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Implementation of Research-based ESL Strategies with Lower Grade Middle School ELLs in the Science Classroom: Findings from an Experimental Study

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Abstract

English language learners (ELLs) benefit when their teachers utilize a wide range of English as a Second Language (ESL) instructional strategies. However, content-area teachers often are unfamiliar with these ESL strategies as they have not received extensive professional development on meeting the needs of ELLs, especially within the context in their content area. In the current study, we explored the instructional differences between sixth-grade science teachers in their use of specific ESL strategies through the use of an observation protocol. Treatment teachers received ongoing, in-depth professional learning on working with ELLs and using ESL strategies. Our research question was: Is there a significant difference between treatment and control classrooms on teachers' implementation of ESL strategies? A total of 1,380 rounds of observation were completed in both treatment and control classrooms during science instruction, with an average of 54.5 minutes per teacher. Chi-square tests were conducted comparing treatment and control teachers' instruction. The results underscored the difference between treatment and control teachers in utilizing some of the specific ESL instructional strategies to enhance their students' science and literacy growth.

Keywords: ESL strategies, science instruction, professional learning, English language learners, literacy-infused science

Academic English in content areas is a major challenge that English language learners (ELLs) encounter every day as they develop proficiency in reading to comprehend the subject in English (Allen & Park, 2011). The language in the content area of science includes characteristics such as density of information, abstraction, and technical aspects of commonly-used words (i.e., words frequently used in a social context but that can have other, more technical meanings in an academic context, such as wave or mass), and such word-meaning issues are frequently not addressed in instructional materials for ELLs (Fang, 2006). Further, a longer period of time than is usually expected for ELLs to acquire the academic language, i.e., cognitive academic language proficiency (CALP), is necessary for school success (Cummins, 1980, 1981a, 1981b; Gagnon & Abell, 2009). The term, "CALP," was proposed by second language acquisition theorist Cummins (1979), and was further elaborated as "students' ability to understand and express, in both oral and written modes, concepts and ideas that are relevant to success in school" (Cummins, 2008, p. 71). CALP should be distinguished from daily conversational language. Midena-Jerez, Clark, Medina, and Ramirez-Marin (2007) concluded that both English speakers and ELLs have equal aptitude for learning scientific concepts and terminology. Therefore, it would appear important for teachers to include opportunities to learn content-specific, academic language for their ELL students.

Hernandez (2012) reported a strong relationship between ELLs' motivation for English language acquisition and teachers' inclusion of strategies used to teach English as a Second Language (ESL). However, content teachers who have ELLs in their classrooms do not feel well prepared to meet students' needs to improve their English language proficiency and content knowledge (Ballantyne, Sanderman, & McLaughlin, 2008; Buckingham, 2012; Gándara, Maxwell-Jolly, & Driscoll, 2005; Mantero, 2005). Despite federal mandates for ESL and/or bilingual education for ELLs, mainstream teachers without adequate ESL preparation provide the majority of instruction for many ELLs (DelliCarpini & Alonso, 2009). As of 2014, more than 30 states did not require professional development for classroom teachers on effective instruction for ELLs (Education Commission of the States, 2018).

Targeted professional development can be effective to enhance content-area teacher instruction. For example, Johnson, Bolshakova, and Waldron (2016) explored how Transformative Professional Development could improve the teaching quality of science teachers and raise ELL science achievement in grades 4-8. Teacher instruction improved through the use of science inquiry, cooperative learning, and the inclusion of culture and language. ELL achievement on the state science assessment grew between 6% to 48% in the number of ELLs receiving a proficient score. Buckingham (2012) suggested that all science teachers should be English language teachers. He conducted an analysis of model secondary science lesson plans in terms of the incorporation of metacognitive strategies known to support literacy development. The lesson plans were created by classroom teachers with special training from university faculty and posted in online lesson repositories maintained by universities. Buckingham reported from his analysis that "while 80% of science teachers include some type of strategic teaching and learning in their lessons, only about 20% of science teachers explicitly utilize strategies as listed in content literacy manuals and promoted by literacy and ESL experts" (p. vii). However, Karabenick and Clemens Noda (2004) found that science teachers in their study expressed a strong desire for including effective ESL strategies as well as quality instructional skills to teach science to ELLs. Relatedly, Rodriguez (2012) underscored the need for professional learning to include appropriate ESL instructional strategies that support students in acquiring CALP and mastering complex science concepts. Caswell, Martinez, Lee, Brauner Berns, and Rhodes (2016) noted that more research is needed on the preparation of mathematics and science teachers to serve ELLs.

For this paper, we situate a description of a set of research-based ESL strategies in the broader research literature regarding teaching ELLs in the science classroom. We discuss how each strategy was integrated in sixth-grade science classrooms with ELLs in Project Middle School Science for English Language Learners (MSSELL; DRL-0822343) and briefly describe the project, followed by a comparison on such usage of the ESL strategies between the treatment and control teachers in the MSSELL research study. Specifically, for this component of the study, we asked the research question: *Is there a significant difference between treatment and control classrooms on teachers' implementation of ESL strategies?* We conclude the paper by offering recommendations, based on the findings from our research, on how to infuse literacy with such ESL strategies into science instruction at middle school levels.

Integrating English Language and Literacy Acquisition in Science

We begin this section of literature review with an explanation of a rationale for integrating English language and literacy acquisition into the science content area that has been developed in previous research and in curriculum and policy documents regarding teaching with ELLs. This is followed by a general summary of research about using ESL strategies in science, and a discussion of more specific strategies that were incorporated in the professional learning and curriculum materials for MSSELL, including the research base for the effectiveness of each of the strategies.

Language and Content Integration

Many ELLs struggle in the content areas (e.g., science) due to language barriers. These students are in the process of developing the academic language necessary for success in school (Cummins, 1980, 1981a, 1981b). Academic language is rife with a wide variety of vocabulary words as well as complex grammatical and sentence structures that can impede ELLs' learning (Snow, 2010). Many words, such as *volume* or *property*, have different subject-specific meanings across different content areas, such as math and science.

As a content area, science poses both challenges and opportunities for ELLs that are two-fold. According to Fang and Wei (2010), science involves the investigation of the natural world through observation, identification, description, and experimentation. At the same time, science can also be understood as a type of discourse, one that is often in writing. In other words, science includes language, a set of behaviors, and a way of thinking about the world that may be new, but also engaging for many ELLs and other students. In order to create opportunities for active engagement in science, it is key that teachers consider ELLs' language and literacy needs and strengths when planning science instruction to make this critical content area more accessible (Calderdón, Slavin, & Sánchez, 2011; Short & Fitzsimmons, 2007).

English literacy is an important component of student success in science, and teachers of ELLs should address this component by incorporating English language and literacy into their science instruction (Fang & Wei, 2010; Lee & Buxton, 2013). In the early elementary grades, students are learning to read (Tong, Irby, Lara-Alecio, & Koch, 2014). At this stage, ELLs pick up increasingly sophisticated language in science texts, practice using the language of science inquiry, and gain a greater conceptual understanding of science topics (Pearson, Moje, & Greenleaf, 2010; Santu, Maerten-Rivera, & Huggins, 2011). However, by the late elementary and intermediate grades, students are expected to read to learn. For ELLs, this means utilizing their developing English language and literacy skills to grasp dense, cognitively-challenging science concepts (Tong et al.).

The literature includes a growing number of effective strategies, programs, and/or models for blending literacy and science teaching (e.g., Lara-Alecio, Tong, Irby, Guerrero, Huerta, & Fan, 2012; Palumbo & Sanacore, 2009; Watkins & Lindal, 2010). For example, Guthrie, Wigfield, Barbosa, Perencivich, Taboada, Davis, Scafiddi, and Tonks (2004) developed Concept-Oriented Reading Instruction (CORI), an evidence-based, science-focused reading program for third graders, that combines explicit instruction of reading strategies, including questioning, summarizing, and activation of background knowledge with hands-on activities, inquiry-based learning, and collaborative groupings. The program has resulted in increased student science achievement and comprehension (Guthrie et al., 2004; Pearson, et al.). Another program, the Reading Apprenticeship Model (Greenleaf, Schoenbach, Cziko, & Muelleret, 2001; Schoenbach, Greenleaf, Cziko, & Huritz, 1999), is embedded with direct and explicit instruction, discussion of textual meaning, and tight alignment of instruction with science objectives. This model has yielded improved English language skills, reading comprehension, and science participation (Greenleaf et al., 2001; Schoenbach et al., 1999).

A number of researchers (e.g., Hapgood & Palincesar, 2007; Santau et al., 2011) are also developing literacy-embedded science interventions that show promise in improving students' vocabulary, use of complex language, and their ability to conduct scientific investigation. As a result of the interventions, students also gained new reading strategies and increased their capacity to express ideas in different styles and formats. Additional integrated science-literacy initiatives include Guided Inquiry supporting Multiple Literacies (GIsML; Palincesar & Magnusson, 2001) and Seeds of Science/Roots of Reading (Cervetti, Pearson, Bravo, & Barber, 2006).

In their initiative, GIsML, Palincsar and Magnusson (2001) combined ongoing professional development for teachers and a guided-inquiry approach to science instruction, to promote students' grasp of the scientific process, investigation, and ways of reasoning. The researchers incorporated first-hand investigations (students directly experience the phenomenon[a] being studied) and second-hand investigations (students read text, such as a science notebook, to see how others interpret phenomenon[a]). The researchers developed the science notebook of a fictitious scientist, which modeled for students how scientists approach and display data, explore evidence, and refine their hypotheses and theories. GIsML included a quasi-experimental study comparing the use of innovative text, such as the science notebook, and more traditional expository text for fourth graders studying light. The researchers found that students in the treatment group demonstrated more learning with the innovative text as opposed to the control group of students; they concluded that the inclusion of science notebooks encouraged to have more discussions about, and thus engagement with, the subject matter.

Seeds of Science/Roots of Reading (Cervetti et al., 2006) integrated reading, writing, and language components into the pre-existing, inquiry-based Great Explorations in Math and Science curriculum, which was developed at the University of California, Berkeley. Cervetti et al. suggested Seeds/Roots materials aid students by clearly linking science and literacy strategies and giving them the space to consider these connections. Drawing on the work of Palincsar and Magnusson (2001), the researchers incorporated the idea of second-hand investigation of scientific texts by students. They argued texts can offer context, provide content knowledge and experience with data, model inquiry and literacy processes, and show how science works.

Promoting Science among English Language Learners (P-SELL; Llosa, Lee, Jiang, Haas, O'Connor, Van Booven, & Kieffer, 2016; Maerten-Rivera, Ahn, Lanier, Diaz, & Lee, 2016) combined targeted science-literacy curriculum, instruction, and teacher professional development to improve instruction and science achievement in fifth grade over a three-year intervention. The standards-aligned curriculum employed an inquiry-oriented approach and provided explicit support of science concepts and language development for ELLs. Professional development workshops reinforced teacher content knowledge and covered hands-on, inquiry-based methods. The cluster randomized control trial resulted in differences between the treatment and control groups on the state science assessment.

Effective Instructional Strategies in Science

ELLs and monolingual English-speaking students share many of the same learning needs in science. Schroeder, Scott, Tolson, