Improving Prekindergarten and Elementary Science Teaching

A Synthesis of Recent DRK-12 Program Investment in This Field

Danielle Ferguson, Isabella Pinerua, and Dean Gerdeman

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Executive Summary

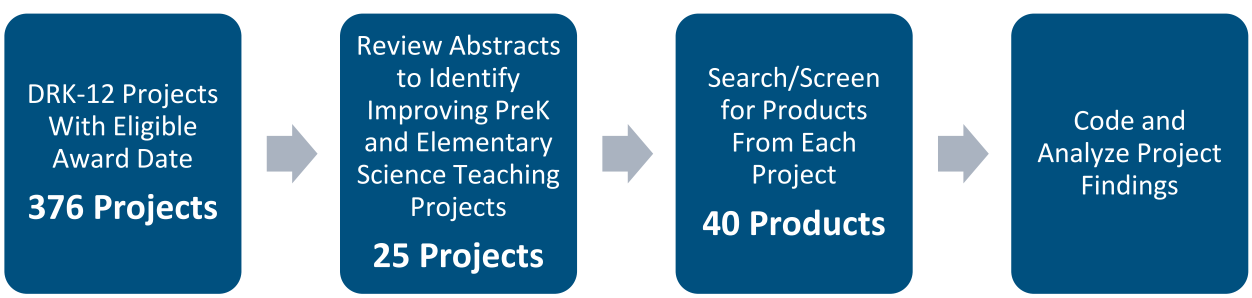
Context and Our Focus

Early science, technology, engineering, and mathematics (STEM) education sets the stage for future STEM learning. The purpose of this synthesis is to understand the findings from investments to improve prekindergarten (preK) and elementary science teaching from projects funded by the National Science Foundation's Discovery Research PreK-12 (DRK-12) program. In the 5 years spanning 2011–15, the DRK-12 program funded or cofunded 25 projects, totaling more than $60 million, related to improving preK and elementary science teaching.

Findings

Our review identified 25 DRK-12 projects related to improving preK and elementary science teaching funded in 2011–15. We synthesized findings from 25 of those projects that produced products (e.g., peer-reviewed journal articles, conference papers) that described the project and outcomes. We synthesized the empirical findings from interventions in four common areas of investment: (a) preservice preK and elementary preparation programs, (b) in-service teacher professional development (PD), (c) instructional materials for preK and elementary teachers, and (d) strategies for diverse learners. We found significant cross-intervention overlap between these projects (see Exhibit ES1).

Exhibit ES1. Overview of Our Synthesis of DRK-12 Projects Related to Improving PreK and Elementary Science Teaching



Preservice PreK and Elementary Preparation Programs

Four projects tested an intervention related to improving elementary teacher preparation programs; none of the projects included preK teachers. Based on the findings reported, providing PD for teachers who serve as mentors for preservice elementary teachers contributed to improvements in teachers' self-efficacy and pedagogical content knowledge (PCK).

In-Service Teacher PD

Fifteen of the 25 projects studied interventions related to improving in-service teacher PD. Based on the findings reported, PD lasting a year or more may lead to gains in preK and elementary teachers' PCK and their students' science content knowledge.

Instructional Materials or Resources for PreK and Elementary Teachers

Eleven projects studied interventions related to implementing science instructional materials by preK and elementary teachers. Of the 11 projects, eight projects reported findings related to teacher and student outcomes. Based on the findings reported, implementing instructional materials or resources, typically/particularly in combination with teacher PD, was associated with observed changes in teachers' classroom practices and increased students' science content knowledge.

Strategies for Diverse Learners

Eight projects studied interventions for implementing strategies for diverse student learners. Seven projects focused on strategies for emerging language learners (i.e., English learners [ELs]), and one project focused on native Hawaiian students. These projects reported that teaching preK and elementary teachers instructional strategies, such as language development and integration of literacy, for diverse learners led to changes in their classroom practices.

Implications for the DRK-12 Portfolio

Our synthesis of the projects related to improving preK and elementary teaching discusses which types of interventions show promise in this key area of investment, as reported by the original resources. The synthesis also highlights some gaps that could be filled in future research. We identified three opportunities for future research investment that should be considered by the DRK-12 program: (a) interventions designed specifically for the lower elementary grades; (b) the development of strategies for diverse populations, aside from ELs; and (c) increase rigorous studies in science education.

Why This Topic?

Young children are fascinated by science, technology, engineering, and mathematics (STEM)–related concepts, such as understanding how machines work, why substances change shape and form, and how animals behave (Valdesolo et al., 2017). These early explorations form a critical foundation for later STEM interest and learning (McClure et al., 2017). In recent years, policymakers have called on educators and researchers to provide evidence-based approaches for fostering early STEM learning. For instance, in December 2019, the U.S. Congress passed the Building Blocks of STEM Act, which highlighted the National Science Foundation's (NSF's) Discovery Research K-12 (DRK-12) program, urging it "to improve the focus of research and development on elementary and prekindergarten [preK] education" in STEM subjects (Building Blocks of STEM Act, 2019).

Research indicates the importance of students learning science early on. As Mensah (2010) argued, "a strong elementary science program sets the foundational skills and knowledge needed for upper grades science learning, and without this early foundation, science across the middle and upper grade spans suffer" (p. 977). The National Research Council (NRC), in its 2007 report *Taking Science to School: Learning and Teaching Science in Grades K–8*, stated that young children can think about science both concretely and abstractly and that their scientific inquiry skills need to be nurtured through authentic science experiences in the early grades (NRC, 2007). However, elementary teachers face professional learning challenges for science instruction, such as inadequate science preparation in preservice teacher programs, limited opportunities for science professional development (PD), and limited content knowledge (Deniz & Akerson, 2013; Hayes et al., 2017; Posnanski, 2010). Science teachers in elementary school also face obstacles by policies that prioritize literacy and mathematics instruction (Berg & Mensah, 2014; Slavin et al., 2012). In addition, many teachers are not adequately prepared to teach using a multicultural lens, which is a critical need, especially in science education (Mensah & Jackson, 2018). Science in the United States is typically taught through a Western European lens, and most of the teachers are White (Mensah & Jackson, 2018). By 2023, the racially minoritized student population is projected to increase by at least 15%, possibly leading to more inequitable educational experiences (Mensah & Jackson, 2018; National Academies of Sciences, Engineering, and Medicine [NASEM], 2021).

The NRC emphasized the need to improve pre- and in-service PD for elementary teachers that enhances their science teaching pedagogy, use of technologies, and knowledge of how students learn science (NRC, 2007). Similarly, NASEM recommended that preK and elementary school leaders ensure that (a) adequate time is dedicated to science and engineering instruction and (b) teachers receive the resources (fiscal, materials, and human) to build their capacities for teaching science and engineering (NASEM, 2021). Enabling these types of conditions and learning environments in elementary science education requires new programs, interventions, and supports for teachers and students. NSF's DRK-12 program is one prominent source of investments in this area.

We examined the intellectual and broader contributions of recent DRK-12 grants focused on preK and elementary science teaching. We reviewed the NSF award abstracts for recently completed or close-to-completion DRK-12 projects (initial award date between 2011 to 2015). Our review of the NSF award abstracts identified 25 projects focused on science teaching from preK to Grade 5, with a total award value of more than $60 million. The goal of this paper is to synthesize what researchers studied and what they learned about how to improve preK and elementary science teaching.

> In the 5 years spanning 2011 to 2015, the DRK-12 program funded or cofunded 25 projects relating to improving preK and elementary science teaching, totaling $62 million in awards.

Four Common Areas of Investment for Improving Science Teaching

Drawing from the recommendations made by the NRC (2007) and NASEM (2021), we identified four common areas of investment for improving science teaching: (a) preservice teacher preparation programs, (b) PD interventions for in-service teachers, (c) instructional materials and resources, and (d) strategies for teaching diverse student populations. In this section, we provide an overview of some of the challenges that preK and elementary teachers face in these areas.

Preservice PreK and Elementary Teacher Preparation Programs

Preservice teacher's prior science experiences play a key role in how they view science and science teaching. Preservice teachers who leave their preparation programs with negative beliefs about science are unlikely to teach science effectively (McClure et al., 2017; Mensah & Jackson, 2018), and the current structure of preservice preK and elementary teacher preparation programs can lead to teachers having a low science self-efficacy by not adequately preparing them to teach science (McClure et al., 2017). Often, preservice programs' science teaching courses are not tailored to the needs of teaching at the elementary level, and in some programs preservice elementary teachers must take the same science content courses designed for science majors, which places greater focus on disciplines and topics as opposed to general science (Bergman & Morphew, 2015). For example, Advard (2010) found that preservice teachers had difficulty answering a research question by developing a scientific investigation after taking two college-level science courses. Consequently, the workforce of elementary teachers often has little confidence in their science teaching skills (Hembree, 1990; McClure et al., 2017).

Professional Development (PD) for In-Service PreK and Elementary Teachers

To teach science effectively, elementary teachers need to have strong science content knowledge and pedagogical skills to address student misconceptions (Nowicki et al., 2013), among other characteristics (e.g., science teaching self-efficacy and confidence). PD could help bridge the gaps in teacher science content knowledge and pedagogical practices (Diamond et al., 2014; Hartshorne, 2008), but teachers face many challenges in accessing and implementing PD (Nowicki et al., 2013). One such challenge is that district and school leadership priorities usually favor mathematics and language arts over science at the elementary level (Deniz & Akerson, 2013; Desimone & Garet, 2015). Another challenge is that teachers receive inconsistent PD, such as one-shot workshops, from multiple providers, and they struggle with determining which parts of the PD they can implement and to what extent they should implement (Desimone & Garet, 2015). Teachers also experience challenges in translating PD theories into practice (Desimone & Garet, 2015).

