Implementing NGSS-designed Curriculum Materials: Promising Results from an Efficacy Study

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Abstract

The Next Generation Science Standards (NGSS) reflect an ambitious vision for science education where students investigate phenomena or solve problems through using and applying disciplinary core ideas in concert with science and engineering practices and crosscutting concepts. Because the NGSS are so different from prior standards, the need for high-quality curriculum materials is especially great. As new curricula go to scale, it will be important to conduct evidence-based research on their efficacy. We conducted a randomized experiment to examine the efficacy of a widely available NGSS-designed middle school curriculum for improving seventh grade students' learning in physical science. A hierarchical linear modeling approach was applied to analyze student learning outcomes as measured by an NGSS-aligned assessment. Initial findings demonstrate evidence of promise of the curriculum materials for supporting three-dimensional teaching and learning. The findings provide support for further research on NGSS-designed materials at other grade levels and within other science domains.

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Implementing NGSS-designed Curriculum Materials: Promising Results from an Efficacy Study

The *Framework for K-12 Science Education* (*Framework*) (National Research Council, 2012) and Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) expand our view of science proficiency as not only what students know, but also how they can use and apply what they know to make sense of phenomena and design solutions to problems. Central to this view is that students should use and apply disciplinary core ideas in concert with science and engineering practices and crosscutting concepts in an integrated manner to build science proficiency. Because this vision for science education is so different from prior standards, the need for high-quality curriculum materials is especially great (see, e.g., Penuel & Reiser, 2018). Encouragingly, science curriculum developers have heeded the call and new curriculum materials are becoming available. As these NGSS-designed curricula are taken up in schools across the United States, it will be important to conduct evidence-based research on their efficacy. Studies that use random assignment are especially important because schools, districts, and states need what is learned from these types of studies to inform decision-making about how best to support NGSS implementation.

This paper describes findings from a study of middle school science curriculum materials that were designed to promote learning as called for by the *Framework* and NGSS. For this study, we conducted a randomized controlled trial (RCT) to examine the efficacy of the widely available Amplify Science Middle School (ASMS) curriculum for improving seventh grade students' learning in relation to NGSS performance expectations in physical science. The ASMS materials are among the first comprehensive curricular programs that have been designed specifically to meet the vision of the *Framework* and address the performance expectations of the NGSS. We investigated the extent to which the curriculum supports NGSS-focused learning (commonly referred to as *three-dimensional learning*) as well as the nature of teachers' implementation. The study was guided by the following research questions:

1. *Student Learning:* What is the impact of the ASMS curriculum on NGSS-focused learning outcomes in culturally and linguistically diverse school settings? How does the impact of the ASMS curriculum vary by student background characteristics?
2. *Curriculum Implementation*: What is the nature of teachers' implementation of the ASMS curriculum? In what ways does the ASMS curriculum influence teachers' NGSS instruction?

Today's Vision for Science Education

The *Framework* and NGSS set forth a vision and foundation for K-12 science classrooms to prepare students to succeed as citizens in the 21st century. In prior standards, proficiency was primarily considered a matter of acquiring core content knowledge and science inquiry was a means to acquire that knowledge. In the *Framework* and NGSS, the science education community emphasizes the high value of providing opportunities for students to not just acquire new knowledge, but also to use and apply that knowledge to deepen their proficiency. This knowledge-in-use perspective represents a different way of thinking about science learning wherein today's students are expected to use and apply knowledge in the context of disciplinary practices—that is, the actual everyday ways of disciplinary reasoning that scientists and engineers use in their respective fields. The basic premise for incorporating disciplinary practices into instruction is that learners, much like professionals, are more likely to advance in their learning when they have opportunities to use and apply knowledge to solve problems, reason with evidence, or make sense of phenomena. The *Framework* and the NGSS emphasize that all students must have the opportunity to learn and actively participate in science through using and applying disciplinary core ideas (DCIs) in concert with science and engineering practices (SEPs) and crosscutting concepts (CCCs) to make sense of phenomena or to solve problems.

