Research Article

Lesson Study for Accessible Science: Building Expertise to Improve Practice in Inclusive Science Classrooms

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Abstract: The Lesson Study for Accessible Science (LSAS) project created middle school teams comprised of both science and special education teachers who engaged in collaborative work to improve instruction in inclusive classrooms. The intervention is based on Lesson Study, a professional development approach that originated in Japan, which supports the systematic examination of practice and student understanding. Using an experimental design, teams of teachers were randomly assigned to the LSAS intervention or to a wait-list comparison group. The results of this study suggest that science and special educators in the LSAS intervention were able to generate more accommodations for students with learning disabilities, and they increased their ability to set an instructional context and adapt an instructional plan to meet science learning goals for all students in an inclusive classroom. They did not, however, show significant increases in their knowledge of science content or learning disabilities. © 2012 Wiley Periodicals, Inc. J Res Sci Teach 49: 1012–1034, 2012
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Increasingly, students with disabilities learn science in "regular" public school classrooms. This is particularly true for students with learning disabilities; nationally, 99% receive some instruction in general education classes, with 54% of this group spending at least 80% of their school day in this setting (U.S. Department of Education, 2010). However, access to a regular classroom environment does not ensure access to science learning. Researchers and educators consistently report lower achievement levels for students with disabilities as compared with their peers without disabilities (Grumbine & Alden, 2006; Lynch et al., 2007; Ofiesh, 2007; Scruggs & Mastropieri, 2004). For instance, in the most recent report from the National Assessment of Educational Progress (U.S. Department of Education, 2011), 11% of eighth grade students with disabilities scored at or above proficient in science compared with 35% of students with no disabilities. The situation does not often improve when students reach high school. Many with disabilities are not encouraged to take the courses they will need to pursue a career in science, technology, engineering, or mathematics (STEM) or to participate in science experiences that will enable them to become scientifically literate citizens who can make informed decisions about policies and issues (Burgstahler, 1994; Burgstahler & Chang, 2009; Mastropieri et al., 2006). Moreover, many non-science careers

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"... will require that students have the ability to collaborate and solve problems using STEM skills. Struggling students are no exception—they will need the same types of knowledge and skills, and will often require additional supports to be successful" (National Center for Technology Innovation, 2010, p. 1).

Furthermore, without opportunities and supports in science education, chances that capable students with learning disabilities will pursue STEM careers are greatly reduced. A recent report from the National Center for Science and Engineering Statistics (National Science Foundation, 2011) indicates that, although the numbers of science and engineering doctoral students have increased in the last ten years, the number of scientists and engineers with disabilities since birth (which would include learning disabilities) are few. Overall, people with disabilities are underrepresented in the science and engineering workforce compared to the population as a whole.

Challenges of and Accommodations for Middle School Students With Learning Disabilities

Moving students toward proficiency is no easy task, in part because, as Kesidou and Roseman (2002) revealed in Project 2061 analyses of middle school textbooks for the American Association for the Advancement of Science, U.S. science education is often a mile wide and an inch deep. Middle school teachers are asked to teach an enormous amount of science content (Schmidt, Wang, & McKnight, 2005), to help students learn to conduct scientific inquiry (National Research Council, 2007), and to prepare students for high school work. The content knowledge that the National Science Education Standards (NSES) lay out for middle school science is ambitious (National Research Council, 1996), and the content standards of states and local districts often go further. As a result, teachers and students in middle school science classrooms scramble to "cover" the curriculum, and deep understanding can suffer as a result (National Research Council, 2007). In an effort to address this concern, the revision of NSES—*Next Generation Science Standards*—based on *A Framework for K-12 Science Education* (National Research Council, 2012), will focus on a limited set of core ideas and crosscutting concepts. The conceptual breath of the *Next Generation Science Standards* will be more focused to allow for deep exploration of important concepts (National Research Council, 2012), however, this will likely still pose challenges for students with learning disabilities.

In addition to challenges associated with learning the substantive content, middle school is also where more demands are placed on reasoning skills to develop abstract and detailed models using atomic-level explanations of physical phenomena and cellular-level explanations of life processes and structures (National Research Council, 2012). Middle school students find it difficult to make sense of phenomena that are "invisible," for example, cells (Tregigdo & Ratcliffe, 2000) or plate tectonics (Gerard, Spitulnik, & Linn, 2010), and to understand and engage in complex scientific processes such as controlled experimentation (National Research Council, 2007) or argumentation (Berland & McNeill, 2010; Kuhn, 2010; Sandoval & Reiser, 2004). With the learning challenges that accompany middle school science, ensuring curricular access and support is essential for students with learning disabilities.

The developmental and curricular challenges of learning science in middle school are exacerbated when students have a learning disability. The Individuals with Disabilities Education Act (2004) defines learning disabilities broadly, as:

> ... a disorder in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, that may manifest itself in

> the imperfect ability to listen, think, speak, read, write, spell, or do mathematical calculations . . . (U.S. Department of Education, 2006).

As suggested by this definition, learning disabilities can influence student learning in numerous and very different ways in science. Research shows that many students with disabilities find it difficult to effectively classify, systematize, find relationships (e.g., similarities and differences, cause and effect), or craft analogies about facts or data (Gore, 2004; Ivie, 1998; Mastropieri et al., 2006; Stefanich, 2007). They also experience difficulties with inductive and deductive thinking (Mastropieri et al., 2006), and with linking ideas to chains of reasoning (Lynch et al., 2007).

Instructional and curricular accommodations have been shown to have a positive influence on students with learning disabilities (Cameto, Knokey, & Sanford, 2011; Campbell, Wang, & Algozzine, 2010; Carter, Prater, & Dyches, 2008; Odom et al., 2005). Accommodations are techniques and materials that help students engage in the learning process, complete assignments, and demonstrate their knowledge without altering the level or amount of content students are expected to learn (National Dissemination Center for Children with Disabilities, 2010; Learning Disabilities Association, 2011). In science, accommodations often focus on helping students develop stronger procedural skills (e.g., how to follow a lab protocol, how to use equipment), apply general organizational strategies (e.g., how to set up clear data charts), and transfer reading and mathematics skills to the science content area (e.g., how to find a main idea in a science reading) (Stefanich, 2007). These interventions are critical for removing barriers, engaging students in scientific work, and helping them to learn facts and skills, but they do not always explicitly address scientific thinking.

By middle school, students with learning disabilities have often acquired strategies to help them make sense of content (e.g., employing a graphic organizer to help them consider and compare structures of single and multicellular organisms they observed), but they cannot always evaluate when it is appropriate to use a particular strategy or when to adapt strategies for new tasks (Archer & Hughes, 2011). Therefore, it is critical for educators to anticipate where students will have difficulty during a lesson and provide instructional techniques that enable them to employ strategies efficiently. Hughes (2011), citing the work of Archer and Hughes (2011), Hattie (2009), Gersten et al. (2009), Vaughn, Gersten, and Chard (2000), and Mastropieri, Scruggs, Bakken, and Whedon (1996), concludes in his meta-analysis that students with learning disabilities perform better when teachers explicitly teach them to internalize strategy use, practice applying strategies to increasingly complex problems/assignments, absorb and use feedback, and generalize to other tasks or situations.

Science and Special Educator Collaboration to Increase Curricular Access

Prior research and practice has shown that professional development that fosters collaborative exchanges among teachers improves content knowledge and practice. Findings of professional development effectiveness (e.g., Desimone, 2009; Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001; Johnson, Kahle, & Fargo, 2007; Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Saunders, Goldenberg, & Gallimore, 2009) suggest that change in teacher knowledge and practice can be predicted for schools in which teacher colleagues participate in professional development together. Other work (Hoban, 2002; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Penuel, Riel, Krause, & Frank, 2009; Penuel et al., 2007) indicates that building professional relationships and trust through collaborative, localized efforts leads to teacher knowledge and changes in practice—"Such trust allows leaders and teachers more latitude and discretion in making difficult decisions, creates clearer understandings of role obligations, and sustains commitment to improving student outcomes'' (Penuel et al., 2007, p. 929, describing findings from Frank, Zhao, & Borman, 2004). Furthermore, professional development which focuses on teachers' collaborative analysis of their practice in a real classroom context can contribute, in as little as a year-long program, to significant teacher and student learning (Heller, Daehler, Wong, Shinohara, & Miratrix, 2012; Roth et al., 2011).

Nolet and McLaughlin (2000, 2005) found that curricular access for students with learning disabilities was more likely when general and special educators worked collaboratively to understand the curriculum, develop shared learning goals for students with learning disabilities, and develop well-matched instructional strategies, including accommodations. This collaboration enabled the teachers to maintain high educational standards through differentiated instruction. In classrooms where this collaboration did not occur, special education became ''a remedial 'catch-all' where teachers worked to pull students along in the curriculum'' (Nolet & McLaughlin, 2000, p. 112). Intervention studies that include science and special educator co-teaching components present positive effects as well (Brusca-Vega, Brown, & Yasutake, 2011; Mastropieri, Scruggs, & Graetz, 2005; McDuffie, Mastropieri, & Scruggs, 2009).

Recent research and reviews of the literature are beginning to illuminate the complex factors that impact science and special educator collaboration (Bouck, 2007; Brigham, Scruggs, & Mastropieri, 2011; Isherwood, Barger-Anderson, Merhaut, Badgett, & Katsafanas, 2011). The roles of science and special educators are evolving, in part, because of the response-to-intervention movement (RTI), a multi-tiered general education initiative to identify and respond to struggling students. While there are disagreements about the nature and purpose of this movement (Fuchs, Fuchs, & Stecker, 2010), RTI is in place in many school districts and special educators find themselves with the opportunity—and many associated challenges—to partner with general educators to provide targeted interventions within and outside an inclusive classroom (Halpert, 2011). Within the RTI model, science educators are responsible for differentiating their instruction to address learning challenges and special educators must follow-up with science-specific supports when changes within these general classrooms aren't having a positive impact. The RTI model draws on expertise from science and special education, so it demands adequate preparation of these educators as well as opportunities for sharing knowledge through collaborative planning (Brownell, Sindelar, Kiely, & Danielson, 2010).

Building on this body of research, the goal of the current project was to provide a collaborative professional development program that could support instructional improvement in inclusive science classrooms. We identified Japanese Lesson Study as a model with great promise for science and special educator collaboration.

Japanese Lesson Study

Lesson Study is a professional development approach that originated in Japan (Isoda, 2010; Makinae, 2010). Working in teams, teachers enter a cycle of reflective practice where they consider their long-term learning goals for students; plan a lesson based on these goals; teach a lesson to students that is carefully observed by team members who collect data on student learning; discuss the lesson they observed; and revise it based on what they have learned (Isoda, 2010; Lewis, 2002; Perry & Lewis, 2008; Wang-Iverson & Yoshida, 2005).

However, Lesson Study is more than a series of steps that allow teachers to craft better lessons. Instead, these collaborative activities enable teachers to enter into a carefully structured deliberative process, providing them with an opportunity to develop professionally and improve practice (Dudley, 2007; Isoda, 2010). Particularly relevant to science and special educator collaboration is the Lesson Study expectation that teachers will "do" the lesson with each other in order to experience it as learners, discuss the content and their own confusions, and, as a result, refine their understanding (Fernandez & Yoshida, 2004; Isoda, Miyakawa, Stephens, & Ohara, 2007). This component of lesson study is critical given the growing expectation in school systems that special educators have a strong understanding of disciplinary content and how to teach it, as well as knowledge of, and ability to identify student learning challenges for a specific content area (Brownell et al., 2010; Haager, Gersten, Baker, & Graves, 2003; Seo, Brownell, Bishop, & Dingle, 2008).

Second, Lesson Study not only incorporates time for instructional planning and discussion as teachers develop lessons, it also focuses teachers' attention on understanding *how* and *why* lessons work to promote understanding (Stigler & Hiebert, 1999; Wang-Iverson & Yoshida, 2005), by anticipating, in advance, student responses at key junctures within the lesson, and determining how the teacher will respond. For science and special educators, this allows them to direct their attention to the needs of students with learning disabilities, consider how the disabilities might manifest within specific lesson activities, and develop and test their pedagogical responses. Furthermore, the process allows them to examine the underlying principles of their teaching (Fernandez & Yoshida, 2004; Isoda et al., 2007) and the curriculum, which is an effective way to support the implementation of classroom innovations (Penuel et al., 2007).

Finally, the locus of control remains within the team of teachers as they look to and learn from their collective expertise. At the same time, Lesson Study provides a structure for inviting technical assistance from "knowledgeable others" (outside specialists) when the need is felt by participants (Lewis, 2002; Wang-Iverson & Yoshida, 2005). While outside specialists can play many roles, they must pay attention to what the team is ready to learn, and support them in making focused improvements (Watanabe, 2011). These opportunities, to seek and share professional knowledge on a formal, ongoing basis, are often rare in U.S. public schools (Dubin, 2009; Hiebert, Gallimore, & Steigler, 2002; Shedd & Bacharach, 1991), and rarer still among those who occupy different roles and have different responsibilities such as science and special educators.

Therefore, we designed our Lesson Study for Accessible Science (LSAS) intervention to support and study collaborative teams of middle school science and special educators as they engaged in a systematic examination of their science instruction for students with learning disabilities. Given the prior research on the effect of collaborative professional development on teachers' content and pedagogical knowledge (e.g., DeSimone, 2009; Desimone et al., 2002; Garet et al., 2001; Heller et al., 2012; Johnson et al., 2007; Penuel et al., 2007; Roth et al., 2011; Saunders et al., 2009), it is important to determine if similar or different effects are found with this particular approach to Lesson Study when science and special educators collaborate. Since the expertise areas of science and special educators are so different, it is also important to determine if there are content learning gains in either area of expertise—teachers' knowledge of science content and process skills, and teachers' ability to identify student learning challenges. We assessed both of these kinds of content learning outcomes in this study. To determine whether or not there is an impact on pedagogical knowledge related to curricular access for special education students found in other studies (Brusca-Vega et al., 2011; Mastropieri et al., 2005; McDuffie et al., 2009; Nolet & McLaughlin, 2005), we assess the general ability to adapt an instructional plan to meet given educational goals, and the more specific ability to develop accommodations for students with learning disabilities to meet these goals.

Lesson Study for Accessible Science (LSAS) Intervention

Our LSAS intervention design remained true to the essence of Japanese Lesson Study, described by Lewis and Hurd (2011), Fernandez and Yoshida (2004), Lewis (2002), and Wang-Iverson and Yoshida (2005), to strengthen key pathways (e.g., teacher knowledge) that lead to instructional improvement (Lewis, Perry, & Hurd, 2004; Lewis, Perry, & Murata, 2006). We departed from Lesson Study practice in one respect. Although Lesson Study groups typically choose their own long-term theme or goal for their work, in our LSAS model we asked teachers specifically to focus on two goals, to build knowledge about the needs of students—especially those with learning disabilities—in inclusion science classes[1] and to create accommodations to increase curricular access. Teachers were informed and all expressed interest in these goals, and they participated voluntarily in the project. The intervention included the following components; each is described in detail below:

- Three cycles of lesson study: a summer institute cycle, followed by fall and spring cycles conducted during the academic year;
- Lesson Study guiding documents and resource books;
- Coaching and phone/email support.

Summer Institute, Fall, and Spring Cycles of Lesson Study

We designed an intensive 4-day summer institute Lesson Study cycle to ‘‘jump start’’ LSAS participants’ project work. Intervention teams participated in simulations to experience challenges often caused by learning disabilities and the impact of accommodations offered by teammates during the activity. Research on learning disabilities and accommodations was also presented.

To provide an overview of Lesson Study steps and to appreciate the kinds of interactions that teachers have as they share and build knowledge, the participants viewed and discussed videotape excerpts of Lesson Study teams in Japan (*Can you lift 100 kg*? produced by Catherine Lewis of the Lesson Study Research Group at Mills College CA; available online at http://www.lessonresearch.net/videos1.html) as they planned and conducted a public research lesson, and then debriefed and revised it. Then, in their teams, LSAS participants set norms, discussing the kind of culture they wanted to create within their team, what might help the team to flourish, and how they would behave when things got hard. Each person also expressed the kind of commitment he/she could make to the other members of their team.

To further prepare for their first cycle of Lesson Study, teams reviewed the following lesson study documents, adapted by the project to support LSAS implementation and to prompt group and individual teacher reflections on their learning throughout the process:

- Choosing a Lesson Study Research Theme, adapted from Lewis (2002);
- Instructional Plan for the Research Lesson, Guidelines for Observing the Research Lesson, Guidelines for Debriefing the Research Lesson, and Lesson Study Report Guidelines, all adapted from Lesson Study Research Group, Teachers College, Columbia University, 2001 (http://www.tc.columbia.edu/lessonstudy/resources.html);
- Stages in the Lesson Study Process, adapted from the work of Lewis (2002); the *Lesson Study Communities in Secondary Mathematics* project at the Education Development Center (http://www2.edc.org/lessonstudy/); and the *Lesson Study Research Group* at Teachers College (http://www.tc.columbia.edu/lessonstudy/resources.html);

- The Lesson Study Report Guidelines to which we added prompts for group and individual reflections on their own learning to provide data for research purposes.

With an understanding of the stages, teams then worked through an abbreviated lesson study process, focusing on a lesson about levers. They began with their own scientific investigations of levers, conducting activities from the FOSS unit, *Levers and Pulleys*, (2000), and determining the key learning goals for students. Then, each team prepared a lesson for grade 4–7 students involved in a science-themed summer program nearby. They collaborated to anticipate student responses to the activities they chose, and created accommodations as they thought necessary to create access for students with learning disabilities. As they developed their lessons, project staff circulated among teams, prompting them when necessary to align the lesson activity with their chosen learning goal, or to be explicit when anticipating student responses.

To prepare for observing the instruction, teachers conducted observations of videotaped classrooms so they could distinguish between student behavior and inferences based on student behavior (e.g., the student did not look up and shrugged his shoulders vs. the student was bored), determine the accuracy of their ''anticipated student responses,'' and note student verbal and written output (i.e., evidence of learning) related to specific instructional decisions and accommodations within the lesson plan. After this observation preparation, one team volunteered to teach their lesson to summer-program students while other participants observed. Everyone debriefed the lesson and discussed how they might re-design and re-teach based on the observational data collected. However, there was not sufficient time to re-design and re-teach the lesson during the summer institute.

