-test.

Exhibit 10. Student Achievement Growth on an Aligned Assessment, Grades 4 and 5 MPACT Students



Note. This exhibit shows results from OLS regression models estimating students' growth on an aligned assessment from assignment to an MPACT Fellow. Assessment scores are measured using z-scores. The sample includes 737 students in grade 4 (n = 320), grade 5 (n = 403), grade 6 (n = 9), and grade 7 (n = 5). Models control for student grade only. The point estimate calculates the increase in students' assessment score, adjusting for grade. The test statistic is the t-statistic from the student's t-test. P values are those associated with the impact estimate and test statistic.
* $p < 0.05$. ** $p < 0.01$. *** $p < .001$.

The exhibit displays the overall effect size for students in the first row, as well as effects for subgroups of students based on student-, teacher-, and school-level characteristics.

Exhibit 11 displays the overall effect size for students in the first row, as well as effects for subgroups of students based on student-, teacher-, and school-level characteristics. We observed positive and significant coefficients for almost all groups of students when examining differences by student, teacher, and school characteristics. Effect sizes ranged from 0.4 to 1.2 standard deviations. Effect sizes were estimated with varying degrees of precision, with groups with larger samples tending to have greater precision.

Exhibit 11. Student Achievement Growth on an Aligned Assessment, by Student, Teacher, and School Characteristics, Grades 4 and 5 MPACT Students

	Sample Size	Point Estimate	Standard Error	Test Statistic	*p* Value	R^2	Correlation Coefficient
Overall	**737**	**0.9*** **	**0.0**	**19.7**	**< 0.001**	**0.2**	**0.6**
Student-Level Subgroups							
Race/ethnicity							
American Indian or Alaska Native; Asian; Middle Eastern or North African; Native Hawaiian or Pacific Islander; Self-described as a race/ethnicity not listed on survey; Chose not to share; Not sure; Skipped question	195	0.8***	0.1	8.7	< 0.001	0.2	0.6
Black or African American	131	0.7***	0.1	6.7	< 0.001	0.2	0.4
Latino/a, Latinx, Hispanic, or Spanish origin	46	1.1***	0.2	6.7	< 0.001	0.4	0.6
Two or more races	58	0.9***	0.2	5.3	< 0.001	0.2	0.5
White	307	1.1***	0.1	15.2	< 0.001	0.3	0.5
Gender							
Female	332	0.9***	0.1	14.3	< 0.001	0.2	0.6
Male	320	1.0***	0.1	13.6	< 0.001	0.2	0.5
Self-described as a gender not listed on survey; Chose not to share; Not sure; Skipped question	85	0.6***	0.1	4.4	< 0.001	0.1	0.5
Home language							
English only	591	0.9***	0.1	17.7	< 0.001	0.2	0.5
At least one language other than English	138	0.9***	0.1	8.9	< 0.001	0.2	0.6
Unable to determine or skipped question	8	-	-	-	-	-	-
Class subject							
Self-contained class	55	0.6***	0.2	3.7	< 0.001	0.1	0.5
STEM	379	1.1***	0.1	17.0	< 0.001	0.3	0.5
Math	241	0.7***	0.1	9.3	< 0.001	0.2	0.5
Science		-	-	-	< 0.001	-	-
Other subject	62	0.7***	0.2	4.5	< 0.001	0.1	0.7
Family engagement with school							
Never or hardly ever	120	0.8***	0.1	6.7	< 0.001	0.2	0.6
Once every few week	78	1.2***	0.1	8.2	< 0.001	0.3	0.5
About once a week	111	1.0***	0.1	9.1	< 0.001	0.3	0.6
Two or three times a week	121	0.8***	0.1	7.5	< 0.001	0.2	0.4
Every day	304	0.9***	0.1	12.1	< 0.001	0.2	0.6

	Sample Size	Point Estimate	Standard Error	Test Statistic	*p* Value	R^2	Correlation Coefficient
Skipped question		-	-	-	-	-	-
Number of modules engaged in							
Exactly 0 modules	19	0.4	0.2	1.7	0.1	0.1	0.6
Exactly 1 module	17	0.9**	0.3	3.0	0.005	0.3	0.7
Exactly 2 modules	348	0.8***	0.1	11.3	< 0.001	0.2	0.6
All 3 modules	353	1.1***	0.1	16.6	< 0.001	0.3	0.5
Teacher-Level Subgroups							
Grade level taught							
Grade 4	468	1.0***	0.1	17.6	< 0.001	0.3	0.5
Grade 5	535	0.9***	0.1	16.3	< 0.001	0.2	0.5
Grade 6	82	0.7***	0.2	4.2	< 0.001	0.1	0.6
Grade 7	17	0.9***	0.3	3.0	< 0.001	0.3	0.7
Experience level							
Novice (< 4 years)	508	0.9***	0.1	10.8	< 0.001	0.2	0.4
Experienced (4+ years)	229	0.9***	0.1	16.9	< 0.001	0.2	0.6
STEM teacher							
STEM	573	1.0***	0.1	19.3	< 0.001	0.2	0.5
Not STEM	164	0.6***	0.1	6.1	< 0.001	0.1	0.6
Subject area							
Self-contained	74	0.5***	0.1	3.7	< 0.001	0.1	0.6
STEM	573	1.0***	0.1	19.3	< 0.001	0.2	0.5
Math	52	0.7***	0.2	3.7	< 0.001	0.1	0.5
Science only		-	-	-	-	-	-
Other subject	38	0.7***	0.2	3.9	< 0.001	0.2	0.8
MPACT Implementation							
Did not teach MPACT in any class		-	-	-	-	-	-
Taught exactly 1 module in all classes	65	0.8***	0.2	4.1	< 0.001	0.1	0.5
Taught exactly 2 modules in all classes	311	0.8***	0.1	11.1	< 0.001	0.2	0.6
Taught all 3 modules in all classes	325	1.1***	0.1	16.2	< 0.001	0.3	0.5
Taught exactly 1 module in a least 1 class	17	0.9**	0.3	3.0	0.005	0.3	0.7
Taught exactly 2 modules in at least one class	335	0.8***	0.1	11.0	< 0.001	0.2	0.6
Taught all 3 modules in at least one class	366	1.1***	0.1	16.7	< 0.001	0.3	0.5
School-Level Subgroups							
School type							
Middle school	219	0.8***	0.1	8.4	< 0.001	0.1	0.5
Elementary school	518	1.0***	0.1	18.3	< 0.001	0.2	0.5
STEM school							

	Sample Size	Point Estimate	Standard Error	Test Statistic	*p* Value	R^2	Correlation Coefficient
STEM	152	0.7***	0.1	8.5	< 0.001	0.2	0.4
Not STEM	585	1.0***	0.1	17.9	< 0.001	0.2	0.6
Urbanicity							
Rural	658	0.9	0.0	18.9	< 0.001	0.2	0.5
Non-rural	79	0.9	0.1	6.6	< 0.001	0.4	0.8
FRPL quartile							
Q1 (lowest rates of FRPL)	56	0.7	0.2	4.1	< 0.001	0.1	0.5
Q2	368	1.0	0.1	15.6	< 0.001	0.3	0.5
Q3	17	-	-	-	-	-	-
Q4 (highest rates of FRPL)	296	0.8***	0.1	12.4	< 0.001	0.2	0.6
Title I							
Title I	558	1.0***	0.1	18.2	< 0.001	0.2	0.5
Not Title I	179	0.8***	0.1	8.2	< 0.001	0.2	0.5

Note. STEM = science, technology, engineering, and math; FRPL = free or reduced-price lunch; Q = quartile. This exhibit shows results from OLS regression models estimating students' growth on an aligned assessment from assignment to an MPACT Fellow. Assessment scores are measured using z-scores. The sample includes 737 students in grade 4 (n = 320), grade 5 (n = 403), grade 6 (n = 9), and grade 7 (n = 5). Models control for student grade only. For details on variables used in subgroup analyses, see Appendix E. The point estimate calculates the increase in students' assessment score, adjusting for grade. The test statistic is the t-statistic from the student's t-test. P values are those associated with the impact estimate and test statistic. Results for models estimating impacts for students were omitted due to collinearity and/or insufficient sample for the following subgroups of students: students who were in a science class, whose home language was not provided or was unable to be determined, who did not provide their level of family engagement in school, who received exactly 0 MPACT modules, who had a science teacher, who had a teacher who did not teach MPACT in any class, or who were in a school which fell into Q3 in terms of the percentage of students eligible FRPL.

$* p < 0.05$. $** p < 0.01$. $*** p < .001$.

Next, we examined the relationship between students' growth on the standardized assessment from baseline to outcome and students' growth on each factor measuring students' behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept. Results are in Exhibit 12. Regression coefficients represent the relationship between students' growth on a given factor (measured on a Likert scale ranging from 1 to 5) and students' growth on the assessment (measured in standard deviations). We find positive and statistically significant associations between students' gains on all four factors measuring students' socioemotional outcomes and their assessment gains. For instance, a one Likert scale gain in students' math self-concept is associated with a 0.27 standard deviation higher gain on their assessment score, all else held equal.

Exhibit 12. Association Between Students' Achievement Growth on an Aligned Assessment and Students' Growth on Measures of Socioemotional Outcomes

Socioemotional Outcome	Point Estimate	Standard Error	*p* Value
Behavioral engagement in math	0.19**	0.07	0.006
Behavioral disaffection in math	0.17***	0.05	< 0.001
Math self-efficacy	0.22***	0.05	< 0.001
Math self-concept	0.27***	0.05	< 0.001

Note. This exhibit displays results from four OLS regression models examining the relationship between students' standardized assessment growth from baseline to outcome and students' growth on a given factor measuring students' behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept. The scale on behavioral disaffection was reverse coded such that a larger value would indicate an improvement in students' behavioral disaffection in math. Point estimates represent the relationship between students' growth on the aligned assessment (measured in standard deviations) and students' growth on a given factor (measured on a Likert scale ranging from 1 to 5). The sample contains 706 students in grade 4 (n = 298), grade 5 (n = 394), grade 6 (n = 9) and grade 7 (n = 5) with complete baseline and outcome data on both the assessment and all survey factors. Models include controls for students' baseline assessment score and baseline value on a given factor, as well as controls identical to those included in models estimated confirmatory student impacts (see Appendix E for more details).

* $p < 0.05$. ** $p < 0.01$. *** $p < .001$.

Teacher Perceptions and Efficacy

Impact Analyses on Teachers' Perceptions of and Efficacy in Programmatic Concepts

Finally, we report on teacher perceptions of and efficacy in programmatic concepts, including teacher perceptions of and/or efficacy in teaching math, computational thinking, spatial reasoning, and the design cycle. Exhibit 13 shows the baseline and outcome data for questionnaire factors for MPACT Fellows and comparison teachers. The exhibit includes the unadjusted mean and standard deviation for each of the four factors at baseline and outcome for MPACT Fellows and comparison teachers. All four factors were on a Likert scale from 1 to 5, with 1 equal to strongly disagree, 2 equal to disagree, 3 equal to neither agree nor disagree, 4 equal to agree, and 5 equal to strongly agree.

Exhibit 13. Baseline and Outcome Statistics for Exploratory Teacher Impact Sample

Measures	MPACT Fellows		Comparison Teachers	
	Unadjusted Mean	Unadjusted Standard Deviation	Unadjusted Mean	Unadjusted Standard Deviation
Baseline Measures				
Teachers' perceptions of teaching math	4.3	0.8	4.3	0.8
Teachers' perceptions of and efficacy in teaching computational thinking	3.6	0.6	3.7	0.6
Teachers' perceptions of teaching spatial reasoning	4.1	0.5	4.1	0.6
Teachers' efficacy in teaching using the design cycle	3.6	1.2	3.4	1.0
Outcome Measures				
Teachers' perceptions of teaching math	4.4	0.7	4.5	0.5
Teachers' perceptions of and efficacy in teaching computational thinking	4.0	0.5	3.7	0.6
Teachers' perceptions of teaching spatial reasoning	4.4	0.5	4.0	0.4
Teachers' efficacy in teaching using the design cycle	4.3	0.7	3.6	1.0

Note. The exploratory teacher impact analytic sample includes 43 MPACT Fellows in 29 schools and 36 comparison teachers in 28 schools.

The estimated impacts of participation in the MPACT program on teacher questionnaire outcomes are in Exhibit 14. We calculated the effect size as Hedges' g (i.e., the covariate-adjusted mean difference minus the treatment coefficient divided by the unadjusted pooled within-group standard deviation). The impact estimate is the unstandardized regression coefficient for MPACT Fellows and is measured in Likert-scale points. On average, participation in the MPACT program demonstrates a positive and statistically significant impact on three of the four factors analyzed, namely, MPACT Fellows' perceptions of and efficacy in teaching computational thinking (point estimate = 0.28, $p < 0.04$), MPACT Fellows' perceptions of teaching spatial reasoning (point estimate = 0.30, $p < 0.02$), and MPACT Fellows' efficacy in teaching using the design cycle (point estimate = 0.67, $p < 0.001$), with the largest impact observed on teachers' efficacy in teaching and using the design cycle. For example, we may interpret this last statistic as follows: MPACT Fellows' grew 0.67 Likert points more than comparison teachers on efficacy in teaching and using the design cycle between fall and spring, all else held equal. We observed no effect on MPACT Fellows' perceptions of teaching math. Results examining variation by teacher subgroup are available upon request.

Exhibit 14. Impact of the MPACT Program on Teachers' Perceptions of and Efficacy in Programmatic Concepts

Measures	Impact Estimate	Standard Error	Test statistic	*p* Value	Effect Size	R^2	Correlation Coefficient
Teachers' perceptions of teaching math	-0.12	0.12	-1.04	0.30	-0.21	0.42	0.59
Teachers' perceptions of and efficacy in teaching computational thinking	0.28*	0.13	2.13	0.04	0.48	0.30	0.33
Teachers' perceptions of teaching spatial reasoning	0.30*	0.12	2.56	0.01	0.63	0.22	0.13
Teachers' efficacy in teaching using the design cycle	0.67***	0.17	3.91	<0.001	0.79	0.48	0.56

Note. This exhibit shows results from intent-to-treat OLS regression models estimating the relationship between teachers' status as an MPACT Fellow and each factor. Factors are in Likert-scale points ranging from 1 to 5. The sample includes 79 teachers (43 MPACT Fellows and 36 comparison teachers). Models include teacher- and school-level covariates. For details on model covariates, see Appendix E. The impact estimate is the unstandardized regression coefficient for the intervention indicator, namely, teachers' status as an MPACT Fellow. The test statistic is the t-statistic from the student's t-test. P values are those associated with the impact estimate and test statistic. The effect size is reported in terms of Hedges' g, based on the adjusted means and the unadjusted standard deviation.
* $p < 0.05$. ** $p < 0.01$. *** $p < .001$.

Descriptive Analyses on Teachers' Perceptions of Program

We also descriptively examined MPACT Fellows' perceptions of the program in terms of the usefulness of professional development, as well as supports and barriers. We further examined differences in MPACT Fellows' and comparison teachers' perceptions of professional development they received during the 2021–22 school year. Detailed results are available upon request.

MPACT Fellows' Perceptions of Program Supports and Barriers. First, we explored MPACT Fellows' perceptions of the helpfulness of the professional development by examining their level of agreement (agree or strongly agree) on a series of statements about the professional development. Overall, MPACT Fellows agreed or strongly agreed that the professional development helped them feel prepared to implement MPACT modules 1–3 (85%–90%), that they learned useful principles related to facilitating the design cycle (95%), that the professional development offered them useful principles related to adapting MPACT modules for special populations of students such as English learner students or students with disabilities (88%), and that they felt prepared to facilitate Tinkercad usage with students (90%). However, only about half of MPACT Fellows agreed or strongly agreed they felt comfortable using and troubleshooting problems with the 3D printer (53%).

For support implementing the program, most MPACT Fellows reported accessing MPACT online tutorials (90%), additional MPACT resources on the website (90%), and communicating with TERC staff or facilitators (95%). About 70 percent of MPACT Fellows also accessed online links to other resources, while only 30 percent of MPACT Fellows accessed the MPACT online forums. In addition, the teacher questionnaire prompted MPACT Fellows to rate the adequacy of these supports on a five-point Likert scale ranging from 1 for *inadequate* to 5 for *excellent*. MPACT Fellows found most supports to be good or excellent (79%–89%), with the exception of the online forums, which 46 percent found to be good or excellent.

> "I know I could've gotten more out of it if I had another teacher participating in the grant on site with whom I could collaborate and maybe get some in-person technical support. It's hard being an island."
> – MPACT Fellow

Additionally, open-ended responses on the teacher questionnaire indicated that community and collaboration with other MPACT Fellows was a key source of support for teachers. MPACT Fellows cited colleagues as an additional support for implementing the MPACT program, and teachers who were the only MPACT Fellow at their school expressed a need for more collaboration and community. For instance, one Fellow wrote, "I know I could've gotten more out of it if I had another teacher participating in the grant on site with whom I could collaborate and maybe get some in-person technical support. It's hard being an island."

On the teacher questionnaire, MPACT Fellows rated several factors as either barriers or supports on a seven-point Likert scale ranging from *substantial barrier* to *substantial support*. We categorized a given factor as a support if 50 percent or more of MPACT Fellows perceived a given factor as a slight support, support, or substantial support. We categorized a given factor as a barrier if at least 20 percent of MPACT Fellows perceived the factor as a barrier or substantial barrier. (This definition is in alignment with the definition for barrier used in our fidelity of implementation analysis). We categorized a factor as neither a support nor a barrier otherwise.

When reflecting on the contextual factors that were supports for implementation, over half of MPACT Fellows reported as supports or substantial supports their skill with Tinkercad (63%), effectiveness of the professional development (77%), ability to differentiate the MPACT curriculum for students with varying prior proficiency in MPACT concepts (60%) and for students with various learning needs (58%), alignment with curriculum or pacing guides (67%), alignment with grade-level standards (72%), students' interest and engagement in the MPACT program (91%), students' understanding of how to complete MPACT activities (70%), and students' understanding of the math used in MPACT lessons (72%).

About a fifth of MPACT Fellows reported as a barrier or substantial barrier their skill with the 3D printer (21%), and an additional 30 percent reported skill with the 3D printer to be a slight barrier. Findings from our analyses of open-ended items on the teacher questionnaire corroborated this finding.

MPACT Fellows reported a tension between the technical difficulties that came with using the 3D printers and the enhanced student engagement. Despite 20–50 percent of MPACT Fellows reporting some challenge with using the 3D printer, several also noted the benefits of 3D printing as it allows students to see their designs come to life. Many MPACT Fellows credited the hands-on nature of MPACT as the reason students were so engaged. Some saw the benefit of using the 3D printer as part of the MPACT program to help make connections between the math students were learning in the program to the real world. For example, one Fellow described, "The kids loved it. We had trouble with the printers for a while, so the fastest way to deflate motivation was not to be able to print the items they made in a reasonable amount of time," while another stated, "I think they're fascinated by their ability to create something on the computer and be able to create something 3-dimensional out of it." Only a few MPACT Fellows reported challenges to using Tinkercad software.

"The kids loved it. We had trouble with the printers for a while, so the fastest way to deflate motivation was not to be able to print the items they made in a reasonable amount of time." – MPACT Fellow

"I think they're fascinated by their ability to create something on the computer and be able to create something 3-dimensional out of it." – MPACT Fellow

Differences in Experiences With Professional Development. In addition to gauging MPACT Fellows' perceptions of MPACT professional development and programmatic supports and barriers, the teacher questionnaire also prompted both MPACT Fellows and comparison teachers to reflect on the professional development they received during the 2021–22 school year. MPACT Fellows' professional development was more likely to include professional development on 3D printers, computational thinking, spatial reasoning, and the design cycle (42%–73%) compared to professional development received by comparison teachers (0%–18%). These differences maintain, but are less stark, for professional development that included project-based learning: 73 percent of MPACT Fellows and 50 percent of comparison teachers received professional development on project-based learning and the design cycle. In contrast, a greater percentage of comparison teachers reported receiving professional development on grade-level math standards (79%), compared to MPACT Fellows (60%). Comparison teachers also reported receiving about seven more hours of professional development (30 hours) during the 2021–22 school year, compared to MPACT Fellows (23 hours).

The questionnaire also prompted MPACT Fellows and comparison teachers to reflect on the quality of the professional development. Overall, MPACT Fellows were more positive toward the professional development they received during the 2021–22 school year. MPACT Fellows were also more likely than comparison teachers to agree or strongly agree that the professional development they received held their attention (88% vs. 68%), that it was aligned to the state math standards they were expected to teach (86% vs. 74%), that they felt prepared to teach the material covered in the professional development (100% vs. 84%), and that they enjoyed the professional development (79% vs. 58%). Further, MPACT Fellows were more likely than comparison teachers to agree or strongly agree that after attending the professional development, they had a better understanding of how STEM professions use computational thinking (83% vs. 26%), spatial reasoning (78% vs. 19%), and the design cycle (86% vs. 19%). Finally, MPACT Fellows were much more likely than comparison teachers to agree or strongly agree that after the professional development, they were better able to give students feedback around math concepts (80% vs. 58%), the design cycle (83% vs. 23%), project-based learning (78% vs. 52%), computational thinking (86% vs. 32%), and spatial reasoning (81% vs. 22%).

Finally, on the questionnaire, all teachers responded to questions about the most in-depth assignment they asked students to do during the previous school year. They also rated the importance of different formats of student engagement and activities in this assignment, on a five-point Likert scale ranging from 1 for *not important at all* to 5 for *extremely important*. Overall, the majority of MPACT Fellows and comparison teachers rated most activities as important or extremely important. However, in a few notable instances, the percentage of teachers differed by 10 percentage points or more. For instance, compared to comparison teachers, MPACT Fellows were somewhat more likely to rate as important or extremely important the following activities: asking students to work on tasks of activities independently (72% vs. 61%), design or build artifacts (86% vs. 72%), create a product for an authentic audience (91% vs. 75%) and with authentic constraints (93% vs. 70%), and create protypes or multiple drafts of the product to improve it (91% vs. 67%).

Discussion

The MPACT program combines project-based learning, math education, and computer science education in a digital fabrication context. Through a combination of teacher professional development, curriculum and materials, and STEM industry mentors, MPACT aims to improve teacher perceptions of and efficacy in programmatic concepts. These teacher improvements are expected to lead to gains in student achievement and socioemotional outcomes. We find mixed results in studying these outcomes.

MPACT was implemented with partial fidelity. Of the 13 individual indicators of implementation across teacher professional development, curriculum and materials, and the use of STEM industry mentors, 10 met the program threshold level. Although all professional development indicators were met, only about half of MPACT Fellows agreed or strongly agreed they felt comfortable using and troubleshooting problems with the 3D printer, and qualitative data suggest that using and troubleshooting the printer may have been a considerable barrier for a subset of MPACT Fellows. Despite the challenges with using 3D printers, MPACT Fellows also reported that 3D printing was a source of student engagement. Additionally, only 65 percent of MPACT Fellows implemented all three modules, which suggests many students may not have had the intended level of engagement with the program. Finally, neither of the two mentor-related indicators were met. Ultimately, MPACT Fellows implemented MPACT in a year marked by ongoing difficulties brought on by the COVID-19 pandemic, where teachers, students, and families were burdened with challenges to their wellbeing. Because the program was not implemented in ideal conditions, or implemented as fully intended, as recommended for efficacy studies by the Institute of Education Sciences and National Science Foundation (2013), we are limited in our understanding of how MPACT may affect educational outcomes in such a scenario.

With respect to teacher perceptions of and efficacy in programmatic concepts, we find the MPACT program to have had a positive, statistically significant, and meaningful impact on three of the four factors analyzed (efficacy in teaching computational thinking, perceptions of spatial reasoning, and efficacy in teaching using the design cycle), with differences in growth between MPACT Fellows and comparison teachers between a third and two thirds of a Likert-scale point, controlling for relevant differences. This finding provides evidence that the professional development delivered to MPACT Fellows, in combination with the materials and curriculum used, often led to the changes in teachers' knowledge and skills that the program intended. However, we do not find an impact on MPACT Fellows' perceptions of teaching math. One possible explanation for this result is comparison teachers received more professional development focused on math instruction, specifically. Teacher questionnaire results reveal that a greater percentage of comparison teachers reported receiving professional development on grade-level math standards (79%), compared to MPACT Fellows (60%). It could be the case that a measure that focused more directly on computational thinking or spatial reasoning may have showed more positive results.

We find that grades 4 and 5 MPACT students grew considerably on an assessment measuring students' knowledge of MPACT-aligned geometry, computational thinking, and spatial reasoning, with students improving nearly a full standard deviation between fall 2021 and spring 2022. This finding provides suggestive evidence that the MPACT program can lead to improvements in student achievement. However, this finding must be interpreted cautiously: there was no comparison group in this analysis, so we cannot determine whether MPACT caused more growth than would have occurred under business-as-usual conditions.

Despite finding impacts on teacher outcomes, and suggestive descriptive results on the student assessment, we do not find any effect of MPACT on student socioemotional outcomes, including behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept. These findings were robust to sensitivity tests, and subgroup analyses did not reveal any meaningful impacts for certain groups of students. Moreover, we continued to find null results even when we restrict the sample to only those MPACT Fellows who implemented all three modules.

These mixed findings may be better understood by examining the range of meaningful and insignificant results, and the relationships between them. Of the four teacher factors analyzed, the only insignificant result we find is the effect of MPACT on teacher perceptions of teaching math. Given that the student outcomes examined all relate to math perceptions, and that comparison teachers reported receiving considerably more professional development on grade-level math standards, it seems likely that the comparison condition is no different from the treatment condition at improving math-related outcomes, specifically. The considerable growth of MPACT students on the assessment, and the documented program impacts on teachers' perceptions, provide some suggestive evidence that the MPACT program could demonstrate impacts on student outcomes in ideal conditions or if examined over a longer time frame, or when using another measure (e.g., an impact measure of only spatial reasoning or computational thinking). However, because the program was not implemented as fully intended, and the lack of a demonstrated impact on student outcomes, we currently can make limited claims about the effectiveness of MPACT. Future research should aim to understand the impacts of the program when implemented with full fidelity, and on a broader range of student outcomes.

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Appendices

Appendix A. Covariate Definitions

Appendix A1: Student Covariate Definitions

Variable Name	Type	Availability	Source	Year	Variable Description
Survey Baseline Factors	Continuous	All students	Student survey	2021–22	These are four continuous variables capturing students' baseline socioemotional outcomes. Using factor analysis, SRI researchers constructed four continuous factors for each of the four constructs measured on the student survey, namely, students' behavioral engagement in math, behavioral disaffection in math, math self-efficacy, and math self-concept. Each construct contained 5–6 items. For a student to be assigned a value for a given factor, the student must have answered at least 80% of items in the factor. The items within each factor were determined using confirmatory factor analyses conducted in 2020–21.
Grade	Categorical	All students	Student survey	2021–22	This is a categorical variable for student grade. Categories include grades 4–7, as well as an unknown category for students who did not provide their grade.
Race/Ethnicity	Categorical	All students	Student survey	2021–22	This is a categorical variable for students' self-reported race/ethnicity. The student survey asked students to select one or more categories that best represented their race/ethnicity from the following options: American Indian or Alaska Native, Asian or Asian American; Black or African American; Latino/a, Latinx, Hispanic, Spanish origin; Middle Eastern or North African; Native Hawaiian or Pacific Islander; White; I prefer to self-describe (please specify); I choose not to share; I am not sure. Students could also skip the question. If students provided a write-in option that aligned closely with a single race/ethnicity listed on the survey, SRI researchers assigned the student as such. If students chose a listed race/ethnicity and either "I choose not to share" or "I am not sure," students were assigned as the race/ethnicity chosen. We created a new category called "Two or more races/ethnicities" if students chose two or more races/ethnicities. Using these data, we made three categories as follows: American Indian or Alaska Native Asian or Asian American Black or African American Latino/a, Latinx, Hispanic, or Spanish origin Middle Eastern or North African Two or more races Native Hawaiian or Pacific Islander White

Variable Name	Type	Availability	Source	Year	Variable Description
					Self-described as a race/ethnicity not listed on survey; Chose not to share; Not sure; Skipped question As much as possible, we opted to use the most granular race/ethnicity data possible. For instance, the above categories are used as control variables in the confirmatory student survey impacts analysis. When conducting subgroup analyses, we collapsed students in categories with small numbers of students in order to have sufficiently large samples to obtain balanced propensity score weights. Specifically, we grouped into a single category the students who chose to self-describe as follows: American Indian or Alaska Native; Asian or Asian American; Middle Eastern or North African; Native Hawaiian or Pacific Islander; Self-described as a race/ethnicity not listed on survey; Chose not to share; Not sure; Skipped question. In subgroup analyses for the confirmatory student survey impacts and for the exploratory student assessment impacts, we use aggregated race/ethnicity categories as follows: American Indian or Alaska Native; Asian or Asian American; Middle Eastern or North African; Native Hawaiian or Pacific Islander; Self-described as a race/ethnicity not listed on survey; Chose not to share; Not sure; Skipped question Black or African American Latino/a, Latinx, Hispanic, or Spanish origin Two or more races White
Gender	Categorical	All students	Student survey	2021–22	This is a categorical variable for student gender. Students were asked on the student survey, “Which of the following best describes you?” and were provided the following options: female, male, I prefer to self-describe (please specify), I choose not to share, and I am not sure. Students could also skip the question. If students provided a write-in option that aligned closely with either “male” or “female” as listed on the survey, SRI researchers assigned the student as such. We also created a new category called “Self-described as a gender not listed on survey” for students who wrote in a gender not listed on the on the survey. Using these data, we made three categories as follows: Male Female Self-described as a gender not listed on survey; Chose not to share; Not sure; Skipped question
Home Language	Categorical	All students	Student survey	2021–22	This is a categorical variable for the languages students speak with their family. Students were asked on the student survey to identify which languages they speak from the following options: Cantonese, English, Mandarin, Spanish, Tagalog, or, I speak another language (please specify). Students could also skip the question. These four languages were included on the survey as they are commonly spoken languages in the study states. If

Variable Name	Type	Availability	Source	Year	Variable Description
					students provided a write-in option that aligned closely with any of the languages identified on the survey, SRI researchers assigned the student as a speaker of that language. We also created a new category called “Speaks a language other than those listed on the survey” for students who wrote in a language not specified on the on the survey. Using these data, we made three categories as follows: English only: Students who reported only speaking English with their families. At least one language other than English: Students who reported speaking at least one language other than English, that is, speaking Cantonese, Mandarin, Spanish, Tagalog, or another language that was not listed on the survey. This category includes students who only speak a language other than English as well as those are multilingual. Unable to determine or skipped the question: Students whose write in option was not able to be categorized into a language listed on the survey or another known language, or students who skipped the question.
Family Engagement with School	Categorical	All students	Student survey	2021–22	This is a categorical variable whose values correspond with Likert scale responses for the question, “How often do you talk about things you have studied in school with someone in your family?” Students were provided the following options: never or hardly ever, once every few weeks, about once a week, two or three times a week, or every day. Students who skipped the question were categorized as Skipped Question.
Class Subject	Categorical	All students	Teacher questionnaire	2021–22	This variable identifies the class subject for the course in which students completed their data collection activities. Class subjects were derived using data from the baseline teacher questionnaire, in which teachers were asked about the class subject for each of the classes participating in the study. Teachers chose from the following options: self-contained class, math, STEM, science, computer science, engineering other (please specify). Class subjects were defined as follows: Self-contained STEM Math Science Other subject (if the teacher selected computer science or other [please specify]). Examples of other subject areas include art, engineering, technology, AVID, or computer science. If a student had multiple classes with teachers in the study (either multiple classes with the same teacher, or classes with more than one study teacher), SRI researchers used the subject of the class in which they completed their baseline student survey. Given that this variable was constructed for each class, this variable may vary within teachers who taught multiple classes.

Variable Name	Type	Availability	Source	Year	Variable Description
Baseline Assessment Scores	Continuous	MPACT students only	Student assessment	2021–22	For MPACT students, this variable is a continuous variable for students' score on the baseline student assessment. Assessments were calculated as percents for the number of points a student earned out of the total number of possible points. As the assessments differed between grades 4 and 5, when analyzing the data, the percentages were standardized within-grade as *z*-scores.
Number of MPACT Modules Engaged In	Categorical	MPACT students only	Teacher questionnaire	2021–22	For MPACT students, this variable captures the number of MPACT modules a student engaged in, ranging from 0 to 3. The spring teacher questionnaire asked each MPACT Fellow which modules they implemented in each of their study classes. Using this data, SRI researchers determined, for each of an MPACT Fellows' classes, whether the teacher had implemented no modules, any one module, any two modules, or all three modules. Students assigned to a given class were assigned this value for the number of modules they would have had the opportunity to engage in.

Appendix A2: Teacher Covariate Definitions

Variable Name	Type	Availability	Source	Year	Variable Description
Subject Area	Categorical	All teachers	Teacher questionnaire	2021–22	This is a categorical variable for a teacher's primary subject area. On the fall teacher questionnaire, all teachers were asked to select the subjects they teach this year across any of their classes For MPACT Fellows, this included classes in which they were planning to teach MPACT as well as other classes. Teachers were asked to select all that applied from the following options: all core subjects, special education, English language arts, math, science, social studies, technology, STEM, or other (Please specify). Using these data, teachers' subject area was categorized as follows: Self-contained: Teacher selected "all core subjects" and/or any other subjects STEM: Teacher selected "STEM" and/or any other subjects, and the teacher was not classified as a self-contained teacher. Math: Teacher selected "math" and/or any other subjects, and the teacher was not classified as a self-contained teacher or a STEM teacher. Science: Teacher selected "science" and/or any other subjects, and the teacher was not classified as a self-contained, STEM teacher, or math teacher. Other subject: Teacher was not a self-contained, STEM, math, or science teacher. Teachers in this category selected one of more of the following categories: special education, English language arts, social studies, technology, or other. Some examples of other subjects teachers wrote in were art or AVID.
STEM Teacher	Binary	All teachers	Teacher questionnaire	2021–22	This variable equals 1 if the teacher was a STEM teacher and 0 if the teacher was not a STEM teacher. This is variable was derived from the Subject Area variable above. STEM teachers were identified as STEM teachers in the Subject Area variable. Non-STEM teachers were teachers whose subject area was self-contained, math, science, or other subject.
Experience Level	Binary	All teachers	Teacher questionnaire	2021–22	This variable equals 1 if the teacher was experienced and 0 if the teacher was a novice. We used teacher self-reported data on teachers' number of years of teaching experience. An experienced teacher was defined as a teacher with four or more years of teaching experience, and a novice teacher was defined as a teacher with less than four years of teaching experience. 2021–22 counted as one year.

Variable Name	Type	Availability	Source	Year	Variable Description
MPACT Implementation	Categorical	MPACT Fellows only	Teacher questionnaire	2021–22	This variable captures the number of MPACT modules that MPACT Fellows implemented across any of their classes (if they taught multiple classes with the MPACT curriculum). We define the following variables: Did not teach any MPACT modules: Teacher did not teach any module in any of their classes. Taught exactly 1 module in at least one class: Teacher taught any one module in at least one of their classes. Taught exactly 2 modules in at least one class: Teacher taught any two modules in at least one of their classes. Taught all 3 modules in at least one class: Teacher taught all three modules in at least one class. Taught exactly 1 module in all of their classes Taught exactly 2 modules in all of their classes Taught all 3 modules in all of their classes.
Grade Level Taught	Binary	All teachers	Teacher questionnaire	2021–22	This is a set of binary variables indicating the grade levels that teachers taught in the 2021–22 school year. For each study grade level (4–7), we created a binary variable equal to 1 if a teacher taught the grade level. Grade levels outside of those in the study were not included. Only classes participating in data collection were included when determining teachers' grade levels. For MPACT Fellows, this included all classes in which they were implementing MPACT. For comparison teachers, this included classes they chose for data collection.
Teacher Baseline Attitudes	Continuous	MPACT Fellows only	Teacher questionnaire	2021–22	These are four continuous variables capturing MPACT Fellows' baseline perceptions of and efficacy in programmatic concepts. Using factor analysis, SRI researchers constructed four continuous factors for each of the four constructs measured on the teacher questionnaire, namely, teachers' perceptions of teaching math, perceptions of and efficacy in teaching computational thinking, perceptions of teaching spatial reasoning, and efficacy in teaching using the design cycle. Each construct contained 3–4 items in the final factor. For a teacher to be assigned a value for a given factor, the teacher must have answered at least 80% of items in the factor. The items within each factor were determined using confirmatory factor analyses conducted in 2020–21.

Appendix A3: School Covariate Definitions

Variable Name	Type	Availability	Source	Year	Variable Description
School Type	Binary	All schools	National Center for Education Statistics (NCES)	2020–21	This variable equals 1 for middle school and 0 for elementary school. Middle schools were identified using data from the Common Core of Data (CCD) and NCES. Middle schools were those that had both grades 7 and 8 (traditional middle school grades), while elementary schools were those that had grades 4–7 but did not have grade 8.
STEM School	Binary	All schools	Teacher questionnaire	2021–22	This variable equals 1 for a STEM school and 0 for a non-STEM school. The variable was constructed using teacher-reported data on whether their school is a designated STEM school. For a few schools where teachers in the same school had differing answers about whether the school was a STEM school, SRI researchers reviewed the school's website and looked for the term "STEM" in the title or school description.
Urbanicity	Binary	All schools	NCES	2020–21	This variable equals 1 if the school is a rural school and 0 if the school is a non-rural school. School urbanicity was identified using CCD data. Rural schools were those whose NCES locale code was 32, 33, 41, 42, or 43. Defined as such, rural schools include all schools defined as "rural" by CCD (locale codes 41–43), as well as schools in remote towns (locale code 33) and distant towns (locale code 32).
FRPL Quartile	Categorical	All schools	NCES	2020–21	This is a categorical variable equal to 1, 2, 3, or 4, corresponding to whether a school was in the bottommost, middle two, or topmost quartile based on the school's percentage of students eligible for free or reduced-priced lunch (FRPL), out of the distribution of peer schools in the country. This variable was constructed using data on the percentage of students eligible for FRPL in all 50 states and the District of Columbia from the CCD who had grades 4–7 students (i.e., schools that had grades comparable to those in the study schools). Using the distribution of schools' percentage of students eligible for FRPL, SRI researchers identified whether a study school was in the bottommost, middle two, or topmost quartile. *Note*: For four study schools from North Carolina, data on the number of students eligible for FRPL was missing from the CCD in 2020–21, as well as the three years prior. For these schools, we obtained data on the percentage of students eligible for the National School Lunch Program from the North Carolina Department of Public Instruction data repository.
Title I Status	Binary	All schools	NCES	2020–21	This variable is a binary variable equal to 1 if the school is a Title I school and 0 if the school is not a Title I school. Schools were identified as Title I using CCD data from NCES. Schools were classified as Title I if they were Title I schoolwide (Title I code 5) or were Title I schoolwide eligible schools (Title I code 4). *Note*: For 14 study schools in California, data on the school's Title I status was missing from the CCD dataset for 2020–21. For one of these schools, we obtained the school's 2020–21 Title I status from California's state education data repository (Ed Data). For the remaining 13 schools, we obtained the school's Title I status from the CCD data from 2019–20.

Appendix B: Detailed Student-Level Characteristics

Student-Level Characteristics	MPACT	Comparison	Overall
Race/Ethnicity			
American Indian or Alaska Native; Asian or Asian American; Middle Eastern or North African; Native Hawaiian or Pacific Islander; Self-described as a race/ethnicity not listed on survey; Chose not to share; Not sure; Skipped question	33.7%	28.7%	26.8%
American Indian or Alaska Native	1.7%	2.0%	1.9%
Asian or Asian American	2.4%	2.5%	2.4%
Middle Eastern or North African	0.3%	0.7%	0.5%
Native Hawaiian or Pacific Islander	0.6%	0.6%	0.6%
Self-described as a race/ethnicity not listed on survey; Chose not to share; Not sure; Skipped question	20.0%	22.9%	21.4%
Self-described as a race/ethnicity not listed on survey	1.9%	2.2%	2.0%
Chose not to share	9.2%	11.0%	10.0%
Not sure	9.1%	9.32%	9.18%
Skipped question	0.2%	0.6%	0.4%
Black or African American	15.0%	17.3%	16.0%
Latino/a, Latinx, Hispanic, or Spanish origin	19.8%	14.9%	17.5%
Two or more races	8.7%	9.0%	8.8%
White	31.7%	30.4%	31.1%
Gender			
Female	44.9%	45.8%	45.3%
Male	44.5%	44.4%	44.4%
Self-described as a gender not listed on survey; Chose not to share; Not sure; Skipped question	10.6%	9.9%	10.3%
Self-described as a gender not listed on survey	4.9%	6.0%	5.4%
Chose not to share	3.8%	3.0%	3.5%
Not sure	3.0%	2.1%	2.6%
Skipped question	0.2%	0.5%	0.3%
Home Language			
English only	67.9%	69.7%	68.7%
At least one language other than English	31.4%	29.2%	30.4%
Cantonese	0.2%	0.1%	0.1%
Mandarin	0.2%	0.5%	0.3%
Spanish	26.4%	20.4%	23.6%
Tagalog	0.4%	0.6%	0.5%
Speaks a different language than those listed	4.5%	7.9%	6.1%
Unable to determine or skipped question	0.2%	0.4%	0.3%
Total students	**1235**	**1084**	**2319**

Note. Exhibit displays item-level statistics for data on student characteristics collected from the student survey and teacher questionnaire for students' self-reported race/ethnicity, gender, and home languages. The exhibit displays item-level data as well as data on aggregate variables SRI researchers created for the purpose of this study. Rows that are indented were aggregated into the category listed above the first indented item. As the question asking students to provide their race/ethnicity was "select all that apply," the percentage of students who self-described as a race/ethnicity not listed on survey, chose not to share, were not sure, or skipped the question may exceed the row total in the aggregate category, as some students chose more than one of the former three options. For details on how variables were aggregated and for definitions on each variable, see Appendix A.

Appendix C. Fidelity of Program Implementation: Components and Indicators

Indicator Number	Indicator	Operational Definition of Indicator	Teacher-Level Threshold	Program-Level Threshold
Component 1: Teacher Professional Development				
1.1	MPACT Fellows participate in online professional development	Teachers either (1) attend two days of synchronous professional development in summer 2021; or (2) view makeup professional development videos and complete a brief check for understanding quiz[1]	Teacher completes one professional development option	At least 60% of sample teachers meet teacher-level threshold
1.2	MPACT Fellows use "just-in-time" professional development[2]	Teachers access just-in-time professional development supports, including MPACT online tutorials, MPACT online forums, MPACT website, support from TERC via email or call, other MPACT online resources, etc.	Teacher reports using at least one form of just-in-time professional development	At least 70% of sample teachers meet teacher-level threshold
1.3	MPACT Fellows review the curriculum guide and understand goals of modules	Teachers review all the lessons plans, including teacher notes, in the curriculum guide and understand the goals of the modules	Teacher agrees or strongly agrees that they reviewed lessons for their grade and understood goals of the modules	At least 70% of sample teachers meet teacher-level threshold
1.4	MPACT Fellows understand how to use and troubleshoot Tinkercad[3]	Skill with Tinkercad is not a barrier to implementation	Teacher reports that skill with Tinkercad is not a barrier or substantial barrier to MPACT implementation	At least 75% of sample teachers meet teacher-level threshold
1.5	MPACT Fellows understand how to use and troubleshoot 3D printers	Skill with 3D printer is not a barrier to implementation	Teacher reports that skill with 3D printer is not a barrier or substantial barrier to MPACT implementation	At least 75% of sample teachers meet teacher-level threshold
1.6	MPACT Fellows understand the design cycle[4]	Teachers understand the steps of the design cycle in which students manipulate real objects, model objects in Tinkercad, and print their 3D designs	Teacher agrees or strongly agrees they learned principles related to the design cycle	At least 75% of sample teachers meet teacher-level threshold
Component 2: Curriculum and Materials				
2.1	MPACT Fellows can access the MPACT curriculum (teacher notes, PowerPoints, student workbooks, etc.)	Teachers are able to access MPACT materials (teacher notes, PowerPoints, student workbook, etc.)	Teacher reports they are able to access the online MPACT materials	At least 75% of sample teachers meet teacher-level threshold
2.2	MPACT Fellows receive all MPACT materials	Teachers receive all materials needed to implement required	Teacher reports they received all maker materials in time and in enough quantity for	At least 75% of sample teachers meet teacher-level threshold

Indicator Number	Indicator	Operational Definition of Indicator	Teacher-Level Threshold	Program-Level Threshold
		modules in time and in enough quantity	classroom implementation as planned	
2.3	MPACT Fellows implement MPACT modules for their grade level	Teachers implement MPACT modules 1–3	Teacher reports they implemented MPACT modules 1–3 for their grade level in all classes in which they taught MPACT	At least 75% of sample teachers meet teacher-level threshold
2.4	MPACT Fellows report that students manipulate, model, and print 3D objects	Teachers report that students manipulate real objects, model objects in Tinkercad software, and have their models printed by the teacher as 3D tangible objects	Teacher reports that their students were able to do at least two of the following activities during the 2021–22 school year: (i) manipulate real objects; (ii) model objects in Tinkercad software; or (iii) have models printed as 3D objects	At least 65% of sample teachers meet teacher-level threshold
2.5	MPACT Fellows address math standards through implementation	Alignment of MPACT with curriculum or pacing guides is not a barrier to implementation	Teacher reports that alignment with curriculum or pacing guides is not a barrier or substantial barrier to MPACT implementation	At least 75% of sample teachers meet teacher-level threshold
Component 3: STEM Industry Mentors				
3.1	Students have the opportunity to engage with STEM industry mentors	Teachers are provided at least three different opportunities for students to engage with mentors	Teacher reports they are aware of at least three opportunities for their students to learn about or interact with mentors provided by TERC	70% of sample teachers meet teacher-level threshold
3.2	Students engage with mentors	Students learn about or interact with mentors	Teacher reports that at least some of their students learned about or interacted with mentors using at least one of the opportunities provided by TERC	At least 75% of sample teachers meet teacher-level threshold

Note. This exhibit shows each component of the fidelity of implementation analysis and the indicators within each component. We ran the fidelity of implementation analysis on the sample of 43 MPACT Fellows participating in the study in the 2021–22 school year.

[1]We asked MPACT Fellows who completed their module 3 professional development to complete a short check for understanding to signify their completion of the module 3 makeup professional development, which was virtual and asynchronous. After viewing a professional development video, MPACT Fellows answered four closed-ended items and three open-ended items. The closed-ended items asked MPACT Fellows about their understanding of key concepts in module 3 for their grade level, including the main math topic covered, the project for the module, and sources of support for implementing the module. The open-ended items asked MPACT Fellows to identify what students were learning in module 3 that was distinct from modules 1 and 2, to reflect on what their students may find challenging in module 3, and how they may support them.

[2]Just-in-time professional development refers to supports that are readily accessible to teacher, including online tutorials and videos available on the MPACT website and direct support from the MPACT team.

[3]Tinkercad is an online 3D modeling program.

[4]In each module, students engage in multi-lesson design cycles in which they collect ideas, make and remake prototypes, design on paper, design in Tinkercad, and make a tangible 3D-printed object.

Appendix D. Student Survey Constructs

Construct	Instrument Name	Instrument Source(s)	Alpha (From Initial Validation)	Alpha (From MPACT Study)
Behavioral Engagement in Math	Engagement vs. Disaffection with Learning Student-Report Survey. Bank of questions about behavioral engagement in school.	Skinner, E. A., Kindermann, T. A., & Furrer, C. J. (2009). A motivational perspective on engagement and disaffection. *Educational and Psychological Measurement, 69*(3), 493–525. https://doi.org/10.1177/0013164408323233	α = 0.61–0.71	α = 0.81–0.84
Behavioral Disaffection in Math	Engagement vs. Disaffection with Learning Survey. Bank of questions about behavioral disaffection in school.	Skinner, E. A., Kindermann, T. A., & Furrer, C. J. (2009). A motivational perspective on engagement and disaffection. *Educational and Psychological Measurement, 69*(3), 493–525. https://doi.org/10.1177/0013164408323233	α = 0.71–0.78	α = 0.70–0.77
Math Self-Efficacy	Patterns of Adaptive Learning Scale (PALS) as adapted by Griggs et al. (2013) for math classes.	Midgley, C., Maehr, M. L., Hruda, L. Z., Anderman, E., Anderman, L., Freeman, K. E., Gheen, M., Kaplan, A., Kumar, R., Middleton, M. J., Nelson, J., Roeser, R., & Urdan, T. (2000). *Manual for the Patterns of Adaptive Learning Scales*. University of Michigan. http://www.umich.edu/~pals/PALS%202000_V13Word97.pdf Griggs, M. S., Rimm-Kaufman, S. E., Merritt, E. G., & Patton, C. L. (2013). The responsive classroom approach and fifth grade students' math and science anxiety and self-efficacy. *School Psychology Quarterly*, *28*(4), 360–373. https://doi.org/10.1037/spq0000026	α = 0.78–0.82	α = 0.84–0.87
Math Self-Concept	Programme for International Student Assessment (PISA 2003) question bank on math self-efficacy.	Schulz, W. (2005, April 11–15). *Mathematics self-efficacy and student expectations: Results from PISA 2003* [Paper presentation]. Annual Meeting of the American Educational Research Association, Montreal, Canada. https://eric.ed.gov/?id=ED490044	α = 0.83	α = 0.83–0.85

Note. This exhibit shows the survey constructs used in the student survey instrument. For each construct, the exhibit displays the original instrument the construct is derived from, the construct validation from the original instrument, and the construct validation from the present study. For both the original instrument validation and the MPACT study, Cronbach's alphas are shown as ranges representing alpha values from the baseline and outcome administration.

Appendix E. Model Covariates

Appendix E1: Student Covariates

Covariate Name	Confirmatory Student Impacts Using Student Survey		Exploratory Teacher Impacts Using Teacher Questionnaire		Exploratory Student Impacts Using Student Assessment	
	(a)	(b)	(a)	(b)	(a)	(b)
	Control Variables in Impact Analysis	**Subgroup Analyses**	**Control Variables in Impact Analysis**	**Subgroup Analyses**	**Control Variables in Impact Analysis**	**Subgroup Analyses**
Survey Baseline Factor						
Behavioral engagement in math	x					x
Behavioral disaffection in math	x					x
Math self-efficacy	x					x
Math self-concept	x					x
Grade						
4	x	x			x	x
5	x	x			x	x
6	x	x			x	x
7	x	x			x	x
Unknown grade	x					
Race/Ethnicity						
American Indian or Alaska Native	x					
Asian or Asian American	x					
Black or African American	x	x				x
Latino/a, Latinx, Hispanic, or Spanish origin	x	x				x
Middle Eastern or North African	x					
Native Hawaiian or Pacific Islander	x					
Two or more races	x	x				x
White	x	x				x
Self-described as a race/ethnicity not listed on survey; Chose not to share; Not Sure; Skipped question	x					
American Indian or Alaska Native; Native Hawaiian or Pacific Islander; Asian; Middle Eastern or North African; Self-described as a race/ethnicity not listed on survey; Chose not to share; Not sure; Skipped question		x				x
Gender						
Female	x	x				x
Male	x	x				x

Covariate Name	Confirmatory Student Impacts Using Student Survey		Exploratory Teacher Impacts Using Teacher Questionnaire		Exploratory Student Impacts Using Student Assessment	
	(a)	(b)	(a)	(b)	(a)	(b)
	Control Variables in Impact Analysis	**Subgroup Analyses**	**Control Variables in Impact Analysis**	**Subgroup Analyses**	**Control Variables in Impact Analysis**	**Subgroup Analyses**
Self-described as a gender not listed on survey; Chose not to share; Not sure; Skipped question	x	x				x
Home Language						
English only	x	x				x
At least one language other than English	x	x				x
Unable to determine or skipped question	x					
Family Engagement With School						
Never or hardly ever	x	x				x
Once every few weeks	x	x				x
About once a week	x	x				x
Two or three times a week	x	x				x
Every day	x	x				x
Skipped question	x					
Class Subject						
Self-contained class	x	x				x
STEM	x	x				x
Math	x	x				x
Science only	x	x				x
Other subject	x	x				x
Baseline Assessment Scores						
Q1 (Bottom quartile)					x	
Q2					x	
Q3					x	
Q4 (Top quartile)					x	
Number of MPACT Modules Engaged In						
Exactly 0 modules		x				x
Exactly 1 module		x				x
Exactly 2 modules		x				x
All 3 modules		x				x

Note. Exhibit shows the student-level covariates used in the confirmatory and exploratory student impact analyses and exploratory teacher impact analyses. For each analysis, columns labeled "a" show the control variables used, and columns labeled "b" show the variables used in subgroup analyses. Subgroup analyses for confirmatory student impacts and exploratory teacher impacts are available upon request. For details on how a given variable was constructed, see Appendix A.

Appendix E2: Teacher Covariates

Covariate Name	Confirmatory Student Impacts Using Student Survey		Exploratory Teacher Impacts Using Teacher Questionnaire		Exploratory Student Impacts Using Student Assessment	
	(a)	(b)	(a)	(b)	(a)	(b)
	Control Variables in Impact Analysis	**Subgroup Analyses**	**Control Variables in Impact Analysis**	**Subgroup Analyses**	**Control Variables in Impact Analysis**	**Subgroup Analyses**
Subject Area						
Self-contained		x		x		x
STEM		x		x		x
Math		x		x		x
Science only		x		x		x
Other subject		x		x		x
STEM Teacher						
STEM		x		x		x
Not STEM		x		x		x
Experience Level						
Novice (< 4 years)	x	x	x	x		x
Experienced (4 + years)	x	x	x	x		x
Grade Levels Taught						
Grade 4		x	x	x		x
Grade 5		x	x	x		x
Grade 6		x	x	x		x
Grade 7		x	x	x		x
Teacher Questionnaire Baseline Factors						
Teacher perceptions of teaching math			x			
Teacher perceptions of and efficacy in teaching computational thinking			x			
Teacher perceptions of teaching spatial reasoning			x			
Teacher efficacy in teaching using the design cycle			x			
MPACT Implementation						
Did not teach MPACT in any class		x		x		x
Taught exactly 1 module in all classes		x		x		x
Taught exactly 2 modules in all classes		x		x		x
Taught all 3 modules in all classes		x		x		x
Taught exactly 1 module in at least one class		x				x
Taught exactly 2 modules in at least one class		x				x
Taught all 3 modules in at least one class		x				x

Note. Exhibit shows the teacher-level covariates used in the confirmatory and exploratory student impact analyses and exploratory teacher impact analyses. For each analysis, columns labeled "a" show the control variables used, and columns labeled "b" show the variables used in subgroup analyses. Subgroup analyses for confirmatory student impacts and exploratory teacher impacts are available upon request. For details on how a given variable was constructed, see Appendix A.

Appendix E3: School Covariates

Covariate Name	Confirmatory Student Impacts Using Student Survey		Exploratory Teacher Impacts Using Teacher Questionnaire		Exploratory Student Impacts Using Student Assessment	
	(a)	(b)	(a)	(b)	(a)	(b)
	Control Variables in Impact Analysis	**Subgroup Analyses**	**Control Variables in Impact Analysis**	**Subgroup Analyses**	**Control Variables in Impact Analysis**	**Subgroup Analyses**
School Type						
Middle school	x	x	x	x		x
Elementary school	x	x	x	x		x
STEM School						
STEM	x	x	x	x		x
Not STEM	x	x	x	x		x
Urbanicity						
Rural	x	x	x	x		x
Non-rural	x	x	x	x		x
FRPL Quartile						
Q1 (lowest rates of FRPL)	x	x	x	x		x
Q2	x	x	x	x		x
Q3	x	x	x	x		x
Q4 (highest rates of FRPL)	x	x	x	x		x
Title I						
Title I	x	x		x		x
Not Title I	x	x		x		x

Note. Exhibit shows the school-level covariates used in the confirmatory and exploratory student impact analyses and exploratory teacher impact analyses. For each analysis, columns labeled "a" show the control variables used, and columns labeled "b" show the variables used in subgroup analyses. Subgroup analyses for confirmatory student impacts and exploratory teacher impacts are available upon request. For details on how a given variable was constructed, see Appendix A.

Appendix F. Teacher Questionnaire Constructs

Construct	Items in Construct	Source	Cronbach's Alpha From MPACT Study
Teacher perceptions of teaching math	Please indicate the extent to which you agree with the following statements about teaching math: - I really enjoy teaching mathematics. - I look forward to mathematics lessons. - I like preparing and planning my mathematics lessons. - Having strong mathematics skills will help students in their future careers.	Frenzel, A. C., Goetz, T., Lüdtke, O., Pekrun, R., & Sutton, R. E. (2009). Emotional transmission in the classroom: Exploring the relationship between teacher and student enjoyment. *Journal of Educational Psychology*, *101*(3), 705–716. https://doi.org/10.1037/a0014695 Russo, J., Bobis, J. Sullivan, P., Downton, A., Livy, S., McCormick, M., & Hughes, S. (2019). Exploring the relationship between teacher enjoyment of mathematics, their attitudes toward student struggle and instructional time amongst early years primary teachers. *Teaching and Teacher Education*, *88*, 1–9. https://doi.org/10.1016/j.tate.2019.102983	α = 0.88–0.89
Teacher perceptions of and efficacy in teaching computational thinking	Please indicate the extent to which you agree with the following statements about computational thinking: - Computational thinking skills are malleable and can be learned. - I am comfortable teaching computational thinking. - I am comfortable designing tasks/activities where students can practice computational thinking without using computers. - I am comfortable designing tasks/activities where students can practice computational thinking without problem-solving.	Yadav, A., Mayfield, C., Zhou, N., Hambrusch, S., & Korb, J. T. (2014). Computational thinking in elementary and secondary teacher education. *ACM Transactions on Computing Education*, *14*(1), 1–16. https://doi.org/10.1145/2576872	α = 0.74–0.80
Teacher perceptions of spatial reasoning	Please indicate the extent to which you agree with the following statements about teaching and applying spatial reasoning: - Spatial reasoning is malleable and can be learned. - If students improve their spatial reasoning, they are likely to get better at math. - Students should regularly practice spatial reasoning.	Pollitt, R., Cohrssen, C., & Seah, W. T. (2020). Assessing spatial reasoning during play: Educator observations, assessment, and curriculum planning. *Mathematics Education Research Journal*, *32*(3), 331–363. https://doi.org/10.1007/s13394-020-00337-8 Burte, H., Gardony, A. L., Hutton, A., & Taylor, H. A. (2020). Elementary teachers' attitudes and beliefs about spatial thinking and mathematics. *Cognition*	α = 0.78–0.86

Construct	Items in Construct	Source	Cronbach's Alpha From MPACT Study
	- Strong spatial reasoning will help students in their future careers.	*Research: Principles and Implication*, *5*(1), Article 17. https://doi.org/10.1186/s41235-020-00221-w	
Teacher efficacy in teaching using the design cycle	Please indicate the extent to which you agree with the following statements about incorporating the design cycle into your teaching: - I am comfortable developing lessons that ask students to engage in a design cycle. - I am comfortable explaining the design cycle in STEM lessons. - I am comfortable teaching students to apply the design cycle in STEM lessons	Foster, M. K. (2021). Design thinking: A creative approach to problem solving. *Management Teaching Review*, *6*(2), 123–140. https://doi.org/10.1177/2379298119871468	α = 0.94–0.95

Note. For each construct, the exhibit displays the items within each construct, the original instrument(s) used to derive these constructs, and construct validation (shown using Cronbach's alphas) from the MPACT study. Cronbach's alphas from the MPACT study are presented as a range representing the alphas for the analytic sample from the fall 2021 and spring 2022 administration. In creating constructs for the teacher questionnaire, SRI researchers used multiple strategies, including using exact items from preexisting surveys, modifying items, or writing new items using ideas and concepts measured in prior literature. Therefore, we do not present Cronbach's alphas for question banks used to derive our constructs, given that several adaptations were made to the original constructs or items.

Appendix G. Fidelity of Program Implementation, 2021–22

Indicator Number	Indicator	% Teachers Meeting Program Threshold	Program Threshold (%)	Indicator Met?
Component 1: Teacher Professional Development				
1.1	MPACT Fellows participate in online professional development	93.0%	60%	Yes
1.2	MPACT Fellows use “just-in-time” professional development	97.7%	70%	Yes
	MPACT Fellows review the curriculum guide and understand goals of modules	88.4%	70%	Yes
	MPACT Fellows understand how to use and troubleshoot Tinkercad	90.7%	75%	Yes
	MPACT Fellows understand how to use and troubleshoot 3D printers	79.1%	75%	Yes
1.6	MPACT Fellows understand the design cycle	88.4%	75%	Yes
Component 2: Curriculum and Materials				
2.1	MPACT Fellows can access the MPACT curriculum (teacher notes, PowerPoints, student workbooks, etc.)	95.4%	75%	Yes
2.2	MPACT Fellows receive all MPACT materials for their grade level	90.7%	75%	Yes
2.3	MPACT Fellows implement MPACT modules	48.8%	75%	No
2.4	MPACT Fellows report that students manipulate, model, and print 3D objects	95.4%	65%	Yes
2.5	MPACT Fellows address math standards through implementation	95.4%	75%	Yes
Component 3: STEM Industry Mentors				
3.1	Students have the opportunity to engage with STEM industry mentors	55.8%	70%	No
3.2	Students engage with mentors	60.4%	75%	No

Note. Exhibit shows the indicator-level results for the fidelity of implementation analysis for the 2021–22 school year. The sample includes the 43 MPACT Fellows in the teacher impact sample. For each indicator, SRI researchers calculated whether a given teacher met the indicator. Next, we calculated the percentage of teachers in the sample who met the teacher-level threshold and compared this percentage with the program-level threshold. As a sensitivity check, we also calculated the percentage of teachers meeting the program threshold using two additional samples—the first, a sample that excluded teachers who had any missing data on any questionnaire item required to assess any indicator (n = 38); and the second, a sample of all teachers who answered at least one question on the baseline and outcome teacher questionnnaire (n = 44), regardless of whether they were included in the teacher impact sample. The results of these sensitivity analyses indicated no notable changes in the percentage of teachers meeting any indicator. Results of these sensitivity checks are available upon request.

Appendix H: MPACT Program Math Concepts and Activities, by Grade

Content or Module	Grade 4	Grade 5	Grade 6	Grade 7
Math Content	Symmetry and angle measurement	Volume and linear measurement	Volume, surface area, and linear measurement	Probability and scale drawings
Module 1	Make a Bookmark	Make a Bookmark	Make a Bookmark	Make a Bookmark
Module 2	Make a Kite from a Single Piece of Paper	Make a Soma Cube Puzzle	Make a Soma Cube Puzzle and a Box to Keep it in	Make Dice for the Sighted and the Blind
Module 3	Make a Stamp to Print With	Make a Toy on Wheels for a Younger Child	Make a Mobile for A Community Center	Modify a Game to be Played by the Sighted and the Blind

Note. This exhibit shows the math content included in each grade level unit and how modules align across grade levels.