Central to this vision is the notion of three-dimensional learning, in which students use the three dimensions of DCIs, CCCs, and SEPs as the means through which to build the proficiencies required to meet the performance expectations of the NGSS. The performance expectations express the integrated goals for three-dimensional learning. They specify what students should know and be able to do in science at a given grade level or across a grade band. A considerable majority of states, representing more than 70 percent of the U.S. student population, now have standards influenced by the *Framework* alone or both the *Framework* and NGSS. Noteworthy is that NGSS performance expectations are articulated in the standards of states that fully adopted the NGSS and in the science standards of many states whose standards are based on the *Framework*.

Role of Curriculum Materials in Supporting the Vision

Because the *Framework* and NGSS are so different from prior standards, it has taken time to develop and make widely available the curriculum materials and assessment resources needed to advance the vision (Pellegrino et al., 2014; Penuel & Reiser, 2018). Also influencing availability has been the gradual shift by states toward adopting standards based on the *Framework* and NGSS. We are now at a point where the vision for science education has become part of education policy in many corners of the U.S. Increasingly, new curriculum materials are becoming available to support teachers in providing instructional experiences that will engage their students in three-dimensional learning. Many of these materials are being designed to meet the ambitious call of the NGSS and to address the performance expectations that are found in state science standards.

Prior research highlights the critical role that curriculum materials can play in supporting teachers and students in making shifts in classroom practice. Well-designed science curriculum materials provide important resources for teachers including routines, instructional strategies, and discussion prompts that can help them take up new formats for instruction (e.g. Harris et al., 2012; McNeill, 2009; Roblin, Schunn, & McKenny, 2017) and provide opportunities for them to learn themselves as they teach (Davis & Krajcik, 2005; Krajick & Delen, 2017). For students, curriculum materials are widely acknowledged for their central role in supporting learning (Geier et al., 2008; Harris et al., 2015; Taylor et al, 2015). Contemporary materials being designed to support new modes of learning, such as the three-dimensional learning of the NGSS, increasingly include structures to engage students in activities in ways similar to how scientists conduct their work along with embedded scaffolds for doing so and with supported practice in reading, writing, and speaking the discourses of science (Penuel & Reiser, 2018).

Curriculum Intervention

ASMS curriculum represents a promising focus for an efficacy study. The curriculum was developed as part of a TK–8 program by the Learning Design Group at the University of California, Berkeley's Lawrence Hall of Science (LHS) in collaboration with Amplify Education

Inc.. Adoption of the curriculum has increased yearly since it became commercially available in 2018. Currently, the materials are in use in middle school students across all 50 states and in a wide range of settings including urban, suburban and rural schools. ASMS aims to provide students in grades 6-8 with opportunities to engage with DCIs, CCCs, SEPs to strengthen their science proficiency. The curriculum package includes a digital platform for students and teachers along with physical materials for hands-on activities. Students interact with physical materials and within a digital workspace with access to custom-written science articles, science simulations, and design tools. Each unit engages students in investigating and explaining an anchor phenomenon in the context of a compelling situation. For instance, in one unit students investigate the anchor phenomenon of an unknown substance discovered in a community's well. The program employs a multimodal approach known as Do-Talk-Read-Write-Visualize that aims to support students with the literacy demands of engaging in science (Cervetti et al., 2012).

Teachers are provided with digital instructional guides along with online monitoring and reporting tools which allow them to view summaries of student progress. The lessons follow an instructional sequence meant to build proficiencies with NGSS PEs over time. Each unit is designed around a learning progression referred to as a *Progress Build*, that culminates in a complex causal explanation that students should be able to make by the end of the unit. The Progress Build draws from the concept of progress variables (Kennedy at al., 2005, Kennedy & Wilson, 2007), which are representations of the knowledge, skills, and other competencies intended to be increased through the learning activities associated with a curriculum.

Methods

Sample

This paper reports findings based on data collected from 15 schools and focuses on science instruction and learning in the domain of physical science. The sample included 3,314 7th grade students from 27 teachers' classes (14 intervention group teachers and 13 comparison group teachers). The participating schools were from three districts across two western states that have NGSS performance expectations as their middle grades state standards. The districts are of varying size (i.e., one large, mid-size and small) and serve diverse populations including multiple racial and ethnic groups. Most schools in the sample were Title I schools.

RCT Background and Influence of COVID

The study reported in this paper was a part of a larger-scale RCT that was carried out during the 2019-20 school year in seventh grade science classrooms in 29 schools. The RCT was set to test the impact of the ASMS curriculum materials on students' physical science and life science learning. Schools within each district were paired based on their demographic characteristics and student prior performance on state math and English language arts (ELA) tests and then randomly assigned to a treatment or control condition. All participating seventh grade teachers in a given school had the same assignment. Teachers in both groups were asked to implement curricular units on the same topics and follow their district sequence and pacing guide.

The RCT was disrupted when the COVID-10 pandemic caused school closures in March 2020. Not all teachers were able to implement their complete year-long science curriculum sequence and administer the full battery of assessments (physical science and life science) in their classrooms before their school campuses closed. The sample we report in this paper includes the 15 schools in seven randomization pairs that were able to fully complete their physical science instruction and administer assessments before school closures. Table 1 compares the analytic sample to the original study sample.

Curricular Context: Treatment Condition

Treatment teachers implemented the ASMS curriculum and received professional development provided by the LHS developers. The workshops were held at three time points during the school year for a total of 24 hours. Content included navigation of the online teaching resources, overview of the Amplify Science approach, and information about teaching the units. The ASMS units we studied were in physical science and addressed the topics of structure and properties of matter (e.g., phase change, energy, and matter) and chemical reactions. These units engage students in using and applying their knowledge to investigate and explain an anchor phenomenon. For instance, in one curricular unit students investigate the anchor phenomenon of an unknown substance discovered in a community's water supply. Each unit culminates with students constructing a causal explanation of the anchor phenomenon.

Curricular Context: Control Condition

Teachers in the control condition were asked to implement their regular curricular units on physical science topics relating to structure and properties of matter and chemical reactions. The range of enacted curriculum materials varied across schools, but all were focused on NGSS instruction. Teachers in one district used a redesigned curriculum for the NGSS, teachers in another used their own district-developed curriculum to address the NGSS PEs, and teachers in the third district mostly used a district-adopted textbook while some used an open-source project-based NGSS curriculum.

Data Sources

Student Learning: Three-dimensional Assessment

At the time that we were preparing for the study, there were no existing off-the-shelf assessments for the NGSS. Subsequently, the research team developed an assessment as the student learning outcome measure of the study that would be fair to both conditions (DeBarger, et al., 2016). The assessment elicits performance with aspects of NGSS PEs related to MS-PS-1, Matter and its Interactions. It includes seven constructed-response tasks that address aspects of disciplinary core ideas, science and engineering practices, and crosscutting concepts. Science and engineering practices addressed by the tasks include developing and using models, analyzing and interpreting data, and obtaining, evaluating and communicating information. Crosscutting concepts include patterns, cause and effect, structure and function, and energy and matter. The tasks were contextualized in scenarios presented in a succinct story format with prompts to elicit integrated responses.

The assessment development was informed by the design work of the Next Generation Science Assessment Project (Harris et al., 2019). To ensure that tasks were fair to both conditions, we focused on PEs in physical science that were in the state standards of the participating schools and that all teachers were expected to teach in seventh grade. The development process started with unpacking each PE into learning targets, defining what it meant for students to show proficiency related to those targets, and developing tasks that allowed students to display this expertise. Once an initial set of tasks were developed, feedback was obtained through expert reviews and cognitive interviews with students. Results were used to increase clarity and alignment to PEs for the tasks. A pilot was conducted with 493 students to gather additional information on the tasks. The results of the pilot were used to make one more round of revisions.

The paper and pencil assessment was designed to be completed within a 50 minute class session. Teachers were requested to administer the assessment within two weeks of completing their instruction of the physical science topics. The collected assessments were randomized and assigned to independent scorers who received extensive training on the rubrics, with one set of assessments used as a training set. Scorers were blinded to students' identities and the research condition. Aside from the training set, over 20% of the assessments were scored by two scorers, with checks for reliability. Any disagreements were resolved by a third scorer. Final scores were totaled to get an overall total score. After completing the scoring, we examined the psychometric properties of the assessment. Overall reliability of the assessment was 0.788.