Instructional Materials and Resources for PreK and Elementary Teachers

Another strategy used to improve science teaching at the elementary level is to provide teachers with supplemental instructional materials or resources, such as textbooks or online games. These supplemental instructional materials and resources often target specific science topics or units, such as astronomy or parts of a plant, but do not necessarily address teaching science more broadly. These instructional materials or resources provided to teachers are often described as PD but typically include limited training and support, such as one-off training rather than continued support as teachers use the materials and resources in practice (Slavin et al., 2012). Teacher interventions that focus on implementing supplemental instructional materials generally do not improve teachers' overall pedagogical practices because, in part, the supports do not easily translate to the teaching of multiple science objectives, and elementary teachers need a wide variety of content knowledge to teach science effectively (Hayes et al., 2017; Slavin et al., 2012).

PreK and Elementary Teaching Strategies for Teaching Diverse Student Populations

There continues to be a national call to improve access to science, yet few studies address challenges related to effectively teaching diverse student populations, such as students of color and emerging language learners (i.e., English learners [ELs]), in preK and elementary science. Studies typically focus on explaining that there is a problem and which culturally relevant practices are not being utilized in science classrooms. For students who are traditionally underrepresented, learning science requires them to effectively cross-cultural borders because science often is taught using White, middle-class worldviews (McGee, 2020; Patchen & Cox-Petersen, 2008). Most of the time, science is taught by White teachers who may not have the knowledge or skills needed to teach students from diverse populations (Adamson et al., 2013). Teachers who attempt to address the needs of students from diverse backgrounds tend to diversify their teaching strategies (e.g., cooperative learning, scaffolding instruction) to address students' academic needs but do not diversify their strategies to include cultural and linguistic experiences (e.g., culturally relevant pedagogy; Patchen & Cox-Petersen, 2008). The instrucional strategies that teachers are trained to implement to address the needs of Els are not typically aligned with the language development needs of this particular group of students. (Settlage et al., 2005). According to NRC, teachers should be prepared to incorporate and build on every child's experience in their classrooms, which means addressing and incorporating the cultural, linguistic, and economic backgrounds of all children (NRC, 2007). Although we understand teaching diverse student populations is a challenge that could be a subsection of the first three challenges described previously, we include it as a separate challenge because it can be viewed through a social justice lens (McGee & Martin, 2011; NASEM, 2021) and is an NSF priority. We want to ensure that the findings related to this issue receive adequate coverage in our analysis.

Further Synthesis Research Needed

Few research reviews and meta-analyses have been conducted on improving preK and elementary science teaching. For example, the Hayes et al. (2017) review focused on characterizing elementary teachers' knowledge of science subject content, and the Slavin et al. (2012) systematic review focused on achievement outcomes for different approaches to teaching science at the elementary level. The major finding was that very few studies evaluated elementary programs using rigorous experimental methods. Of the 333 published and unpublished articles that Slavin et al. (2012) reviewed from 1980 to 2011, only 17 studies met their criteria of rigor. Moreover, another prior review that focused on the role of reflection in mathematics and science elementary teacher PD programs between 2000 and 2012 found that few studies meet all five components of Desimone's PD framework (Saylor & Johnson, 2014).[1]

The DRK-12 program has made substantial investments in the study of science instruction. Synthesizing the knowledge generated from these research projects can provide insights into

[1] The five components of Desimone's PD framework are as follows: (a) content focus: activities focused on subject matter content and how students learn that content; (b) active learning: opportunities for teachers to observe, receive feedback, analyze student work, or make presentations versus passively listening to lectures; (c) coherence: content, goals, and activities that are consistent with the school curriculum and goals, teacher knowledge and beliefs, the needs of students, and school, district, and state reforms and policies; (d) sustained duration: PD activities that are ongoing throughout the school year and include 20 hours or more of contact time; and (e) collective participation: groups of teachers from the same grade, subject, or school participate in PD activities together to build an interactive learning community.

improving science teaching at the preK and elementary levels. This synthesis adds to the limited number of syntheses related to improving preK and elementary science teaching and provides initial insight into what researchers learned from DRK-12–funded projects in the four areas previously identified: (a) preservice teacher preparation programs, (b) PD interventions for in-service teachers, (c) instructional materials and resources, and (d) strategies for teaching diverse student populations.

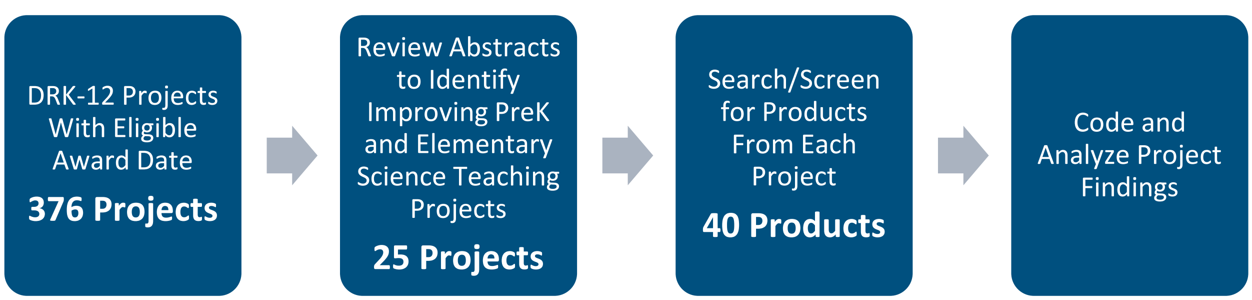
What Was Studied?

This synthesis presents findings from a set of 25 DRK-12 projects that focus on improving preK and elementary teachers' abilities to teach science. It describes the problems or topics related to preK and elementary science teaching that we studied, the methods and approaches used or developed to test teacher interventions, and what researchers learned from these investments. See Appendix A for a discussion of our methodology for the synthesis.

Our Synthesis Approach

For this synthesis, we identified DRK-12 projects relevant to the topic of preK and elementary science teaching and coded and synthesized findings presented in publications and products associated with these projects (Exhibit 1). We examined DRK-12 projects with an original award date spanning January 2011 to December 2015, to focus on recently completed or close-to-completion projects. We downloaded the award abstracts for all DRK-12 awards in this date range using NSF's website and selected projects with abstracts that described plans to study an intervention, program, or practice related to early science teaching. This process yielded 25 eligible projects.[2]

Exhibit 1. Overview of Our Synthesis of DRK-12 Projects Related to Improving PreK and Elementary Science Teaching



[2] The process initially identified 27 funded projects. Two projects were dropped because the research products identified did not provide enough information about the findings.

To identify products to review, we searched six sources, targeting documents that referenced the numeric NSF award ID or documents that project leaders listed on the Research.gov or Community for Advancing Discovery Research in Education (CADRE) websites. We also reached out to Principal Investigators directly to request products that are not publicly available or that we may have missed, which resulted in 40 research products. (See Appendix A for the process for searching for and screening products from the NSF projects.) The types of products identified include peer-reviewed journal articles, conference papers and posters, brief project outcomes reports submitted to NSF (typically one to three pages), and one graduate thesis. Sixteen of the 25 projects produced peer-reviewed journal articles. Six of the 25 projects produced only a project outcomes report, which provides limited information.

We used a coding structure (Appendix B) developed by the lead researcher and coded the 40 products using NVivo software. Findings from these products were synthesized and are reported at the project level. The level of specificity about the project design, study sites and locations, demographic information about participants, and scale of the studies varied greatly across these projects and therefore affected the extent to which we could synthesize information about the projects.

The remainder of this section provides a high-level summary of the methods and approaches used in the DRK-12 projects, based on the products reviewed.

What Types of PreK and Elementary Science Teaching Investments Were Studied?

We categorized the 25 projects synthesized in this report into four common types of investment for improving preK and elementary science teaching. Three of the investments address the mechanism for supporting teacher learning and instruction: (1) preservice elementary teacher preparation programs, (2) PD for in-service preK and elementary teachers, (3) instructional materials and resources for preK and elementary teachers. The fourth type of investment addresses a common focus of the projects: teaching strategies for diverse learners in the preK and elementary grades. This fourth cross-cutting type was included because it represented a common and intentional area of emphasis in the DRK-12 projects and is also emphasized in the literature on elementary science teaching.

Projects could be coded to more than one intervention category. Of the 25 projects reviewed, 13 were coded to a single intervention type, and the rest were coded to two or three types. For example, two of the projects coded as preservice teacher preparation programs also included PD for in-service teacher participants to build their capacity to serve as mentors. Five projects that studied training in-service teachers also incorporated strategies for teaching diverse student populations. PD for in-service teachers was the most common type of investment (Exhibit 2). Project details, such as the project title and intervention type, are in Appendix C.

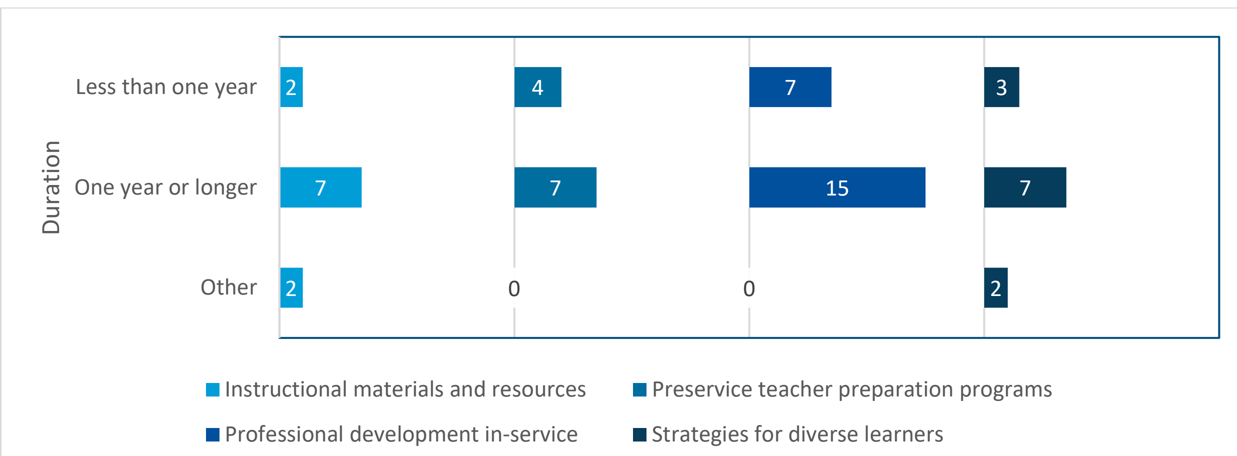
Exhibit 2. Overview of Number of Projects by Type of Teaching Intervention

Common types of teaching intervention	Number of projects
PreK and elementary teacher preparation programs	4
PD for in-service preK and elementary teachers	15
Instructional materials and resources for preK and elementary teachers	11
PreK and elementary strategies for diverse learners	8

Note. Projects could be coded as applying to more than one area of intervention.

Most projects implemented interventions that lasted a year or longer (Exhibit 3). Interestingly though, a few projects were conducted over a very short period. For example, one project (Deniz et al., 2017) studied an intervention that lasted a week, focused on a 3-day PD program on the role of engineering in the Next Generation Science Standards (NGSS) and associated teacher changes in view on the nature of science.

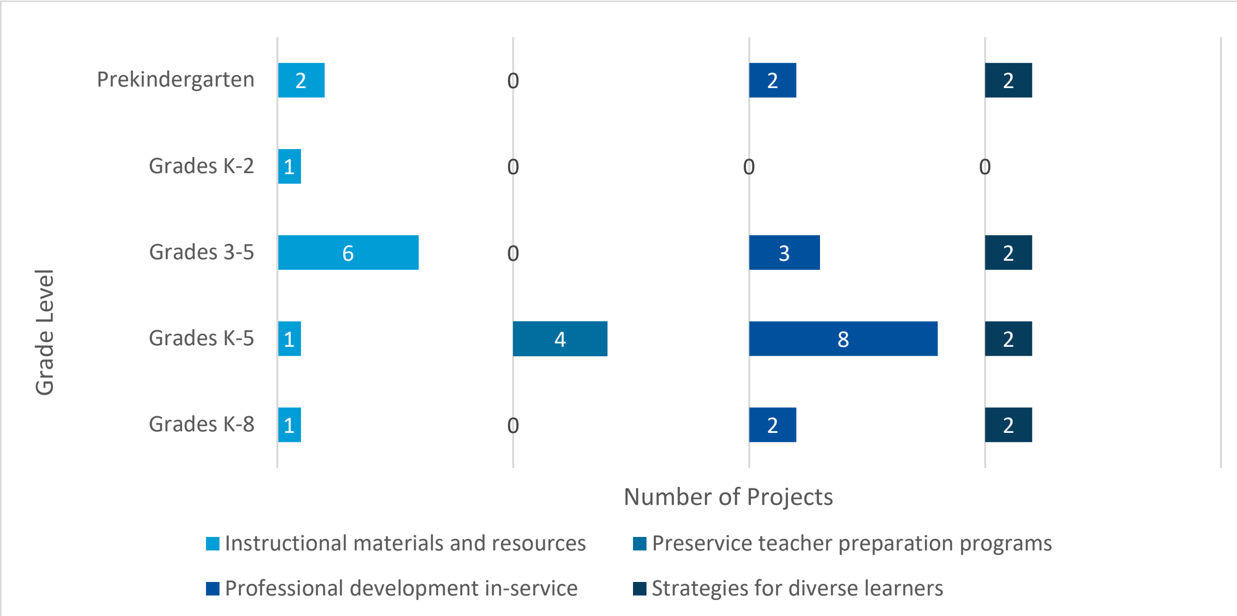
Exhibit 3. Duration of the Projects by Type of Intervention



Note. The projects denoted as "Other" are from product/intervention descriptions in which the duration was missing.

Most of the projects focused on preservice or elementary science instruction in Grades 3–5 or overall elementary Grades K–5 (Exhibit 4). Only one project (Romance et al., 2018) tested a teacher intervention for Grades K–2. A few projects focused at the preK level or included both elementary and middle school grades (coded as Grades K–8).

Exhibit 4. Number of Projects by Grade Level Across Four Common Areas of Intervention

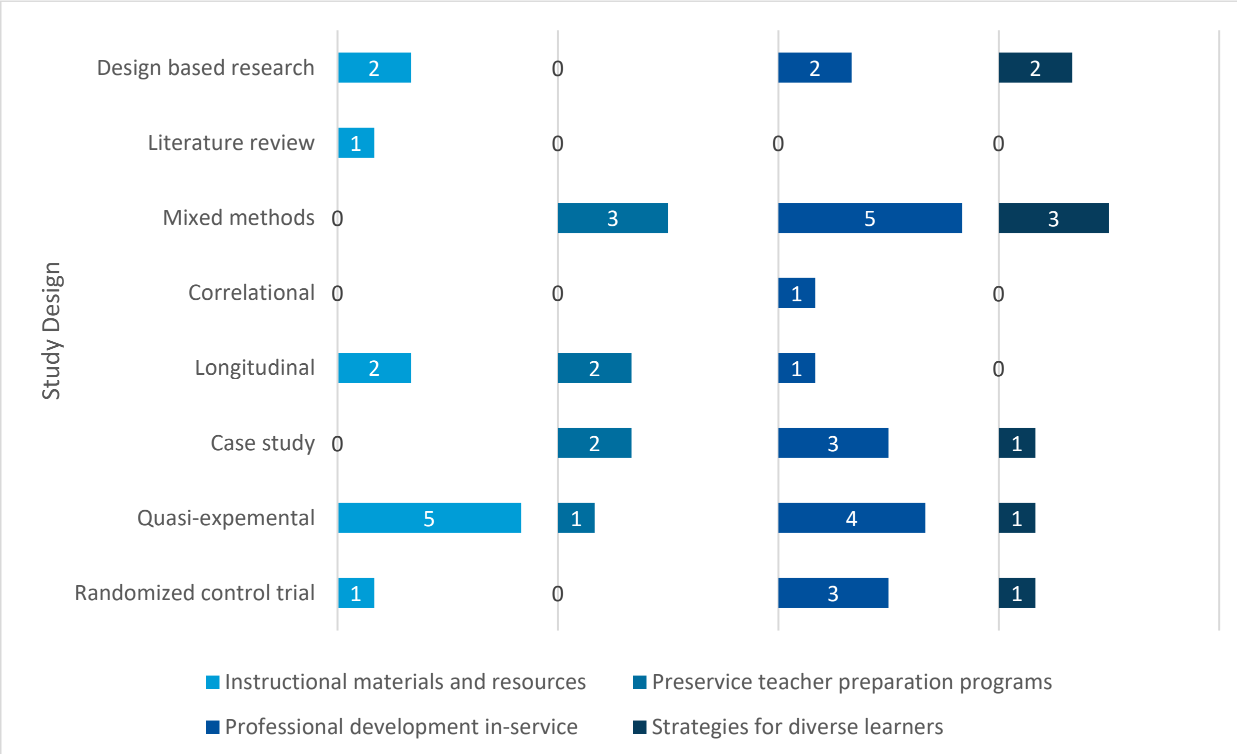


Note. A project could be coded in more than one grade band if it had more than one product that reports on different grade bands.

What Methods and Approaches Were Used or Developed?

Researchers used a variety of methodologies to study the four areas of intervention. The two most used research methodologies were quasi-experimental and mixed methods (qualitative and quantitative data collection). Because we coded one or more products from each project, we also found that some projects employed more than one methodology. For example, one project (Miller et al., 2013) generated three products that used three research methodologies—longitudinal, quasi-experimental, and mixed methods (qualitative and quantitative data collection)—to study the implementation of changes they made to a preservice elementary teacher preparation program. Overall, we did not find any major distinctions in methods use by intervention type (Exhibit 5).

Exhibit 5. Methods Used to Test Interventions by Common Areas of Intervention



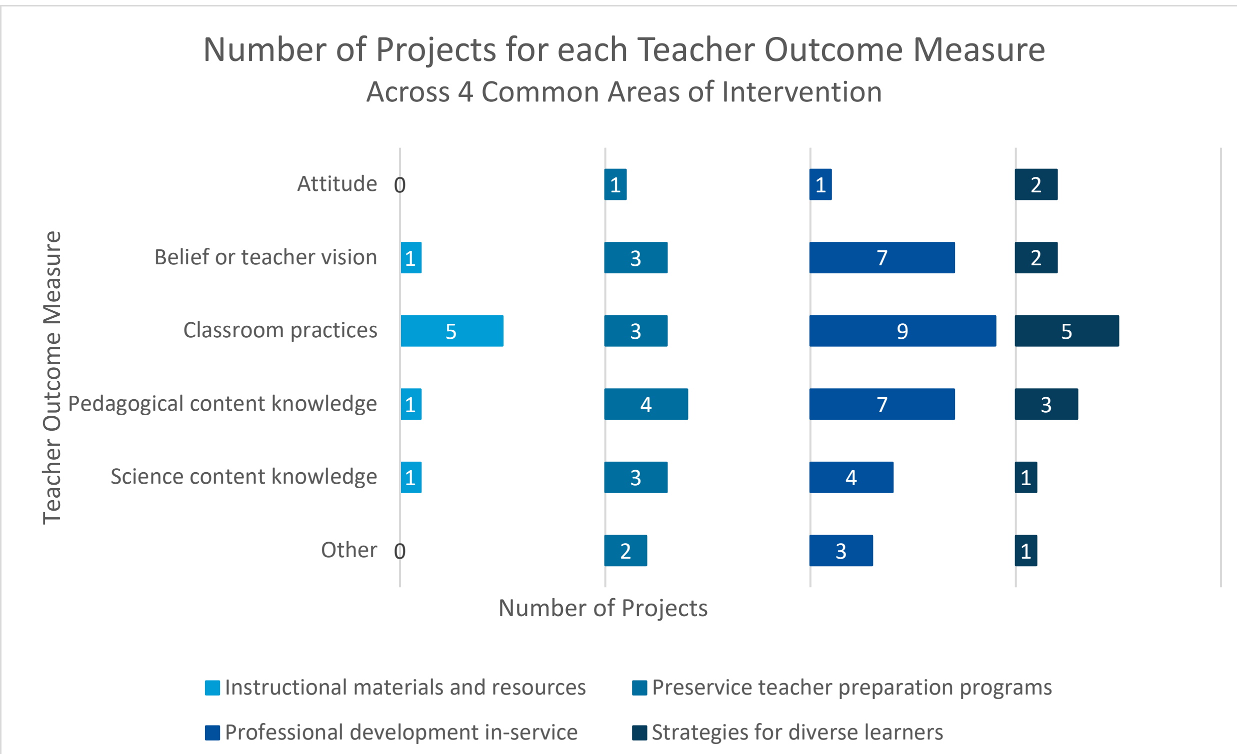
Note. Projects could be coded to more than one study design.

Researchers also used various data sources to collect evidence for their interventions. The top three most used data sources were surveys (16 projects), interviews (11 projects), and summative assessments (10 projects). Focus groups, formative assessments, and teacher evaluations were each used in 1 project.

What Was Learned About Improving PreK and Elementary Science Teaching?

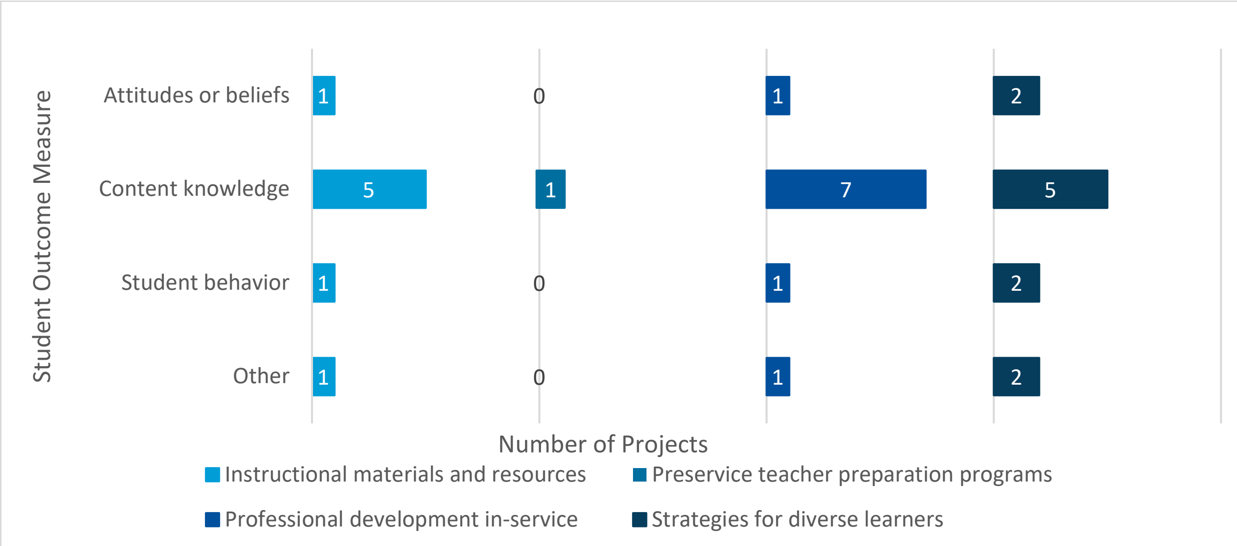
Of the 25 projects coded, 22 projects reported on teacher outcomes (e.g., classroom instructional practice, pedagogical content knowledge [PCK], beliefs), 13 projects reported on student outcomes (e.g., content knowledge, student behavior, beliefs), and 12 projects reported on both teacher and student outcomes (Exhibits 6 and 7). There is considerable overlap in projects that reported on both teacher and student outcomes and the types of outcomes reported. Only two projects (Lee et al., 2019; Russ, 2017) did not report on teacher or student outcomes. These projects reported on the instructional materials they developed using the funds from their DRK-12 grant.

Exhibit 6. Teacher Outcomes Measured by Common Area of Intervention



Note. Projects could have reported more than one outcome. The "Other" category refers to outcomes other than teacher attitudes, beliefs/vision, pedagogical content knowledge, or science content knowledge.

Exhibit 7. Student Outcomes Measured by Common Area of Intervention



Note. Projects could have reported more than one outcome. The "Other" category refers to outcomes that could not be coded to one of our four main intervention types.

We used a thematic analysis approach to synthesize what was learned from these projects focused on improving preK and elementary science teaching. For each common area of investment, we provide a high-level description of the research methodologies used in the projects and the key findings that were most often reported in each set of products. These findings were typically of a positive nature. There were not enough examples of negative or null results that resulted in the development of a theme related to any particular type of teacher intervention which could be due to selective reporting bias. Next we provide a few examples of projects that support the key findings. As mentioned earlier, the products reviewed contained varying levels of information; therefore, our general approach in describing the examples was to summarize the observable information provided by the author related to the methodology, sample, and data analysis. When possible, we provide examples of projects that utilized rigorous methodologies because they are more likely to produce stronger evidence.

What Was Learned From Preservice PreK and Elementary Teacher Preparation Program Interventions?

We coded four projects as focused on preservice teacher preparation programs. All four projects focused on improving teacher practicum by restructuring the science methods course. In addition, two of the projects added a PD component for the in-service cooperating teacher. The most reported research design used was mixed methodology (three projects) and case studies (two projects). One project included a quasi-experimental design (QED). Review of results indicated that providing PD for in-service teachers who served as preservice elementary mentors improved both preservice and in-service teachers' self-efficacy and PCK.

Researchers reported providing PD to preservice teachers and their in-service elementary teacher mentors improved self-efficacy of both teachers.

During the practicum experience, preservice teachers typically work with a mentor, an in-service elementary teacher, who provides feedback on how to improve practice. Two projects found that providing PD to both preservice teachers and their mentors led to an increase in the self-efficacy of both teachers. For example, Miller et al. (2019) used both quasi-experimental and mixed methods to study the effect of redesigning a preservice teaching program by implementing a methods course taught by professors from the College of Science and Technology and offering PD to the 46 mentor teachers. These researchers used the Teachers Beliefs about Effective Science Teaching (TBEST) survey of preservice–mentor conversations to capture change in preservice and mentor teachers' science teaching self-efficacy. Preservice teachers' self-efficacy was measured by analyzing their pre-post scores on two constructs on the TBEST survey (Confirmatory Science Instruction and All Hands-on All the Time) and transcripts of conversations with their mentors. The preservice teachers (n = 58) significantly increased their abilities to recognize and understand effective science teaching compared with the control group (n = 166). Mentor teachers' (n = 36; 78% of the participating mentors) pre-post scores for the Mentor's Belief About Learning Theory and Hands-on Pedagogy scales on the TBEST survey demonstrated a significant increase in their understanding of elementary science instruction.

Cite et al. (2017) reported similar findings about the increased self-efficacy of mentor teachers for coaching preservice elementary teachers after receiving PD. In this case study, the mentor teachers received PD from their graduate professor as they offered PD (i.e., coaching) to preservice elementary teachers. To illustrate, one mentor teacher recalled that, during a reflective conversation with her graduate professor regarding her beliefs about coaching preservice teachers, she realized an inconsistency between her beliefs and her practices. She stated that this discussion led to a change in her beliefs about how to effectively coach preservice science teachers. Her beliefs about her role as a coach changed from assessing if mentee teachers got the right answer to understanding a mentee teacher's ideas by viewing them as learners.

Researchers reported providing PD to preservice teachers and their in-service elementary mentors led to improving both teachers' PCK.

The two projects described in the section above also reported promising evidence that providing PD to preservice teachers and their in-service mentors increased the PCK of both teachers. Miller et al. (2019) found that preservice teachers who participated in the intervention taught higher quality science lessons than did the preservice teachers who did not participate. Furthermore, in both projects (Cite et al., 2017; Miller et al., 2019), mentor teachers increased their PCK for training and coaching preservice science teachers. Both studies used qualitative data analysis methods to demonstrate changes in mentor teachers' PCK. By analyzing transcripts of conversations between preservice teachers and their mentors, Miller et al. (2019) indicated that, after receiving PD, mentor teachers shifted their conversations with preservice teachers from classroom management strategies to the key elements of elementary science instruction, such as eliciting student ideas and helping students understand the role of evidence in scientific investigations. (A more detailed description of this study is in the project spotlight in Box 1.) Cite et al. (2017) used analysis of the mentor teachers' Pa-PeRs[3] to identify areas in which their PCK could be improved and ways in which their PCK related to coaching elementary teachers improved. For example, one mentor teacher stated that this intervention helped "deepen our topic-specific PCK knowledge and skills for teaching light, expanding our repertoire of instructional strategies, activities, and representations in order to support elementary teachers in building their understanding" (Cite et al., 2017, p. 289).

[3] A Pa-PeR is a "narrative account of a teacher's PCK that highlights a particular piece, or aspect, of science content to be taught" and "is designed purposefully to unpack a teacher's thinking about a particular aspect of PCK in that given content" (Loughran et al., 2006, p. 24).

Box 1. Project Spotlight: PD for Preservice Teacher Mentors

Model of Research-Based Education (MORE) for Teachers (NSF award #1119678; total funded amount approximately $3 million)

Why spotlight this project?

The project redesigned a preservice teacher preparation program by providing PD for the in-service teachers who served as mentors for preservice teachers during their practicum.

What was studied?

This project used a mixed-methods research design to study the effects of MORE for Teachers mentoring PD program on mentor teachers' beliefs about effective elementary science teaching and ability to mentor preservice teachers. It also studied how preservice teachers' beliefs about science teaching changed. Data from forty-six in-service cooperating teachers and 24 preservice teacher mentees were analyzed using the TBEST survey.

What was found?

The quantitative and qualitative findings are as follows:

- **TBEST survey results**. Miller et al. (2019) found that mentor teachers showed significant increases on the TBEST scales related to mentors' beliefs about learning theory and hands-on pedagogy based on the analysis of their paired-sample *t*-test results from the pre-post TBEST survey. Preservice teachers also had significant gains on the TBEST scales (i.e., Confirmatory Science Instruction and All Hands-on All the Time) as compared to the control group who did not participate in the restructured preservice program courses.
- **Mentoring conversations**. Miller et al. (2019) also analyzed the transcripts of the conversations that mentor teachers had with their preservice mentees. Mentoring conversations shifted from initially focusing on the preservice teachers' classroom management to how classroom management impacted students' science learning after the PD. After the PD, mentor teachers also changed how they talked about the observations of the preservice teachers. Mentors moved from a consulting stance to more of a coaching stance. In a coaching stance, mentors and preservice teachers had more balanced conversations; in a consulting stance, however, mentor teachers did most of the talking.

What Was Learned From PD Interventions for In-Service PreK and Elementary Teachers?

We coded 15 projects focused on PD for in-service teachers. The primary evidence generated from this group of projects resulted from findings reported in products from 11 of these projects, which focused on sustained PD (lasting one year or longer). Of these 11 projects, 9 used methods designed to allow for causal inference: 4 used a QED, 3 used a randomized controlled trial (RCT), and 2 included an RCT and a QED. The other 2 projects used mixed methods with descriptive research. The most salient themes were that sustained PD (lasting a year or longer) increased teachers' PCK and students' science content knowledge. In this section we highlight some of the projects aligned to these themes.

Researchers reported providing sustained PD may lead to gains in preK and elementary teachers' PCK.

Five projects measured the change in teachers' PCK after participating in PD for a year or longer. Gerde et al. (2017) conducted an RCT to investigate the impact of a mostly online PD program focused on improving science outcomes in Head Start classrooms serving students from low-income backgrounds. Seventy-one Head Start classrooms were randomly assigned to either the control or experimental group, and teachers in the experimental group received in-person PD for several days. Teachers also received online coaching for 2 years, which included video-based reflections of their lesson plans and lessons that included curriculum developed by California State University–Long Beach. Both the PD and online coaching focused on using science practices to discuss real-world scenarios and integrating literacy and mathematics in their science lessons. At the end of the intervention, preK teachers in the experimental group reported having a better understanding of what early childhood science teaching involved and implementing more science practices related to exploration, observation, experimentation, and vocabulary compared with the teachers in the control group.

Chinn et al. (2018) tested a design-based implementation intervention as part of a 3-year graduate course that included four classes from fall 2015 through summer 2018. In this course, four elementary teachers designed, implemented, and evaluated a place-based, culturally sustaining curriculum for native students from Hawaii and American Samoa.[4] Teachers created the curriculum using information gathered from interviews with elders in the community, applying community and curriculum mapping strategies, and using the Hawai'i NGSS and Na Hopena A'o standards as frameworks. Researchers concluded that teachers could incorporate pedagogies that included phenomena situated in their students' world.

Finally, Roth et al. (2017) used an RCT to investigate the impact of a video-based PD program on Grades K–8 teachers' practices and student learning. The researchers studied a yearlong PD program and analyzed teachers' PCK through video recordings of the lessons before and after the intervention. Researchers found that the teachers who participated in the video-analysis portion of the PD (n = 32) increased their use of pedagogical strategies related to making student thinking visible and creating coherent science lessons ($p < .01$). This finding was compared with teachers who received only the content deepening portion of the PD (n = 16).

[4] The American Samoan component was implemented in the last year of the project.

Researchers reported students' content knowledge increased after their teachers participated in sustained PD.

Eight of 15 projects that included a focus on in-service preK and elementary science instruction also included student outcome measures. The student outcomes measured included science content knowledge, attitudes and beliefs, student behavior, English language arts content knowledge, and career awareness outcomes. Because teachers were the primary target of these interventions, typically these projects described how teachers were placed into comparison or experimental groups or the PD that teachers received more so than reporting on student outcomes in detail. These projects found that students' science content knowledge increased following the sustained PD that their teachers received, as measured by standardized science assessments. Three of these projects included comparison groups, and the students whose teachers' received PD scored significantly higher than did students in the control classrooms.

What Was Learned From Instructional Materials and Resources for PreK and Elementary Teachers?

Eleven projects tested instructional materials or resources. As mentioned previously, these supplemental instructional materials and resources often target specific science topics or units but do not necessarily address teaching science more broadly. The primary evidence generated from this group of projects resulted in findings from products in six projects focused on the implementation of instructional resources. The most noticeable theme was implementation of targeted instructional materials or resources for specific topics or units, typically accompanied by a professional development component, can lead to changes in teachers' PCK or increases in student content knowledge.

Researchers reported that implementing targeted instructional materials and resources resulted in reported changes in teachers' PCK.

Six of the 11 projects that studied an intervention related to implementing instructional materials or resources with the addition of professional development reported changes in teachers' PCK. Of the six projects, two projects used an RCT, one project used design-based research, and three projects utilized a QED (one QED was also a longitudinal study). These projects found that teachers who received professional development and who implemented the materials or resources, such as curriculums focused on engaging preschool students in science education (three projects), a multidisciplinary curriculum that included math, science, literacy and social and emotional learning (one project), a model-based learning curriculum (one project), and a curriculum focused on community knowledge (one project), were more likely to increase their use of science practices, such as observations and predictions.

Projects that incorporated rigorous RCT or QED research methods reported significant positive changes in teacher PCK. For example, Gerde et al. (2017) conducted an RCT with 71 classrooms from eight participating preK programs to evaluate the effectiveness of a preschool program's ability to improve school readiness of students from low-income backgrounds. Teachers in the treatment group received multiple days of PD, visited a Children's Garden, and had 2 years of online coaching related to a guidebook developed at California State University–Long Beach. The report does not mention how many classrooms were assigned to the control versus experimental groups. Teachers in the treatment group used the guidebook and were coached (i.e., receiving feedback on lessons and reflections on video recordings of their lessons) on implementing literacy and mathematics into their science lessons and recognizing when to use science practices when the opportunities arose (i.e., when students saw worms on a rainy day). Teachers in the experimental group reported significant changes in their science instruction, and they used science practices (e.g., having students make observations) to facilitate student learning than teachers in the control group.

In another project (Vahey et al., 2018), a group of researchers, children's media producers, and science advisors worked together to develop a preK science curriculum, *Early Science With Nico and Nor,* to improve preK teachers' science teaching and student learning. They developed a three-unit curriculum that included science practices for core ideas in life, physical, and earth science. After 2 years of pilot testing and development, they conducted a quasi-experimental study of the curriculum implementation in 20 preK classrooms (10 classes implemented the curriculum, and 10 classrooms were in the comparison group). Based on classroom observations and interviews with teachers in the experimental group, researchers reported teachers used science practices (e.g., observing, describing, comparing, contrasting) and teachers scaffolded students' learning and changed activities to fit the needs of their students.

Finally, Zangori et al. (2017) conducted a quasi-experimental comparative study with third-grade teachers to implement a modeling-enhanced curriculum related to the water unit from the *Full Option Science System* (Delta Education, 2019) curriculum. The study included five classrooms. In Year 1 researchers collected baseline data from these teachers, and in Year 2 they implemented the modeling-enhanced curriculum. Based on classroom observations, researchers reported that, after participating in the PD and implementing the model-enhanced curriculum, teachers in two classrooms changed their classroom instruction to better support student understanding of unobservable components of the water cycle related to groundwater. These same teachers increased their use of the explanatory process, a key component of modeling-based explanations.

Researchers reported implementing instructional materials and resources increased student content knowledge.

Seven of the 11 projects that tested interventions related to implementing instructional materials or resources reported an increase in students' science content knowledge as measured by assessments and classroom observations. Of these seven projects, six of them included professional development for teachers. four of these projects were described in the section above (reported changes in PCK). In the RCT conducted by Gerde et al. (2017), preK students whose teachers implemented the California State University–Long Beach guidebook activities increased their abilities to support claims using evidence compared with the control group classrooms.

Romance et al. (2018) is an example of a project that studied an intervention that did not include a professional development intervention as far as we could tell from the project outcomes report. This project conducted a longitudinal study of the effect of an evidence-based instructional model that incorporated literacy into the science curriculum (resource), *Primary Science IDEAS,* on student science and reading knowledge. Students in Grades 1 and 2 whose teachers implemented science instruction that incorporated reading/literacy during a 3-year period increased their scores on the reading and science subtests of the Iowa Test of Basic Skills.

What Was Learned From Interventions That Taught PreK and Elementary Teachers' Strategies for Diverse Learners?

We coded eight projects that focused on preK and elementary teachers' strategies for teaching diverse learners. Three of the eight projects provided descriptions of products designed to address the needs of diverse learners but provided little information about teacher or student outcomes, if any. For the remaining five projects, four projects studied strategies to support ELs, and one project tested a strategy for engaging native Hawaiian students. Of these five projects, two projects used mixed methods, two projects used design-based research, and one project used an RCT. The major theme that emerged from these five projects was that incorporating strategies to specifically support the student population of interest was associated with reported changes in teachers' PCK.

Researchers reported use of instructional strategies designed for diverse learners influenced teachers' PCK.

Based on findings from five projects, preK and elementary teachers' classroom practices changed after implementing instructional strategies intentionally designed for diverse learners, specifically ELs and native Hawaiian students. Four of the projects studied interventions that included supports for ELs such as integrating elementary science, engineering, and language arts curriculum aligned to NGSS with EL supports, embedding STEM instructional practices that support ELs, incorporating public media that support EL science learning, and developing an urban ecology curriculum that engages ELs. The fifth project studied a placed based curriculum that included strategies to support native Hawaiian students.

Two of these projects (El-Moslimany et al., 2017; Wolsky & Taylor, 2016) studied an intervention for preK teachers. El-Moslimany et al. (2017) used design-based research to develop and evaluate a PD program that investigated STEM teaching strategies to support preK ELs. This project evaluated the PD program after completing multiple iterations of the PD with different participants. The first iteration included 45 teachers and eight master teachers (coaches), and the second iteration included 25 teachers and six coaches. One outcome of this project was a description of key elements to include in this type of PD, such as reflective coaching strategies. Reflective coaching allows teachers to have collaborative conversations with their mentors. In addition, El-Moslimany et al. (2017) found that participating in the intervention led teachers to become more interested in providing opportunities in their classrooms to support ELs. The other project that focused on preK teachers (Wolsky & Taylor, 2016) used a mixed-methods approach to investigate the effectiveness of incorporating a science curriculum that that has been fully translated into Spanish and public media (e.g., animations, games, mobile apps) to motivate preK students to explore the world around them. By analyzing survey and focus group data, researchers reported that preschool teachers increased the amount of science activities they did in their classrooms and increased their skills in teaching science.

Another project (Lee et al., 2016) used an RCT to study the impact of an intervention for fifth-grade ELs. This project tested the implementation of a curriculum and PD in a 3-year period. This project analyzed data from a researcher-developed survey and a summative assessment completed by participants from 33 randomly assigned treatment schools (116 fifth-grade teachers) and 33 control schools (116 fifth-grade teachers) across three districts in one state. Researchers found that this intervention had a positive effect on teachers' science knowledge in all four measures of instructional practices: teaching for understanding, teaching for inquiry, language development strategies, and home language use. Box 2 provides a more detailed description of this study.

Box 2. Project Spotlight: Teaching Strategies for Els

Developing Integrated Elementary Science, Engineering, and Language Arts Curricula Aligned With NGSS (NSF award #1209309; total funded amount approximately $5 million)

Why spotlight this project?

This project demonstrates a study tested across three common areas of intervention: in-service teacher PD, instructional materials or resources, and strategies for diverse learners. In addition, this study uses a rigorous study design (cluster RCT), and the Principal Investigator had two projects funded during the 2011–15 time period (both projects totaled almost $5 million).

What was studied?

This project used a cluster RCT to study the effects of the Promoting Science Among English Language Learners (P-SELL) intervention on elementary teachers' science content knowledge and instructional practices. Sixty-six fifth-grade classrooms from three different school districts were randomly assigned to the control and treatment groups (33 classrooms in each group).

What was found?

The quantitative findings are as follows:

- **Teachers' science content knowledge**. Lee et al. (2016) developed, piloted, and psychometrically validated a science test that included publicly released National Assessment of Educational Progress, Trends in International Mathematics and Science Study, and selected state assessment items that measured fifth-grade content designed for 8th- or 10-grade students. Two test forms were created, each having 30 multiple choice and three open-response items. Although there was no significant difference in the science test scores of the teachers in the treatment and control groups, multilevel analysis showed that the intervention had a positive impact on teachers' science knowledge.
- **Teachers' instructional practices**. Lee et al. (2016) also administered a revised version of a questionnaire from their previous research (see Lee & Maerten-Rivera, 2012, for details) that included two constructs: (a) teacher demographics and background and (b) teachers' self-reported practices in science teaching. Similar to the science content knowledge findings, multilevel analysis showed that the intervention had a positive impact on teachers' instructional practices (i.e., teaching for understanding, teaching for inquiry, language development strategies, and home language use).

Finally, one project (Chinn et al., 2018) studied an intervention for teaching strategies for native Hawaiian students and found that teachers who participated in a yearlong graduate seminar focused on training teachers to develop curricula that implements Native Hawaiian and 21st century STEM knowledge and practices, Seminar in Place-Based Education, increased their interest and use of indigenous texts and language in their elementary classes. This project used a design-based implementation research model of STEM PD.

What Are the Key Takeaways?

This synthesis examined DRK-12 projects that tested interventions to improve preservice teacher preparation programs, in-service teacher PD, instructional materials and resources, and strategies for diverse learners. In this section, we summarize the three key takeaways from this synthesis.

One key takeaway from this synthesis is the potential importance of providing PD for cooperating in-service teachers who serve as mentors for preservice elementary teachers. Prior research has reported that elementary teachers who serve as mentors for preservice teachers can lack the knowledge and skills to provide mentoring and lack training to build their capacity as mentors (Hudson, 2007). Four of the projects reviewed focused on preservice teacher preparation programs, and two of the projects provided PD for the in-service mentor teacher. The interventions studied reported improvements in the PCK and self-efficacy of both the preservice and mentor teachers. Incorporating intentional strategies for building in-service teachers' mentoring capacities may be a promising strategy for preparing preservice teachers for entering the classroom.

Another key takeaway from this synthesis is that elementary teachers may benefit from participating in sustained PD that lasts a year or longer. This takeaway is consistent with findings in prior literature. Desimone and Garet (2015) explicitly posited that PD that lasts throughout the school year is a best practice that leads to change in teacher outcomes. DRK-12 grants are awarded for 3 to 5 years, but some projects tested PD interventions that lasted less than 1 year. The projects that reported the most changes in teacher practice and increasing student content knowledge were those projects that provided preK and elementary teachers with sustained PD. Both preservice and in-service teachers who received sustained PD also showed increased science PCK. Supporting and testing longer term PD interventions may be an important consideration for researchers, developers, and funders attempting to help improve elementary science teaching.

The final key takeaway is the importance of continued research and development related to strategies for diverse student populations. Although it was surprising that most of the projects funded related to strategies for diverse learners focused on supporting ELs, they produced evidence suggesting that teachers are more likely to consider the needs of this group of students if they are explicitly taught strategies to do so.

Opportunities for Future Research

In this section, we provide recommendations for future research based on our synthesis of a set of recent DRK-12 projects focused on improving preK and elementary science teaching. We do not assume that these recommendations are a comprehensive reflection of the collective research on elementary science instruction.

Increase research in preK and lower elementary grades.

Few projects reviewed tested interventions in preK and K–2 grades, reflecting a broader limitation in the research on science teaching. McClure et al. (2017) noted that "currently early STEM research funding appears to be skewed toward older children" (p. 7). Because early learning for young children in science can set the stage for future science learning (McClure et al., 2017; NASEM, 2021; NRC, 2012), teacher preparation and PD for science teaching with young children is an important are for further research and development. Opportunities are available through the DRK-12 program and other funding sources to focus more specifically on preK and early elementary classrooms, across the four common areas of investment framed in this synthesis study. Considering the takeaways of this study, previously highlighted, sustained PD programs and PD for mentor teachers are potential priorities for future research with preK and K–2 teachers.

Expand research and investment in interventions for diverse elementary student populations beyond ELs.

Among the underrepresented populations in STEM, the group of DRK-12 projects reviewed primarily focused on ELs. ELs are an important population for research and development for improving elementary teaching, as are other groups that were not as much the explicit focus of the projects. A long-standing issue is that students of color have limited access to quality STEM instruction, which impacts their abilities to participate in the STEM workforce. This issue has been cited throughout the literature as an issue of social justice (NRC, 2012). This issue is further complicated by the ongoing COVID-19 pandemic, which has disproportionately affected Black, Brown, and Indigenous students (NASEM, 2021). Research on interventions on improving elementary science teaching for all underrepresented and marginalized communities is a crucial area of investment for research.

Increase the Use of Rigorous Research Methodology

Improving elementary science teaching is a key priority for students' future success in STEM. Given the small scale of research in this area, it would be beneficial for researchers to use more rigorous research methods that could generate results that are generalizable and can be scaled up. Of the 25 projects reviewed, only 3 projects used a RCT design; therefore, we could not confidently report the effectiveness of the outcomes of the 22 projects, which suggests an area for improvement in grantees producing and publishing work, such that findings are more readily reproducible to educators and other researchers. It may be helpful for NSF and other funders to consider how to provide greater incentives or expectations for the level of rigor in projects to push this area of research forward.

Conclusions

The DRK-12 program has made a significant investment in improving preK and elementary science teaching in four common areas of interest: (a) preservice preK and elementary teacher preparation programs, (b) in-service teacher PD, (c) instructional resources for preK and elementary teachers, and (d) strategies for diverse student populations. Most of the funded projects tested in-service PD interventions and focused on Grades 3–5 teachers. Promising results suggest that providing PD for preservice elementary teachers and their in-service mentor teachers as part of the preservice teacher preparation program can improve both teachers' self-efficacy and PCK, sustained PD for a year or longer can increase in-service teachers' PCK and students' content knowledge, and strategies that specifically focus on language development for ELs can lead to positive changes in classroom practices. Although investment in this area has provided important insights on how to improve this field, we also identified some gaps that we believe could be addressed by STEM researchers in the coming years, including the following: (a) design interventions specifically for the lower elementary grades; (b) develop strategies for diverse populations, aside from ELs; and (c) increase rigorous studies in science education.

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Appendix A. Review Methodology

This appendix provides an overview of the synthesis methodology that we used for this report.

Project Selection

From NSF's website, we searched for awards meeting the following criteria: (a) had an original award date between January 1, 2011, and December 31, 2015; (b) were tagged with DRK-12 program element code 7645, and (c) were active or completed. This search yielded 428 awards. However, some awards linked to the same project. For instance, a "collaborative research" project will have multiple NSF awards given to separate institutions, although the awards are part of the same project. After removing duplicate awards based on matching titles and abstracts, we identified 376 unique projects. We selected the award date range to focus on projects that were recently completed or are close to completion.

We searched for preK-related and elementary-related keywords in the award abstracts for these 376 projects (e.g., *early childhood*, *early scien**, *prek*, *pre-k*, *kindergarten*, *first grade*, *grade 1*), narrowing the list of potential projects to 112 projects. An experienced systematic reviewer (David Miller) reviewed award abstracts for these 112 projects, eliminating ones that were clearly irrelevant to preK or elementary science education and designating borderline cases for group discussion. In this screening process of award abstracts, we selected projects relevant to improving preK or elementary science teaching. This criterion meant the project aimed to study an intervention or practice to improve early science teaching such as through (a) pre-service preparation programs, (b) professional development for in-service teachers, (c) resources or tools to teach science topics, or (d) strategies for teaching diverse learners.

The award abstracts have at least two major limitations: (a) they are brief synopses that likely do not capture the full extent of each project's goals, and (b) the project goals may change between the time of award and the time of research. Given these limitations, we therefore erred on the side of inclusion when in doubt, so that we could use the associated products to inform our eligibility decisions. We removed projects if we could not find at least one product that was relevant to improving preK and elementary science teaching (see next section). This process yielded 25 projects related to improving preK and elementary science teaching.

Product Search

We used six sources to identify the publications and resources that the selected projects produced: Web of Science, ERIC, PsycINFO, Google Scholar, Research.gov, and the CADRE website (cadrek12.org). This search strategy targeted (a) documents that referenced the numeric award ID and/or (b) documents that project leaders listed on the Research.gov or CADRE websites.

Using the three literature databases (Web of Science, ERIC, and PsycINFO), we searched for the numeric award ID in the funding information search fields (e.g., the grant number field for Web of Science). Using Google Scholar, we searched for documents whose full text contained the numeric award ID and the terms “NSF” or “National Science Foundation.” Google Scholar can complement searches of scientific databases by finding relevant gray literature sources (Haddaway et al., 2015). We conducted these searches using the full list of award IDs connected to the 25 selected projects. For instance, a collaborative research project will have multiple award IDs, and we searched for documents containing any of those award IDs. To complement these award ID-based search methods, we developed web scrapers in the rvest package in R (Wickham, 2019) to automatically extract citations and other resources (e.g., links to project websites and videos) from the project-specific pages on the Research.gov and CADRE websites. For Research.gov, this search included the public project outcome reports.

We merged the search results from these six different sources using the *revtools* package in R (Westgate, 2019), yielding 333 unique citations after removing duplicates. These citations indexed a diverse set of records and abstracts, including journal articles, conference presentations, book chapters, project websites, project outcome reports, videos hosted on the CADRE website, and other miscellaneous records. After identifying these citations, we also sent emails to each project’s PI listing the citations we found, asking the PIs to provide any other products relevant to improving preK and elementary science teaching.

Product Selection

For each NSF project, we identified between one and three products that were most closely related to improving preK and elementary science teaching. Product screening occurred in two main phases: (a) identify the products related to the synthesis topic and (b) select the one to three products per project that were the most complete and relevant. We limited the maximum number to three products per project for reasons of practicality (i.e., create a manageable number of products to review) while ensuring representation across projects.

For the first screening phase, we identified documents that reported empirical research (quantitative or qualitative) addressing at least one of the following common areas of intervention for preK and elementary teachers:

- Preservice teacher preparation programs
- Professional development interventions for in-service teachers
- Instructional materials and resources
- Strategies for teaching diverse student populations

Screeners considered three questions: (a) Does the study address Grades preK–5? (b) Does the study address an intervention or practice to improve preK and elementary science teaching? (c) Is the study an empirical research project (excluding purely conceptual papers and discussion papers)? Documents were retained in screening Phase 1 if the answer was "yes" to all three questions, reducing the number of identified citations from 333 to 63.

For screening Phase 2, we further restricted the corpus by limiting the maximum of products to three per project, for reasons of practicality, as noted earlier. We prioritized products that were

- peer-reviewed (e.g., journal article as opposed to conference poster),
- the most relevant to improving preK and elementary science teaching, and
- provided the most complete reporting of results related to improving preK and elementary science teaching (e.g., when similar sets of results were reported across multiple products, such as a journal article and a conference paper).

This report's lead author trained junior staff for screening Phase 1. Training steps included (a) providing example study screening decisions during the initial training phase, (b) listing common reasons for exclusion (e.g., study focused on identifying characteristics of "good" teachers), and (c) conducting periodic dual screening checks on the junior screeners' decisions. Screening phase 2 was, admittedly, more subjective, so the lead author conducted the Phase 2 screening rather than training junior staff. Phase 2 screening reduced the number of citations from 63 to 40.

Product Structured Coding

We quantitatively coded the products for the presence of key features, such as the common area of intervention studied or the research methods used. The "What Was Studied?" section provides the results from this coding. As noted in that section, we coded at the product level and then summarized frequencies at the project level, summarizing 40 products nested within 25 NSF projects. We summarized at the project level as a meaningful unit of analysis that gave equal weight across projects (rather than weighting toward projects that produced many documents).

We created a sheet using a Microsoft Word document with the structured codes and text descriptions for each coding category (see Appendix B for a complete list of codes). The lead author trained junior staff on an example set of three study articles, met with them on a weekly basis to address questions about the coding categories, and reviewed their codes to help ensure consistency across coders.

Synthesis of Empirical Findings

We also summarized the studies' empirical results in three steps. First, we coded lines of text from the results sections using NVivo, categorizing each relevant text section on results about the four common areas of intervention: preservice preK and elementary teacher preparation programs, professional development for in-service preK and elementary teachers, instructional materials and resources for preK and elementary teachers, and preK and elementary teaching strategies for diverse learners. We chose a qualitative synthesis approach, rather than a quantitative meta-analysis approach, because the studies varied widely in research methods and often were qualitative in nature (Thomas & Harden, 2008). For instance, many studies were in-depth qualitative case studies based on interview data, for which extraction of quantitative effect sizes and formal meta-analysis would be inappropriate.

Limitations

The synthesis is not intended to systematically represent all DRK-12 grants that included an emphasis on preK and elementary science teaching in recent years. This research focused on a purposively selected sample of projects feasible to study with the methods summarized in this paper. The methods rely on publicly available publications and products, restricting the observable data about projects to what is reported in these documents. In addition, the goals, interventions, methods, and outcomes of these projects varied considerably, potentially limiting how coherently we can synthesize contributions across projects.

Appendix B. Coding Structure

Exhibit B1. Codes Used to Synthesize Projects

Coding field	Response options	Definitions
1. What problems or topics related to elementary science teaching were studied?		
Interventions in four common areas	• Preservice teacher preparation programs • PD interventions for in-service teachers • Instructional materials and resources • Strategies for teaching diverse student populations (e.g., ELs, socioeconomic status, race/ethnicity, gender, students with disabilities, urban students, rural students)	
Teacher demographics	• Experience level or number of years teaching • Level of education	
Elementary science content (What Works Clearinghouse, 2020)	General science	Related to science content in two or more of domains listed as well as concepts that cut across disciplinary boundaries, known as “cross-cutting concepts” (e.g., the role of patterns; cause-and-effect relationships; stability and change in natural systems); includes knowledge of science practices (from the “science and engineering practices” described in the NGSS), such as forming hypotheses and making predictions, control of variables, and planning and conducting systematic investigations (experiments and observations)
	Life science	Includes the structures and functions of living things at different scales; growth, development, and reproduction of organisms; information processing and behavior in organisms; matter and energy transfer in living things and ecosystems; inheritance of and variation in traits;

Coding field	Response options	Definitions
		natural selection and adaptation; evidence of common ancestry; biodiversity
	Earth and space science	Includes the structures, properties, and materials of Earth; tectonics; Earth's place in the solar system and universe; changes in Earth across time; water, weather, and climate; energy in Earth systems; biogeology
	Physical science	Includes the properties of matter and changes in matter; force, motion, and interactions of forces; energy and energy transfer and conservation; relationship between energy and forces; properties of waves; electromagnetic radiation
2. What methods and approaches were used or developed to test interventions and resources for elementary science teachers?		
Study design	Randomized controlled trial	Randomly assigns members to the experimental group (receives intervention) and control group (does not receive intervention). One variable is manipulated to determine its effect on other variables.
	Quasi-experimental	Members of the experimental and control groups are not randomly assigned. One variable is manipulated to determine its effect on other variables.
	Case study	A single subject or case describes the development of an individual or group across time.
	Observational	Researchers observe and record the effect of an intervention on a group/case.
	Longitudinal	Measures behaviors of a group people across time.
	Correlational	Looks for relationships between two or more variables in the same environment (cannot determine cause and effect).
	Mixed methods	Studies include the collection of both qualitative and quantitative data.

Coding field	Response options	Definitions
	Other	
Type of intervention tested (Slavin et al., 2012; Zee & Koomen, 2016)	• Professional development – Workshop (a single, short educational program designed to teach or introduce practical skills, strategies, or ideas) – Course (credit or noncredit college/university course) – Video-case reflection (a video recording of classroom activities) – Professional learning community (a group of professionals who meet regularly to share ideas and improve teaching and/or student outcomes)	Activities designed to change teacher practice and/or student outcomes
	Curricula	A set of learning objectives, content, and materials used to teach content
	• Educational tools – Science kits – Multimedia content/web-based laboratory exercises	Materials used to teach content, such as laboratory equipment and online simulations
	Mentoring/coaching	An experienced professional meets regularly with a teacher to assist him/her in changing their practice
	Teacher preparation program	Undergraduate courses taken to prepare students to become teachers
	Other	

Coding field	Response options	Definitions
Duration of the intervention tested	• One time (a specific number of hours or 1 day) • A week (multiple days) • A month • Semester • One year or longer • Other	
3. What types of evidence were generated about the implementation and outcomes of the interventions and resources?		
Data source (CADRE, 2014; Saylor & Johnson, 2014; Slavin et al., 2012; Zee & Koomen, 2016)	• Summative assessment (e.g., standardized tests) • Formative assessment (workshop feedback from participants) • Video-based reflection (evaluation) • Artifacts (e.g., examples of student work, meeting notes, meeting agendas) • Interviews • Anecdotal note-taking • Surveys • Focus groups • Teacher evaluation • Classroom observations • Other	
Teacher outcomes	Attitude	How teachers feel about teaching
	Classroom practices	Routines or strategies that teachers employ (e.g., extent to which teachers use inquiry-based approaches; amount of time spent on science during a typical day; accuracy of science content evident in teaching)
	Pedagogical content knowledge	Knowledge about content and how to teach it
	Science content knowledge	Knowledge about science

Coding field	Response options	Definitions
	Belief/teacher vision	Hammerness (2001) defined teacher vision as “a set of images of ideal classroom practice for which teachers strive” (p. 143).
	Other	
Student outcomes (CADRE, 2014)	• Attitudes/beliefs • Student behavior (e.g., completion of homework, test preparation, cooperative work, attendance, discipline violations) • Content knowledge • Other	
4. What types of products and content did the projects disseminate to researcher and educator audiences?		
Product types (CADRE, 2014)	• Presentations/poster sessions • Journal articles • Websites • Professional networks • Workshops • Newsletters • Commercial products or publications • Popular media • Reports (not articles or books) • Social media • Blogs • Books/book chapters • Webinars • White or working papers • Curricula • Course • Other	

Appendix C. Supplemental Table

Exhibit C1. Information About Projects Included in the Synthesis

Principal investigator	Project name	NSF award number and title	Product type	Intervention type: Preservice	Intervention type: Professional development for in-service	Intervention type: Instructional materials and resources	Intervention type: Strategies for diverse learners
Hasan Deniz	Developing Integrated Elementary Science, Engineering, and Language Arts Curricula Aligned With Next Generation Science Standards	1551143	Research summary report		x		
			Journal article		x		
Daniel Hanley	Model of Research-Based Education for Teachers	1119678	Journal article	x			
			Project outcomes report	x			
			Journal article	x	x		
Maria Araceli Ruiz-Primo	Collaborative Research: Examining Formative Assessment Practices for English Language Learners in Science Classrooms	1118876	Graduate thesis				x
Laurie Van Egeren	Cluster Randomized Trial of the Efficacy of Early Childhood Science Education for Low-Income Children	1119327	Poster		x		
			Project outcomes report		x		
			Journal article		x		
Okhee Lee	Developing Integrated Elementary Science, Engineering, and Language Arts Curricula Aligned With Next Generation Science Standards	1209309	Journal article		x	x	x
			Book chapter		x	x	x
Leema Berland	Fostering Pedagogical Argumentation: Pedagogical Reasoning With and About Student Science Ideas	1316232	Journal article				x
			Journal article			x	

Principal investigator	Project name	NSF award number and title	Product type	Intervention type: Preservice	Intervention type: Professional development for in-service	Intervention type: Instructional materials and resources	Intervention type: Strategies for diverse learners
Sara Lacy	Collaborative Research: Focus on Energy: Preparing Elementary Teachers to Meet the NGSS Challenge	1418052	Journal article		x		
			Research report		x		
Okhee Lee	Supports for Science and Mathematics Learning in Pre-Kindergarten Dual Language Learners: Designing and Expanding a Professional Development System	1503330	Journal article			x	x
Delinda Van Garderen	QuEST: Quality Elementary Science Teaching	1316683	Journal article		x		
			Journal article	x	x		
Alissa Lange	Promoting Science Among English Language Learners (P-SELL) Scale-Up	1417040	Journal article		x		x
			Conference paper		x		x
Julie Sarama	Early Childhood Education in the Context of Mathematics, Science, and Literacy	1020118	Journal article			x	
Pauline W. U. Chinn	Exploring Ways to Transform Teaching Practices to Increase Native Hawaiian Students' Interest in STEM	1551502	Project outcomes report		x		x
Craig Strang	Collaborative Research: Researching the Efficacy of the Science and Literacy Academy Model	1223021	Journal article		x		
			Journal article		x		
Patrick Smith	Knowledge Assets to Support the Science Instruction of Elementary Teachers (ASSET)	1417838	Journal article			x	
Nicole Wickler	Exploring Ways to Enhance Science Learning for English Language Learners Through Improvement in Teacher Self-Efficacy Beliefs	1321242	Journal article		x		
Temple Walkowiak	PROJECT ATOMS: Accomplished Elementary Teachers of Mathematics and Science	1118894	Journal article	x			
			Journal article	x			

Principal investigator	Project name	NSF award number and title	Product type	Intervention type: Preservice	Intervention type: Professional development for in-service	Intervention type: Instructional materials and resources	Intervention type: Strategies for diverse learners
Philip Sadler	Professional Development Models and Outcomes for Science Teachers (PDMOST)	1417438	Journal article			x	
			Journal article		x		
Cory Forbes	Modeling Hydrologic Systems in Elementary Science (MoHSES)	1220675	Journal article			x	
			Journal article		x		
Christopher Wilson	Videocases for Science Teaching Analysis Plus (ViSTA Plus): Efficacy of a Videocase-Based Analysis-of-Practice Teacher Preparation Program	1220635	Conference presentation	x			
Thomas Moher	DIP: Community Knowledge Construction in the Instrumented Classroom	1324977	Journal article			x	
			Research report			x	
Nancy Romance	An Integrated Instructional Model for Accelerating Student Achievement in Science and Literacy in Grades 1–2	1316433	Project outcomes report			x	
Marisa Wolsky	Peep's World/El Mundo de Peep	1222607	Project outcomes report		x		x
Magaly Lavadenz	Quality Urban Ecology Science Teaching for Diverse Learners	1503519	Project outcomes		x		x
Linda Darling-Hammond	Improving Competency in Elementary Science Teaching	1317068	Project summary report		x	x	
Philip Vahey	Next Generation Preschool Science: An Innovative Program to Facilitate Young Children's Learning of Science Practices and Concepts	1316550	Project outcomes report			x	

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