The fall and spring lesson study cycles proceeded in succession after the summer institute. The time for a team to complete a cycle ranged from 10.7 to 19.5 hours. The teams followed the same process as they had during the summer, except that during the school year teams re-designed and re-taught the lesson to a new group of students, enabling teachers to employ what they had learned from the first lesson and test instructional changes informed by their observations. They also wrote a Lesson Study Report at the conclusion of each of these cycles. Teachers adhered to the lesson study guidelines and used the lesson study documents to support all phases of each cycle. Because teachers were instructing students from their own schools or districts, they were expected to explore students' learning abilities and challenges more fully through discussions with team members who knew the students and, when applicable, by reviewing students' Individualized Education Programs or 504 plans. This specific information enabled teachers to anticipate student response to instruction more precisely and to respond with improved lesson plans and accommodations.

Lesson Study Guiding Documents and Resource Books

In addition to the lesson study documents described above, each intervention teacher was provided with three resource books about lesson study (Lewis, 2002), curricular access (Nolet & McLaughlin, 2005), and developing accommodations (Gore, 2004).

Coaching and Phone/Email Support

In lieu of invited visits by ''knowledgeable others,'' project staff provided coaching at three points within the fall and spring cycles. These coaching sessions usually took place the first time each team met, at some point when they were preparing the research lesson, and in the debriefing meeting after the lesson was taught. The two coaches developed a protocol to assist them in delivering coaching uniformly. They used a variety of strategies to help teams think deeply about their goals, including open ended prompts designed to surface what teachers knew or to make their thinking explicit, reflective speech designed to reflect back to teachers what they had stated as their desired outcomes, affirmative statements designed to explicitly affirm and encourage specific practices and, less frequently, suggestions. Finally, project staff provided phone and email support upon request.

Research Design, Recruitment, and Participants

We employed an experimental research design where teams of teachers were randomly assigned to the LSAS intervention group or to a wait-list comparison group. From July 2006 to June 2007, intervention group teams participated in the LSAS intervention and both groups participated in data collection activities. Comparison group teams were invited to participate in LSAS professional development once the research phase concluded. We measured the extent to which LSAS influenced teachers': knowledge of science content and process skills, ability to identify student learning challenges, ability to adapt an instructional plan, and ability to develop accommodations for students with learning disabilities.

We collected longitudinal data (i.e., measuring the same phenomena on multiple occasions) that was organized hierarchically from individual science and special education teachers who were nested in teams assigned to either intervention or comparison groups. Our mixed methods data collection strategy allowed us to capture quantifiable teacher ratings and to code observed discussion responses and written responses to open-ended questions.

Participants were recruited as teams from school districts in the northeast U.S. that met three key criteria: (1) the proportion of students with learning disabilities was at or above the national average of 13.2%; (2) participants taught in inclusive science classrooms; and (3) their location was within a 2-hour drive of investigators. Those who wished to participate assembled a team of middle school science and special education teachers who would work together both in and outside the classroom throughout the project period. We suggested that teams consist of approximately 5 members and include at least 2 special educators when possible (1 special educator was required). As an additional incentive for participation, a choice of graduate credit from a local university or professional development points was offered to teachers for their study participation as well as a stipend to compensate them for the out-of-school hours in which they did lesson study work.

There were 16 active teams in the study divided evenly between the intervention and comparison groups. Because the sizes of teams varied and several of the larger teams were randomly assigned to the comparison group, the total number of teacher participants in each group differed, with 37 teachers on intervention teams and 46 teachers on comparison teams. On average, there were 4 teachers per intervention group team and 5 teachers per comparison group team. During the study period, there was slight attrition in both groups. Exit interviews identified unexpected personal situations (e.g., an ill family member, a new baby) as the reason teachers dropped out of the study.

By the end of the research phase, the eight teams in the intervention group were comprised of 32 teachers from 10 middle schools across 5 different urban and suburban districts, and the 8 teams in the comparison group were comprised of 41 teachers from 7 middle schools across 4 different urban and suburban districts. Additional information about participants is provided in Table 1. Overall, teacher demographic variables were comparable across all teams. The average number of years teaching was nine with most at the middle school level. All held Bachelors degrees and 75% held Masters' degrees. Eleven teachers from the intervention group and 7 teachers from the comparison group had observed or participated in

Table 1
Final distribution of recruited teachers

	Intervention Group	Comparison Group
Number of teams	8	8
Number of teachers across teams	32	41
Size of teams	3 Teams of 5 2 Teams of 4 3 Teams of 3	1 Team of 8 1 Teams of 6 4 Teams of 5 1 Team of 4 1 Team of 3
Grade levels across teams	5–8	5–8
Number of science teachers across teams	18	23
Number of special educators across teams	14	18

lesson study prior to the study. This difference was not statistically significant (χ^2 (1, $N = 73$) = 2.90, $p = 0.08$).

Instrumentation, Code Development, and Data Collection

Teacher Assessment

We created three parallel versions of a teacher assessment to capture teachers' knowledge of science content and process skills, ability to identify student learning challenges, ability to adapt an instructional plan, and ability to develop accommodations for students with learning disabilities. We adopted an approach developed by Joan Heller of Heller Research Associates for the WestEd *Understanding Science* project (www.wested.org/cs/we/view/pj/372) in which teacher assessments were designed to measure teachers' ability to adapt an instructional plan. We collaborated closely with Dr. Heller as we developed our instruments. The assessment addressed the intervention by focusing on the following aspects of the work teachers were doing in their Lesson Study teams:

- Identifying goals of the lesson.
- Aligning the classroom activity with the goal.
- Anticipating student responses to the activity.
- Designing instruction to address these anticipated responses.

Each version of the assessment included a scaffolded inquiry lesson from a published sixth grade science curriculum—Pearson Scott Foresman Science 6 (2003). The lessons included hands-on lab work followed by discussion and activities aimed at helping students to summarize and extend their understanding. We selected lessons with this structure because they employ an approach typical in many science classrooms. Furthermore, such lessons place meaning-making demands on students with learning disabilities that require instructional support. The lessons were as follows:

- Baseline version: included a lab activity—Experimenting with membranes—from Chapter 4: How do cells differ?
- Mid-point version: included a lab activity—Investigating chemical change in a reaction—from Chapter 3: How are chemical reactions described?
- Final version: included a lab activity—How do organisms inherit traits—from Chapter 4: Investigating variation in seedlings.

Different science lessons were chosen for each assessment to avoid bias due to teachers' remembering both the content and their responses over the relatively short time-span between assessments (about four months). We tried to ensure that the pedagogical complexity and cognitive demands of the three assessments were equivalent by choosing three typical, general science lessons designed for sixth grade, since this grade level represented the lower end of the range of grades that participants taught. Since teachers taught across different science domains, we chose lessons in biology and chemistry to represent some of this range. An experienced classroom teacher and the PIs, one a special education researcher and the other a scientist/education researcher, analyzed the chosen lessons for equivalence in pedagogical approach and for student task (e.g., degree of emphasis on prior knowledge, the level of abstract thinking required, the application of knowledge).