Curriculum Implementation: Instructional Logs and End-of-year Survey

We developed and employed a weekly online instructional log and an end-of-year survey to investigate teachers' curriculum enactment and instruction in both conditions. The log and survey included (a) enactment questions that focused on self-report of lessons and activities enacted in a given week, modifications made (and reasons why), and successes and challenges encountered with the materials, and (b) instruction questions that focused on frequency and depth of engaging students with the NGSS dimensions (especially the science and engineering practices), instructional strategies employed, and instructional successes and challenges.

Analysis and Results

Attrition and Baseline Equivalence

With 15 of the 29 schools remaining in the analytic sample, the overall attrition at school level is 48.3% and differential attrition is 3.3%. The overall rate of non-response at student level within the 15 schools was 46.3%, differential attrition 12.5%. Baseline equivalence was established based on students' prior 6^{th} grade math and ELA state test results from spring 2019. No statistically significant difference was detected between z-scores in the sample of students in the non-attrited schools ($p > 0.05$), nor in the final analytic sample ($p > 0.05$).

Effects on student learning

For the student learning outcome analysis, we compared posttest scores of students in treatment schools with posttests of students in control schools by fitting 2-level hierarchical linear models (HLM) with students nested within schools.

The following two-level model was applied:

$$Test_{ijk} = \alpha_0 + \beta_1 newPre_{ijk} + \beta_2 dPre_{ijk} + \beta_3 Tx_{jk} + \Sigma\beta_I I_{ijk} + \Sigma\beta_{dI} dI_{ijk} + \Sigma v_S Stratum_k + \tau_{jk} + \varepsilon_{ijk}$$

where subscripts i, j, and k denote student, school, and stratum; *Test* represents student achievement score (total or item score); *newPre* represents the baseline measure with missing values coded to a constant; *dPre* is the missing indicator for *newPre*; *Tx* is a dichotomous variable indicating student enrollment in a school that has been assigned to treatment or control condition; *I* is a vector of other control variables for students, measured prior to exposure to the intervention; *dI* is a vector of missing indicators for *I*; *Stratum* represents a vector of fixed effects for *k–1* strata; τ represents a random variable for schools, and ε is an error term for individual students. The intervention effect is represented by β_3, which captures treatment-control differences on the outcome variable after controlling for all covariates and study design factors (strata).

The baseline measures we controlled for included ELA and math scores from the 2018-19 state-wide tests. Because the study sample came from different states, the baseline scores were first converted to the z-scores based on the respective mean score and standard deviation from the state. The resulting z-scores were then used in the subsequent analyses. Other covariates included the following student demographic information: gender, English Language Learner (ELL) status, Individualized Education Program (IEP) status and race/ethnicity.

The results are shown in Table 2. The adjusted mean total score in the treatment group was 13.85 (standard deviation = 5.12) and 12.03 in the comparison group (standard deviation = 4.89). The difference was statistically significant ($p < 0.01$). The estimated effect size was +0.36 (Hedge's *g*). The results suggest that implementing ASMS had a significant positive impact on student learning in physical science.

Implementation of the ASMS curriculum and effects on instructional practice

Teachers reported having a positive experience with the ASMS curriculum. Preliminary survey findings indicate that most treatment teachers (>80%) agreed that they and their students benefited from using the ASMS materials. Eighty-eight percent of treatment teachers reported that ASMS supported them in engaging students in science discourse, 73% planned to continue using ASMS after the study ended, and 54% reported that using ASMS changed the way they taught science.

We also found differences in instructional practice between teachers in the intervention and comparison schools. Teachers in both experimental groups were also asked to complete an instructional log each week regarding their instruction on the physical science topics. Preliminary findings from the logs show that when teaching physical science, teachers in the control group spent a greater percentage of instructional time having their students planning and carrying out scientific investigations (1.57 effect size, Hedge's *g*), applying mathematics and computational thinking (0.91), analyzing data (0.58), providing hands-on experiences for students (0.89), and watching demonstrations of scientific concepts(0.36). Teachers in the treatment group, on the other hand, were more likely than comparison teachers to report that they provided students with opportunities to read scientific texts (1.12), write about their thinking and reasoning (0.36), and communicate their scientific thinking to peers (0.19) as well as providing more opportunities for students to engage in the scientific and engineering practices including evaluating and communicating information (0.63), constructing explanations (0.26), and engaging in argument from evidence (0.25).

