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Curriculum Materials Make a Difference for Next Generation Science Learning:

Results from Year 1 of a Randomized Control Trial

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Contents

Executive Summary

This report describes findings from a study of middle school science curriculum materials. In the study, middle school science teachers who used curriculum materials that presented opportunities for students to engage in science practices improved their students' performance on next generation science assessments. The study took place in a large urban district and was conducted by researchers at SRI international, University of Colorado Boulder, and Michigan State University with support from a grant by the National Science Foundation.

The context of the study makes the findings particularly important for policy and practice. Students in urban schools typically have limited access to full sets of current, high quality science curriculum materials. In addition, the middle school years are a critical time for engaging students in learning science: educational research shows a steep decline in science interest and achievement among middle grades students. This decline is especially pronounced in large urban school districts with high percentages of students from low-income families and students from groups that are underrepresented in science, technology, engineering, and mathematics (STEM) fields. The positive impact found in this study shows that it is possible for high-quality materials to improve achievement in science in this type of setting.

The curriculum that was the focus of this study, *Project-Based Inquiry Science*, provides structured opportunities for students to engage in two key science practices emphasized in the *Framework for K-12 Science Education (Framework)*—constructing explanations and developing and using models. The *Framework* was used to develop the *Next Generation Science Standards (NGSS)*, and it emphasizes student engagement with eight science and engineering practices as essential to developing proficiency in science. The practices that the *Project-Based Inquiry Science* materials address are not typically emphasized either in traditional textbooks or kit-based science curricula.

To measure the impact of the curriculum materials, the researchers conducted a randomized controlled trial in sixth grade science classrooms across 42 schools in one large urban school district. All of the district's middle schools were randomly assigned to one of two implementation conditions, a treatment condition under which sixth grade science teachers implemented the project-based science curriculum, or a comparison condition under which sixth grade science teachers implemented the district's standard science curriculum. Science teachers in both conditions implemented curricular units on the same science topics in physical science and in Earth science. The researchers provided teachers in both curricular conditions with professional development on the *Framework*.

Students who participated in the project-based science curriculum outperformed students in the comparison curriculum on outcome measures that were aligned to core ideas and science practices in the *Framework*. In order to permit a fair comparison between conditions, the science content topics covered on the outcome measures were addressed in both the project-based science curriculum and the standard science (comparison) curriculum. Moreover, the science content topics addressed in the outcome measures were also aligned to the school district's own state science standards. Finally, the science practices addressed in the study's measures were introduced to teachers in both curricular conditions through professional development on the *Framework* prior to implementation.

These results show that science curriculum materials that include opportunities for students to engage in science practices, in ways similar to those recommended by the *Framework* and embodied in the new national standards, can prepare students for next generation science learning. The results also show that research-based curriculum materials can impact teaching practice by providing resources that make it more likely that they will engage students in science practices.

Study Context

Main Finding

Curriculum materials with opportunities to engage in science practices are shown to have a positive impact on next generation science learning outcomes.

The *Framework for K-12 Science Education* (National Research Council [NRC], 2012) presents a new challenge to education: to deepen all students' understanding of disciplinary core ideas through active engagement in science and engineering practices and application of crosscutting concepts. The *Framework* emphasizes that science is not just a body of knowledge but also a set of practices for investigating, modeling, and explaining phenomena in the natural world. In addition, it calls for a focus on a limited number of disciplinary core ideas and crosscutting concepts that are explored through science and engineering practices over multiple years, so that students have opportunities to build knowledge and revise their understanding over time.

The *Framework* is the guiding document for the new *Next Generation Science Standards* (NGSS). Realizing the vision of the *Framework* is likely to require significant changes to curriculum and instruction. Today, few students have opportunities to engage deeply in science and engineering practices, particularly those essential to developing science knowledge: developing and using models, constructing explanations, and engaging in argument from evidence (Banilower et al., 2013). Instead, most traditional science instruction emphasizes memorization of discrete facts and focuses on a broad range of topics (Schmidt, McKnight, & Raizen, 1997).

Research shows that curriculum materials can both help teachers make these kinds of changes to instruction and help students learn science. To be effective, materials must engage students in science and engineering practices, stress connections among disciplinary core ideas and practices, and highlight crosscutting concepts (Krajcik, McNeill, & Reiser, 2008). For teachers to use such materials effectively, moreover, teachers need access to high-quality professional development of extended duration that is focused on the science content to be taught (Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Penuel & Gallagher, 2009; Roth et al., 2011).

To realize the vision of the *Framework*, all students will need opportunities to learn from encounters with high-quality curriculum materials where they engage in science and engineering practices. This will require expanded access to research-based materials, such as those developed with funding from the National Science Foundation. At present, just six percent of middle school teachers report having access to such materials, and more than half report that their textbooks are more than eight years old (Banilower et al., 2013). In the coming years, new materials that are more fully aligned with the vision of the *Framework* and *NGSS* will need to be developed. In the meantime, equity can be improved by expanding teachers' access to professional development in the *Framework* and increasing students' access to materials that provide at least some opportunities to engage with core ideas, science and engineering practices and crosscutting concepts.

In this study, we investigated the impact of a comprehensive research-based curriculum called *Project-Based Inquiry Science* in a large urban school district. The curriculum materials provide significant opportunities to engage in two key science practices—constructing explanations and developing and using models—that are emphasized within the *Framework*. The district where we conducted our study is one with a high percentage of students from low-income families and students from groups that are underrepresented in science, technology, engineering and math (STEM) fields. Our findings from the first year of the study, detailed in this report, show that the materials can have a positive impact on teaching and next generation science learning outcomes.

Research Questions

Our study is designed to answer three research questions:

1. How can curriculum materials support student science learning that integrates core ideas, science and engineering practices, and crosscutting concepts?
2. How can curriculum materials support improvements to teachers' instruction?
3. How do improvements in teachers' instruction relate to student learning outcomes?

Study Design

We conducted a randomized experiment in sixth grade science classrooms across 42 schools in one large urban school district to test the impact of the curriculum materials. We randomly assigned schools to either a treatment or comparison condition; all sixth-grade science teachers in a given school had the same assignment. The treatment condition teachers implemented the project-based science curriculum and received professional development in the *Framework for K-12 Science Education* and in the use of the curriculum materials. The comparison condition teachers received professional development in the *Framework*, but they implemented the district-adopted textbook from the McDougall-Littell series with their students. Teachers in both groups were asked to implement curricular units on the same science topics in physical science and Earth science. In addition, all teachers were asked to follow their district science sequence and curricular pacing guide.

Setting and Participants

The school district where we conducted the study is highly diverse. It is comprised of 42% African American, 32% White, 18% Hispanic/Latino, and 6% Asian American students. District-wide, 54.7% of students are eligible for free or reduced-price lunch.

All middle schools in the district were invited to participate in the study and randomly assigned to either the treatment or comparison condition. We compiled rosters for each school and identified a total of 57 sixth-grade science teachers in 21 schools assigned to the treatment condition and 51 sixth-grade science teachers in 21 schools assigned to the comparison condition. A total of 57 treatment teachers and 46 comparison teachers consented to participate in the study. Of these, 55 treatment teachers and 39 comparison teachers contributed data to the study. This represented 96% of treatment teachers and 85% of comparison teachers rostered in the district. Of the nine teachers who consented to participate but did not contribute data to the study, eight of these were teachers who were either reassigned out of sixth grade science or left the district during the school year. Each teacher in the study selected one of their classes to be their “study class” from which student data was collected. More than 2,400 students participated in these study classes.

Curriculum Materials Provided to All Teachers in the Treatment Condition

Project-Based Inquiry Science (PBIS) is a comprehensive, 3-year middle school science curriculum that is sold and distributed by It's About Time® publishers (www.iat.com). The curriculum is comprised of 8-10 week units in life, physical, and Earth science, spanning Grades 6 through 8. The units were developed through funding from the National Science Foundation, with major investments made in the design of the materials and with associated professional development for teachers to understand the content of the units and how to teach them.

PBIS curricular units present challenges in which students investigate phenomena and apply concepts to answer a driving question or to achieve a design challenge. The driving question or challenge typically targets a core idea in science, and the activities within each unit provide students with multiple occasions for investigating as scientists would—through observations, asking questions, designing and carrying out experiments, analyzing data, building and using models, and constructing scientific explanations. With a strong focus on important science content and integrating scientific practices, the PBIS curriculum's design matches well with the new directions in science education.

The PBIS units that we studied are in the areas of physical science (energy) and Earth science (processes that shape Earth's surface). The energy unit (2012) is organized around the ideas of energy, conservation of energy, and energy transfer. Students engage in multiple investigations and activities and take on the challenge of designing a Rube Goldberg machine capable of turning off a light. The Earth science unit (2010) focuses on processes within Earth, such as the movement of tectonic plates that cause geologic activity. In this unit, students engage in a sequence of investigations and activities in pursuit of answers to the driving question, "What processes within the Earth cause geologic activity?" The materials for both units include a teacher's guide, student text, and accompanying student materials for conducting investigations.

Curriculum Materials Available to All Teachers in the Comparison Condition

Teachers in the comparison condition used the district-adopted textbook, McDougall Littell's (2005) Science for Grade 6. The textbook teaches content and skills found in the district's home-state standards and earlier standards documents, including the *National Science Education Standards* (National Research Council, 1996) and the Project 2061 *Benchmarks for Science Literacy* (AAAS, 1993). It is organized around big ideas, such as "The movement of tectonic plates causes geologic changes on Earth" (Earth science) and "Waves transfer energy and interact in predictable ways" (physical science). Like most other statements of learning goals found in contemporary science textbooks, the big ideas and key concepts do not blend disciplinary core ideas, practices, and crosscutting concepts. Also, like other standard textbooks, the big ideas are presented as expository text, supplemented by rich graphical displays and pictures. The textbook also includes a number of brief investigations for hands-on experiences related to key concepts.

Professional Development Provided to Teachers in the Treatment Condition

Teachers in the treatment condition were invited to participate in a series of PBIS curriculum-focused workshops provided by the publisher. The workshops took place at three time points during the school year and ranged between 1-3 days. The content of each of the workshops was aligned with the district's curricular pacing guide.

The first workshop was held over three days. This workshop was designed to introduce teachers to the curriculum and the introductory unit they would teach. The second and third workshops were one day each in duration. An October workshop prepared teachers for the physical unit (*Energy*); a January workshop prepared teachers for the Earth Science unit (*Ever-changing Earth*). Across all three workshops, teachers had opportunities to learn about the design principles underlying the curriculum. Professional development workshop leaders emphasized connections between the *Framework for K-12 Education* and curriculum activities and structures, with particular attention given to the role of scientific practices of explanation and modeling within the curriculum. Teachers worked as their students might through condensed versions of the curriculum units they would teach. They were additionally given an opportunity to align the new curriculum with their district pacing guide within small groups and in collaboration with district personnel. Teachers who did not attend a given workshop were offered an opportunity to attend a make-up session.

A total of 53 teachers attended either the 3-day summer workshop or accompanying make-up session (48 and 5, respectively). A total of 48 teachers attended the October school-year workshop, and 47 teachers attended the January workshop.

Professional Development Provided to Teachers in Both Conditions

We invited teachers in both the treatment and comparison conditions to participate in a two-day workshop focused on the *Framework*. The workshop was held prior to the beginning of the school year. All teachers who attended the workshop received a complimentary copy of the *Framework for K-12 Science Education* (NRC, 2012). The professional development activities in the workshop emphasized the *Framework* vision; learning about disciplinary core ideas through driving questions; science practices, with particular emphasis on developing and using models; and how core ideas, practices and crosscutting concepts could be integrated as part of instruction.

A major focus of the professional development was on developing and using models. In the workshop, teachers had practice developing and revising models and writing scientific explanations related to material they were required to teach (per state standards). For example, during the workshop, teachers worked in small groups on an activity addressing the particle nature of matter from the *Investigating and Questioning our World Through Science and Technology* curriculum (Krajcik, Reiser, Sutherland, & Fortus, 2013). In these small groups, teachers created models of what happens to air inside a syringe when the syringe plunger is pushed and pulled. Teachers then shared and compared those models with their colleagues – presenting their small group work with the larger group.

Teachers who did not attend the two-day workshop were invited to attend a make-up session. A total of 40 teachers from the treatment condition and 32 teachers from the comparison condition participated in the *Framework* workshop. Teachers from both conditions who did not attend the two-day workshop or make-up session were provided with all the workshop materials, including a copy of the *Framework*.

Measures

The study included multiple measures of student learning outcomes and teaching practice. Below, we describe two sets of measures used in this analysis: two end-of-unit assessments of student learning and instructional logs of teacher practice.

Student Learning Measures

In conducting this study, we developed measures that were instructionally sensitive to both conditions (DeBarger, Penuel, & Harris, 2013). This approach reflects a basic principle of fairness: students cannot be expected to know what they have not had an opportunity to learn. In order to permit a fair comparison between conditions, the science core ideas covered on the outcome measures were aligned to the *Framework* and addressed in both the project-based science curriculum and the standard science (comparison) curriculum. Moreover, the science content topics addressed in the outcome measures were also aligned to the school district's state science standards, to which the district ultimately held teachers accountable. Finally, as noted earlier in the report, the science practices addressed in the study's measures were aligned to the Framework and introduced to teachers in both curricular conditions through professional development workshops on the *Framework for K-12 Science Education* prior to implementation.

Two assessments were developed, one for physical science and one for Earth science. The items for the assessments blend content knowledge and science practices (specifically explanation and developing and using models). Many of the tasks on the assessments have multiple parts, including multiple choice questions and constructed response questions. For full credit on the most complex items, students must construct models that include scientifically accurate content knowledge and describe how their model helps to explain a phenomenon. The constructed response items were scored using a rubric and scoring guide by a team of SRI researchers and experienced science teachers that were not involved in the study. The scorers had prior experience in scoring constructed response assessments such as these and received extensive training on the rubrics. Additionally, scorers were blinded to students' identities and the research condition.

The assessments were tested in an earlier pilot study. The pilot study examined the person and test reliability of each of the tests using modern psychometric techniques, as well as the interrater reliability of scores on rubrics for open-ended items. Most of the items worked very well to inform a unidimensional measure combining conceptual science knowledge with scientific practice and together produced a test reliability coefficient of at least .80 for both assessments. The analyses also indicate that while scoring at the item part level produces consistent scores among multiple raters, bundled models provided better fit of the data to a unidimensional proficiency scale. Interrater reliability for scoring was at least .80 on all items except for two Earth science items, which were revised prior to conducting the randomized controlled trial.

Instructional Logs

In addition to studying learning outcomes, we also investigated teachers' implementation of the curriculum materials in both conditions, as well as teachers' reports of student engagement in science practices. We developed a weekly online instructional log to document teachers' use of the materials and the enactment of instruction with their students.

Within each log teachers were asked a series of questions about their use of materials and their teaching during that week of instruction. For example, teachers were asked to identify the kinds of materials used, the lessons and activities they taught that week, whether they made any modifications to the lessons as well as the source of each modification, which state standards they addressed that week, and what instructional successes and challenges they encountered.

In addition, for each of the eight science practices in the *Framework*, teachers were asked how often they engaged their students in these practices. Notably, the online log asked teachers not how often they themselves enacted the science practices in class, but to indicate how often they provided opportunities for their students to perform the practices. There were four response options for each of the eight science practices: *during every class, several times during the week, once or twice during the week,* or *not at all.*

In the field test, there was evidence of a correlation between the frequency with which teachers engaged students in science practices and scores on the assessments, providing some validity evidence that logs were capturing instruction hypothesized to influence learning outcomes.

Procedure

Assessments. Teachers in both conditions administered end-of-unit assessments after teaching their physical science unit and after teaching their earth science unit. Each unit assessment was administered during class over two sequential days (about 90 minutes total).

Instructional logs. Teachers in both conditions completed online instructional logs on a weekly basis during the study. All teachers were sent an email towards the end of each week with a link to fill out their individual instructional log. The logs were completed online, similar to a typical online survey. Teachers were encouraged to complete the logs within a week of receiving the link. Teachers who did not complete them within a week received an automated reminder email.

Approach to Analysis

We compared posttest scores of students in treatment classrooms with posttests of students in comparison classrooms by fitting hierarchical linear models to the data and controlling for students' prior achievement on their fifth grade science, mathematics, and reading scores on state tests. A second set of models fit to the data explored potential moderator variables, including gender, race/ethnicity, and mean prior achievement level of the class. Prior achievement differences between treatment and comparison groups were also analyzed, and none were statistically significant. Effect sizes for differences calculated for baseline scores ranged from +0.09 for science to +0.22 for reading, in all cases favoring the comparison group.

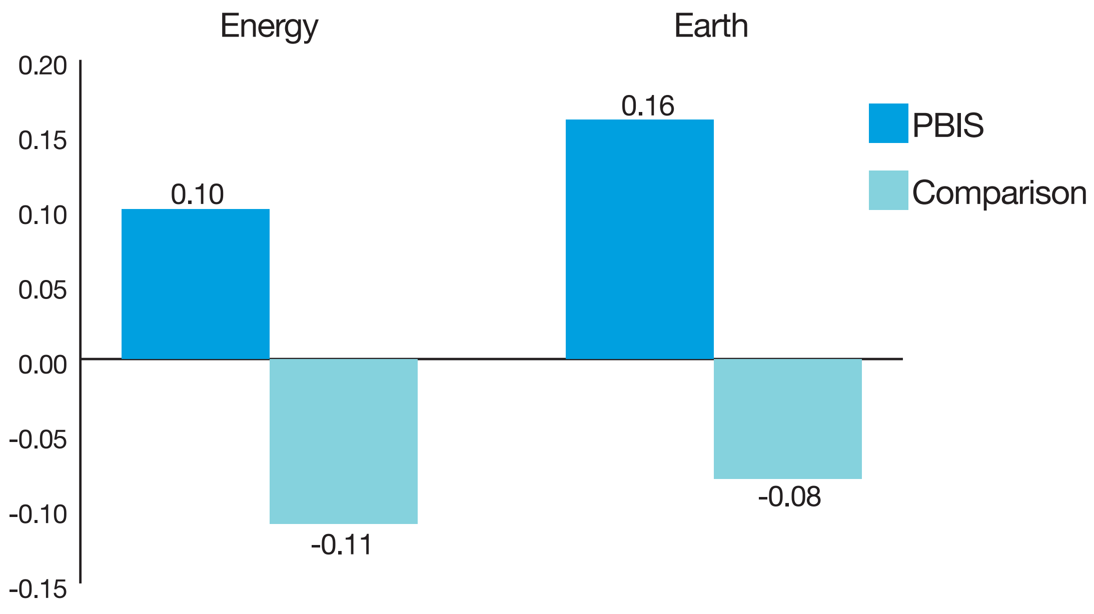
Results

The study results indicate a significant positive impact on student learning for one of the two units, as well as a positive impact on teaching practice. Below, we describe these findings in greater detail.

Impacts on Students

Students in *PBIS* classrooms scored higher on both post-unit tests than students in comparison classrooms (Figure 1). For the physical science (energy) unit, the estimated impact was statistically significant ($p = 0.04$). For the Earth science unit, the estimated impact fell just below statistical significance ($p = .056$). The estimated effect sizes were +0.21 and +0.25 respectively.

Adjusted Mean Outcomes Scores, by Condition



The magnitude of the effect is slightly below the magnitude reported in past large-scale studies of *PBIS*. In past summative evaluation of earlier versions of *PBIS*, student performance on post-tests improved significantly from pretest performance (Geier, et al., 2008; Gray, et al., 2001; Krajcik, Marx, et al., 2000) relative to comparison students. Estimated effect sizes were moderate ($+0.37 \leq d \leq +0.44$) for larger studies that relied on standardized test scores to large ($+1.0 \leq d \leq +1.5$) for smaller-scale studies that relied on researcher-constructed performance tasks closely aligned to the learning goals of the materials.

There were no statistically significant initial differences between the *PBIS* and comparison group students on prior achievement scores in fifth grade science, reading, or mathematics. In some cases, the comparison group students' baseline scores were higher, but the effect size was below 0.25 for all comparisons.

Impacts on Teaching

PBIS teachers were more likely to engage their students in four science practices as their units progressed than were comparison teachers:

- Constructing explanations
- Developing and using models
- Planning and carrying out investigations
- Asking questions

For each of these practices, there were only small initial differences between *PBIS* and comparison teachers' self-reported instruction. But, as units progressed, comparison teachers' engagement of students in science practice decreased significantly, especially in comparison to *PBIS* teachers.

Discussion and Conclusions

This study is the first to assess student learning from science curriculum materials using measures that are aligned to the *Framework for K-12 Science Education*. The results show that science curriculum materials that include opportunities for students to engage in selected science practices, in ways similar to those recommended by the Framework, can prepare students for next generation science learning. Students who participated in the project-based science curriculum outperformed students in the comparison curriculum on outcome measures that were aligned to core ideas and science practices in the *Framework*.

A key feature of the project-based science curricular units is a strong focus on students using science knowledge to engage in the practices of constructing scientific explanations and using scientific models. The materials also include supports for teachers to help their students participate in these practices. Importantly, the results highlight that research-based curriculum materials can also impact the teaching practices of teachers who are striving to help students achieve the ambitious learning goals in the new standards.

The findings reported here are from the first year of a two-year evaluation of the curriculum materials. The sixth-grade teachers who implemented the project-based science units were all new to the curriculum. This is noteworthy because prior research tells us that teachers often face a number of challenges in effectively enacting new reform-oriented curriculum materials. These results show that teachers, despite being new to the materials, were able use them relatively effectively to help their students learn. Year 2 will involve the same schools and many of the same teachers as Year 1, and give us a unique opportunity to see how teachers in the second year of implementation fare.

Policy Implications

Implementing the vision of the *Framework for K-12 Science Education* will present significant challenges to teachers. Curriculum materials provide important models for teachers to use in implementing new ideas in teaching to help them meet new expectations for student learning. But few materials today are even partly aligned with the vision outlined in the *Framework*, especially in ways that will help teachers develop skill in engaging students in important science practices such as explanation and developing and using models. At present, no states have implemented assessments that are aligned to the *Framework*, so assessments today do not provide good models for teachers to use to plan instruction that embodies the *Framework* vision.

The study findings provide an important basis for investments in both new curriculum materials and new assessments. New materials that provide students with more robust opportunities to engage in science practices that are not typically implemented in today's science classrooms can help students learn. It is unclear, however, whether that learning can be documented using traditional assessments. Investments in new assessments are needed in order to measure learning in ways that are consistent with the *Framework*. The results from this study were obtained using assessments that were aligned to the *Framework*; they included multi-component tasks that measured science learning that integrated disciplinary core ideas, practices, and crosscutting concepts.

The study findings are also important because they provide evidence for the role of curriculum in promoting equity in science education. Boys and girls learned at similar rates in the study, as did students from different racial and ethnic backgrounds. This finding is significant, as it shows that a core principle of the *Framework*—that all students can learn—is possible to realize at scale in a large urban school district.

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