In addition to the lab activity, each version of the assessment included a three- or four-paragraph profile of a fictional sixth grade student with mild to moderate learning disabilities. The profile described the student's typical approach to learning tasks and a general description of student output from lab activities. The student profiles for the assessments were analyzed by two of our advisors and by a TERC specialist on learning disabilities to ensure that each, while focusing on a different student, described similar classroom responses to the general challenges that science classrooms pose.

Teachers were asked to read the lesson and profile carefully and then respond to probes that captured aspects of their pedagogical knowledge related to our research. Probes were:

- About whole-class instruction: "Specify what changes you would make to this lesson for the children in your classroom. Feel free to set the context for this particular lesson, and to make any changes you think you'll need."
- About creating accommodations: "Describe the additional modifications or accommodations you would make so that <name of fictional student> could achieve the stated science learning goals of the lab activity. Address the following questions *for each accommodation* you describe:
  (a) What challenge(s) does the student with learning disabilities face in this lesson?
  (b) What accommodation would you design to address the challenge(s)?
  (c) Why do you think the particular accommodation(s) you describe would help the student achieve the stated science learning goals of the lab activity?"

Teacher Assessment Coding Rubric

Since the responses to the assessment prompts were open-ended, standardized codes for the project outcomes were established and applied to each version of the teacher assessment. Codes for the dependent variables are shown in Supporting Information Table 1.

To establish reliability of the coding rubric, four researchers coded teacher responses and then compared their codes. Adaptations were made to the codebook until coder percent agreement on each section of the coding rubric was at least 80%. Thereafter, assessments were coded independently by project researchers, with discrepancies resolved to reach 100% coder agreement. Four dependent variables were generated from this coding process and were defined as follows:

(1) *Science Knowledge*: The level of sophistication of the science content and process skills included in a teacher's responses.
(2) *LD Student Challenges*: The number of different learning challenges, which inhibit access to the science content and achieving the science learning goals, the teacher identified for the profiled LD student.

(3) *Instructional Planning*: The number of adaptations a teacher identified to the science lesson instructional plan that were necessary to meet the given science learning goals.
(4) *Number of Accommodations*: The total number of accommodations a teacher developed for the profiled LD student to address their challenges for the given lesson.

Teachers could score a maximum of seven points for the variables Instructional Planning and LD Student Challenges. The Science Knowledge variable was constructed as a Guttman scale with four levels, which meant that teachers could score a maximum of four since each level assumes that all levels lower on the scale are also present. The Number of Accommodations variable was tallied (the range across all assessment responses was 0 to 10) to generate a total for each lesson.

The teacher assessments were administered three times over the course of the study—at the beginning of participants' engagement with the project in July 2006 for the intervention group and October 2006 for the comparison group (baseline), at the research mid-point in January 2007, and at the conclusion of the intervention in May–June 2007 (final).

Face validity of the assessments was established through piloting with nine middle school teachers (who were not study participants), evenly distributed across grades and roles represented in the study. Instruments were revised based on educators' verbal feedback and analysis of their written responses to open-ended questions about the design of the instruments.

Teacher Survey

For this analysis of LSAS impact, we used survey data to capture general demographic information as well as data related to education/training and teaching experience at baseline. The survey was administered at the beginning of participants' engagement with the project (July 2006 for the intervention group and October 2006 for comparison group) and at the conclusion of the research phase (May–June 2007).

Analytic Approach

Analysis of Data

Descriptive statistics and correlations were generated for all of the dependent (from Teacher Assessment) and independent variables (from Teacher Survey). The univariate distributions for each variable were checked for violations of normality, and the bivariate correlations were checked for evidence of multicollinearity. All of the quantitative data were reviewed for missingness, data entry errors, and out-of-range values. No imputation strategies were used to address missingness since it was primarily a result of participant attrition, rather than item-level missingness. We determined that following randomization, the teams assigned to intervention and comparison groups were comparable with respect to all demographic variables and most dependent variables. The differences detected are discussed in the Results Section.

To examine the effects of lesson study and teacher role on changes in teachers' knowledge and practice, a series of three-level hierarchical linear models (HLM) for longitudinal data were utilized separately for each dependent variable:

- Level 1 (*within-person*) contained scores for each individual at each assessment occasion.
- Level 2 (*between-person within team*) contained variables that differed across persons within a team such as whether the individual was a science teacher or a special education teacher (ROLE: 0 = Special Educator, 1 = Science Teacher).

- Level 3 (*between-teams*) contained team level data such as whether the team was in the intervention or comparison group (GRP: 0 = comparison, 1 = LSAS intervention).

Given the nested structure of the data and the multilevel research question, HLM was the appropriate modeling technique (Raudenbush & Bryk, 2002). For all dependent variables, we fit polynomial functions of time that expressed change by three parameters: intercept, linear slope, and curvature. Our models allowed for variation in the level-1 intercepts (due to our coding of time, the level-1 intercepts reflect the value of the outcome score at the January assessment for teacher knowledge), variation in the linear slope coefficients (rate of change at the January assessment), and the variation in the quadratic coefficient (acceleration in rate of change over time). By accounting for the shared variance due to the nesting, the procedure correctly estimated standard errors for coefficients at each level of the model. Partitioning of the variance using the intra-class correlation coefficient (ICC) indicates how much variance lies within and between teams.

In discerning the best fitting model for each dependent variable, the following steps were taken:

(1) An unconditional growth model (no predictors at level 2 or 3) was used to provide estimates of the average trajectory across all teams on the dependent variable and the heterogeneity around the average trajectory (i.e., how teams differ from the average);
(2) Teacher role (ROLE) was included as a predictor of each parameter at level 2 and retained if found to be significant;
(3) Treatment group (GRP) was included as a predictor of each parameter at level 3 and retained if significant.

For each dependent variable, the model that contained only significant effects of individual and/or team level variables was retained as the final model. Evidence that the final model was a significant improvement over the unconditional model was provided by the Likelihood Ratio Test, which examines the difference in model deviance statistics—distributed as a chi-square relative to the difference in model degrees of freedom. Time was coded as the month from onset into the study and was centered at the sixth month (January), which was the first instance of concurrent measurement. This was done by subtracting six from each value of month to result in new coding where time was equal to zero at month six (i.e., January). Given that initial measures of variables in the intervention group were completed in July while initial measures for the comparison group were taken in October, the first time point for the comparison group was coded as -3 while the first time point for the intervention group was coded as -6; thus time is zero (0) in January when both groups were measured simultaneously.

Preliminary analyses indicated that the relation between each of the teacher knowledge constructs and time was best fit by a quadratic model. In other words, growth was curvilinear over the period of study. Given that we had only three occasions of measurement it was difficult to fit a curvilinear model because that requires three parameters for its expression—leaving no degrees of freedom to estimate both the model parameters and the residual variance. In order to facilitate estimation of the model, we estimated the measurement error at level 1 (e) to the value expressed by the formula using a conservative estimate of reliability (rel = 0.75) and the variance (SD^2) of the dependent variable with the formula $e = (1 - \text{rel}) \times SD^2$.

A representation of the unconditional model for all of the teacher knowledge variables was as follows:

Level 1 (Within Individual)

$$\text{DV} = \rho_0 + \rho_1(\text{Time}) + \rho_2(\text{Time}^2) + e$$

Level 2 (Between Individual)

$$\rho_0 = \beta_{00} + \text{r}_0$$
$$\rho_1 = \beta_{10} + \text{r}_1$$
$$\rho_2 = \beta_{20} + \text{r}_2$$

Level 3 (Between Team)

$$\beta_{00} = \gamma_{000} + U_{00}$$
$$\beta_{10} = \gamma_{100} + U_{10}$$
$$\beta_{20} = \gamma_{200} + U_{20}$$

where DV is the dependent variable in each analysis; ρ_0 is the intercept, interpreted as the predicted value for the DV at time zero (i.e., January); ρ_1 is the coefficient for the instantaneous rate of change at time zero, or the rate of growth in January (i.e., the tangent to the growth curve in January); ρ_2 is the coefficient describing the effects of the quadratic term, or the acceleration/deceleration in change. The conditional model included the teacher's role as science or special educator (ROLE) at level-2 and treatment group at level-3 (GRP).

Given that measurement error was fixed at level 1 (*e*), the unexplained variance in each dependent variable was attributable to variance components at level 2 and level 3. The ICC, or the proportion of variance in the intercept, linear, and quadratic slope coefficients that is attributed to individual and team characteristics for the unconditional model is presented. The ICC indicated that 80.91% of unexplained variance in instructional planning in January and 91.88% of the unexplained variance in the linear rate of change was attributable to individual characteristics, with the remainder being attributable to team characteristics. Fixed effect coefficients for the final models for instructional planning are presented in Table 3 and random effect variance components are presented in Table 4. The ICC indicated that 62.21% of unexplained variance in number of accommodations in January was attributable to individual differences and 37.79% attributable to team differences. Fixed effect coefficients for the final models for number of accommodations developed are presented in Table 5 and random effect variance components are presented in Table 6. We did not find significant effects of the intervention on LD student challenges or teacher science knowledge. The ICC indicated that 79% of unexplained variance in LD student challenges in January was attributable to individual differences and 21% attributable to team differences; and for science knowledge it was 73.11% attributable to individual differences and 26.89% to team differences.

Results

Teacher Assessment

To examine whether or not the randomization was effective, the baseline scores for each dependent variable were explored. The intervention group differed significantly from the comparison group for two of the four dependent variables at baseline, science knowledge and LD

Table 2
Pre-test differences between intervention and comparison group on dependent variables

Outcome Variable	Comparison Group Mean (*SD*)	Intervention Group Mean (*SD*)	*F*-Value
Instructional Planning	2.00 (0.99)	2.28 (1.44)	0.990
LD Student Challenges	1.81 (0.74)	2.34 (1.13)	6.049*
Science Knowledge	0.76 (1.01)	1.47 (1.08)	8.421**
Number of Accommodations	3.69 (1.51)	4.03 (1.49)	0.938

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

student challenges, while the other two, instructional planning and number of accommodations, did not differ (see Table 2).

Teacher Science Knowledge and LD Student Challenges. Unconditional models for science knowledge and LD student challenges dependent variables did not indicate significant differences between intervention and comparison groups. Specifically, there was no effect of treatment on the number of learning challenges teachers identified, nor in their level of science knowledge. Since the intervention group participants were significantly higher at baseline in these two knowledge areas, we adjusted for this difference in our modeling by including the variable in the model. The results trended towards a positive effect of LSAS, though they were still not significant.

Instructional Planning. Teachers' instructional planning adaptation for the whole class rose from its initial value at the first assessment occasion, peaked at the midpoint in January and then declined slightly at the end of the intervention (see Figure 1). The fixed effects model in Table 3 indicates a significant effect of treatment group on the intercept; whereas the initial level of instructional planning ability among teams in the comparison group had a value of 2.06, in January for teams that received the LSAS intervention this level was larger by a value of 0.57. There was no effect of teacher role or treatment on the coefficients for the linear and quadratic components of the model, therefore these components are fixed to be equivalent across individuals and teams. We used the estimates in the tau matrix to calculate the proportion of variation explained by the treatment. Being part of the LSAS intervention cohort explained 66% of the variation in instructional planning measured in January.

While cohort accounted for significant between-team variance in the intercept, analyses of the variance components indicated that there was still significant variance in mean level of instructional planning ability left to be explained both between individuals, and between teams. The addition of cohort to the model lead to an improvement in model fit as indicated by significant improvement in deviance statistic ($\Delta\chi^2(1) = 4.94$, $p < 0.05$).

The final random effects model indicates that for the level-2 variance components—there was significant between individual variance in the January intercept value for level of instructional planning ability, in the January rate of change, and in the curvature (see Table 4). This means that although there is an average instructional planning ability for each team, the individuals on a team vary around this average. There is a growth trajectory for each team member and that varies around the average for the team. For the level-3 variance components there was also significant unexplained variance between teams in instructional planning ability in January, and in its instantaneous rate of change.

Number of Accommodations. The number of accommodations that teachers identified for the student profiled in the assessment rose from its initial value at the first assessment

Table 3
Instructional planning fixed effects coefficients

Variable	Coefficient	*SE*
Intercept in January	2.06***	0.18
Group	0.57*	0.23
Rate of change in January	−0.08***	0.02
Quadratic curvature	−0.02**	0.01

Note: Group: 0, comparison; 1, intervention.

Table 4
Instructional planning random effects variance component

Random Effect	SD^2	χ^2	*p*
Between-individual			
Intercept in January	0.89	167.94	0.00
Linear rate of change in January	0.02	121.03	0.00
Quadratic curvature	0.00	144.04	0.00
Between-team			
Intercept in January	0.07	24.31	0.03
Linear rate of change in January	0.00	25.29	0.03
Quadratic curvature	0.00	22.03	0.08

Table 5
Number of accommodations fixed effects coefficients

Within-Individual	Coefficient	*SE*
Intercept in January	4.54***	0.35
Group	0.94*	0.35
Teacher role	−0.86**	0.27
Rate of change in January	0.01	0.03
Quadratic curvature	−0.03*	0.01

Note: Group: 0 = comparison; 1 = intervention; Teacher role: 0 = special educator; 1 = science teacher.

Table 6
Number of accommodations random effects variance component

Random Effect	SD^2	χ^2	*p*
Between-individual			
Intercept in January	0.92	127.66	0.00
Rate of change in January	0.03	121.32	0.00
Quadratic curvature	0.00	109.62	0.00
Between-team			
Intercept in January	0.68	24.79	0.02
ROLE effect on intercept	0.09	6.78	>0.50
Rate of change in January	0.00	9.79	>0.50
Quadratic curvature	0.00	18.38	0.14

Note. ROLE: 0 = special educator; 1 = science teacher.

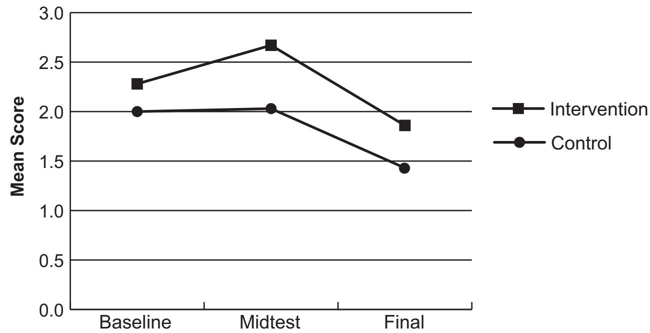

Figure 1. Mean score of teachers' ability to develop an instructional plan for the whole class.

occasion, peaked at the midpoint in January in Assessment 2 and declined slightly at the end of the intervention in Assessment 3 (see Figure 2). The coefficient for the quadratic term was significant and negative, indicating that change in accommodations decelerated over time (see Table 5). The fact that the coefficient for the linear term was not significantly different from zero means that the rate of change in January was flat. Analyses of the variance components indicated that there was significant between-individual variance in the January average number of accommodations teachers were able to generate, and significant between-team variance in January.

The reduction in deviance indicated that the final model was a significant improvement over the unconditional model ($\Delta\chi^2$ (6) = 15.74, $p < 0.05$). The final random effects model indicates a significant effect of cohort (level 3) and teacher's role (level 2) on the average number of accommodations teachers were able to generate in January. Receiving the LSAS intervention increased average number of accommodations of 4.54 by a magnitude of 0.94 units. Within each team, regardless of whether the team received the LSAS intervention, science teachers' average number of accommodations was lower by a magnitude of 0.86 (see Table 6). The cumulative effect of cohort and teacher role indicated that in January, the average number of accommodations that special educators in the intervention group generated was 5.48 and for science teachers it was 4.62. In the comparison group, special educators generated 4.54 followed by science teachers at 3.68. We used the estimates in the tau matrix to calculate the proportion of variation explained by the treatment. Being part of the LSAS

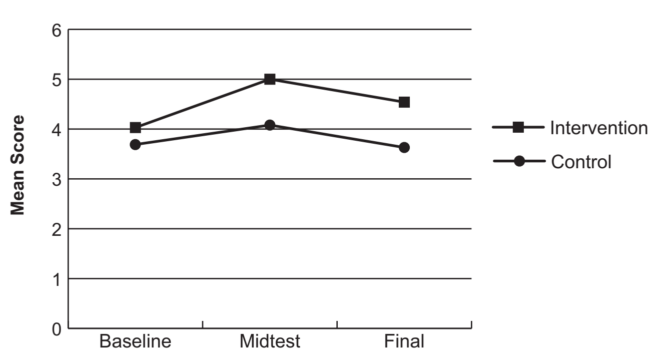

Figure 2. Mean number of accommodations that teachers identified for the student profiled in the assessment.

intervention cohort explained 5% of the variation in the number of accommodations measured in January.

Analyses of the variance components indicated that there still remained significant unexplained variance in average number of accommodations both at the individual level and at the team level; however, there was no unexplained variance in the effect of teacher role on average number of accommodations (see Table 6).

We found a decline in instructional planning and number of accommodations scores from the mid-point assessment to the final assessment perplexing, since we would have expected scores to remain steady (see Figures 1 and 2).

Therefore, we investigated a variety of plausible reasons to explain the decline (e.g., examining whether or not teachers spent less time on the final assessment given their tight schedules at the end of the year), but we found no significant explanations.

Conclusion and Discussion

Based on their review of science teaching and special education literature as well as their own research study, Grumbine and Alden (2006) assert that "learning is enhanced when teachers recognize and teach to diverse learning styles and strengths" (p. 27). However, translating this obvious and sensible-sounding principle into practice is not easy, and Grumbine and Alden acknowledge that it requires multiple implementation approaches. Thus, it is encouraging to identify a professional development experience that can provide opportunities for science and special educators to strengthen their knowledge about differentiated instruction by providing opportunities to design and critique science lessons that are embedded with accommodations.

As indicated by a significant change between the baseline and mid-point assessments, teachers participating in the LSAS intervention successfully increased their ability to generate accommodations for students with learning disabilities. It appears that reflecting on and discussing students' work and learning behaviors influenced intervention teacher responses to a similar dilemma on the assessment, allowing them to generate a significantly greater number of accommodations, on average, than the comparison group. Even though there was a significant effect of the intervention, it was only a small contributor, accounting for 5% of the increase in accommodations developed.

For some teams, paying attention and responding to students with disabilities by creating accommodations was a catalyst for making class-wide instructional changes. Assessment data showed that the intervention group teachers as a whole, showed significantly higher scores for classroom instructional planning after LSAS participation. As teams moved through the LSAS cycles, they began to restructure entire lesson plans. In the midpoint assessment, there was more focus on aligning lesson activities to emphasize science learning goals and on scaffolding class experiences to better ensure access for *all* students. The intervention was a major contributor (66% of the variance) to this positive change in instructional planning.

Although instructional changes were significant, we also theorized that by sharing expertise teachers would increase their knowledge of science concepts and processes as well as their understanding of learning disability challenges. We did not see significant change in these areas on the teacher assessment. We suspect that the LSAS intervention had less impact in these areas, in part, because teachers eliminated two critical features of the intervention in their implementations. Many teams did not explore the science concepts of the lesson themselves during their instructional planning process, as is typically done in lesson study. Similarly, they did not discuss students' learning disabilities through a review of their Individualized Education Programs. Both of these components were modeled at the summer institute and explicit verbal and written instructions to include these components were given. Even coach encouragement during the LSAS process and offers of help did not change this—most teams determined that these were the most expendable LSAS activities when they felt pressed for time.

While not every aspect of the LSAS intervention produced significant change, our positive results echo findings in the literature suggesting that co-teaching and/or collaborative planning between science and special educators can prepare them to meet a range of student learning needs in inclusive science classrooms (Brigham et al., 2011; Brusca-Vega et al., 2011; Mastropieri et al., 2005; McDuffie et al., 2009). Professional development to support collaboration is needed given the trend of placing more students with disabilities in science classes full-time, and increases in the number of schools that implement response-to-intervention (RTI). The latter will expect both general and special educators to differentiate whole-class instruction and design content-specific supports for students with disabilities (Brownell et al., 2010).

However, as researchers have noted, collaborative work between general and special educators is complex and many variables seem to influence collaborative efforts including: teacher compatibility (Bouck, 2007; Isherwood et al., 2011); common planning time that allows teachers to assume a more diagnostic-reflective manner as they consider students', needs and the cognitive demands of the lesson (Brusca-Vega et al., 2011; Isherwood et al., 2011); and familiarity with curriculum/content (Isherwood et al., 2011; Mastropieri et al., 2005). We concur and suggest that several elements of LSAS addressed these variables. Consistent with Lesson Study, our model provided structured opportunities for creating a positive team culture as teachers established collective norms and agreed-upon lesson goals. It also provided opportunity for teachers to assume a diagnostic-reflective stance when they were asked, as part of the LSAS intervention, to anticipate student responses and gather evidence to support or refute their predications during peer-observation of the team lesson. On the other hand, our project design did not include explicit structures for coaching during the "doing science" stage of the lesson study. Thus, LSAS teachers did not become more familiar with the curriculum and showed no significant change in their development of science knowledge.

Recent studies (Heller et al., 2012; Roth et al., 2011) of effective approaches to science professional development have shown the importance of teachers' close analysis of practice, paying particular attention to where classroom activities explicitly connect to the larger science ideas being taught. Heller and colleagues note that teachers in their study who engaged in "critical analysis of trade-offs in instructional options, with detailed consideration of science content embedded in decisions about classroom practice" continued to show significant positive effects in the follow-up year of their study (Heller et al., 2012, p. 355). By observing lessons, debriefing these observations, examining student work, and identifying alternate approaches to instruction as they revised and re-taught their lesson, LSAS teachers not only generated more accommodations, they expanded their focus by adapting instructional plans that more fully focused on science learning goals.

Like Roth and her colleagues, our findings also challenge the assumption that effective professional development needs to happen in "long-term, multi-year programs" (Roth et al., 2011). While we agree that teacher learning can and should be supported beyond one year, we believe that by determining the focus of the lesson study at the outset, providing a condensed but authentic lesson study cycle via a summer institute, and scaffolding teams' work through coaching and written materials, teachers were able to maximize their single year commitment to what is typically a much longer professional development approach. These modifications helped them to maneuver around schedule challenges and cope with the discomfort some experienced when examining their instructional beliefs in the company of colleagues whose roles differed from their own. As a result, LSAS promoted growth and discovery for participating teachers and new opportunities to improve practice in their inclusive science classrooms.

Limitations and Future Research

We remain concerned that we could not explain why there was a decline in teachers' performance between the mid-point and final assessments. Our post hoc hypotheses—including those specific to teacher work on the assessment (e.g., as they became more familiar with the assessment, they no longer identified simpler instructional changes or accommodations) or more generally about their work during the final cycle of the intervention (e.g., teachers put less time into the spring lesson study cycle and, therefore, did not consolidate their learning)—turned out to be false and did not seem to contribute to the decline. In fact, teachers' individual written reflections within their spring cycle reports were in direct contrast since most stated that they continued to have a positive experience, with some teachers specifically flagging new opportunities for learning. Therefore, we suspect that the final assessment was problematic. Despite our efforts, it may not be parallel with the baseline and midpoint assessments, and thus, did not capture teacher learning. In order to use this kind of authentic assessment, tailored to measure the impact of teachers' analysis of practice, we must refine and test it further with the help of researchers external to our project.

Furthermore, we heed the cautions of lesson study experts about making broad claims from a single, randomized controlled trial. Given the limited knowledge in the field about lesson study implementation in U.S. settings (Lewis et al., 2006), it is premature to assume that the outcomes of LSAS are generalizable to lesson study. Instead, we suggest that LSAS offers an example of a successful modified lesson study model that remains true to the philosophy and overall structure of the Japanese innovation while making departures to address specific goals and the realities of U.S. public school policies and structures. Moreover, it offers a foundation upon which to create and research professional development opportunities to engage educators in different roles and with different kinds of expertise in analysis of practice, building upon recent studies in this area (Heller et al., 2012; Roth et al., 2011).

Finally, our LSAS research focused entirely on teacher change. While an appropriate first step in refining a practicable professional development model for the U.S. context, future research should carefully study student learning resulting from the teacher-collaborative planning process. In addition, as suggested by Brigham et al. (2011) and Isherwood et al. (2011), this work should describe how teams of teachers develop and balance differentiated whole-class instructional approaches with accommodations geared to the specific needs of students with learning disabilities to improve science curricular access for all students.

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Notes

[1]The classrooms included students who had Individualized Education Plans (IEPs) or ADA Section 504 plans specifying that they would receive science instruction in the general education classroom but might require specific accommodations to access the science curriculum.

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