Discussion and Conclusion

To date, few NGSS-designed science curriculum programs have been rigorously examined. The results from this randomized controlled trial contribute to this emerging research base. This study joins a small yet increasing number of experimental studies extending from the elementary grades (e.g., Iveland et al., 2021), to middle school (e.g. Harris et al., 2015) and to high school (e.g., Schneider et al., 2022) that are examining classroom implementation and impact on learning of curriculum materials that aim to support today's vision for science education.

Results from this experimental study show that the curriculum intervention was effective in promoting students' science learning. It was found that students in ASMS classrooms outperformed students in the control condition on an assessment designed to elicit performance with aspects of NGSS performance expectations for physical science. Results from our examination of curriculum implementation across both conditions show that the intervention supported teachers in the treatment group to engage their students more often in constructing explanations, engaging in argumentation, and in obtaining, evaluating, and communicating information. These three scientific practices from the NGSS are central components of the ASMS intervention. It could be that having students frequently engage in these scientific practices benefitted them in regard to using and applying their knowledge on the assessment. Related, another study result was that teachers in the control group spent more time than their counterparts in engaging their students in planning and carrying out scientific investigations, which is another important scientific practice from the NGSS. That the teachers in the treatment group spent less time with their students on planning and carrying out scientific investigations is indicative of what is emphasized less in the ASMS materials. At this time, there is very little research evidence available regarding what may be the best weighting of scientific practices that should be included within instructional sequences in curricula. What is clear is that the emphasis on scientific practices vary in the types of NGSS-designed curriculum materials that are going to scale. More work remains to be done on the benefits and trade-offs of time devoted to the various scientific practices and specifying the situations in which they are most likely to be effective in advancing student learning.

A limitation of this study is that it focused on just one domain and at one grade level that is part of the more comprehensive ASMS curriculum spanning across the 6-8 middle grades. The full curricular intervention covers all the science domains and is designed to support instruction toward meeting the breadth of NGSS performance expectations for this grade band. Had the study included more domains and grade levels, a more definitive conclusion of overall impact on learning for the intervention could have been drawn. Still, because the full range of ASMS units that span the domains are infused with the same pedagogical approach and were developed with the same design principles (Barber et al., 2021), the study's findings on student learning in the domain of physical science stand to provide evidence of promise for the overall NGSS-designed curriculum. Importantly, the findings encourage further research on ASMS curriculum implementation and its impact on student learning at other grade levels and within other science domains.

We are in an era where new NGSS-designed materials are becoming widely available across K-12. Among the most recent examples are the OpenSciEd materials (e.g., Edelson et al., 2021) that are now being released. As new materials become more widely used across different geographic regions and with varying student populations, additional studies at larger scale and with concerted attention to student diversity and equity will be needed. This current and future research work is greatly needed and will be critical for ensuring that the vision of the *Framework* and the NGSS is realized for all students.

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Tables and Figures

Table 1. Summary of Study Sample

Group	Originally Enrolled Pre-COVID (based on class rosters submitted by teachers)			Analytic Sample (students with valid assessment data and consent)		
	# Schools	# Teachers	# Students	# Schools	# Teachers	# Students
Treatment (Tx)	15	32	2,834	8	14	817
Control (Cx)	14	27	2,865	7	13	963
Total	29	59	5,699	15	27	1,780

Table 2. Result of Impact Analysis

Learning Outcome Measure	Treatment Adjusted Mean (Sd) (N=817)	Control Adjusted Mean (Sd) (N=963)	Difference	Std. Error	*p*-Value	Hedge's *g*
Physical Science Learning Assessment (Score range: 0-25)	13.85 (5.12)	12.03 (4.89)	1.82	0.4428	<.001	0.36

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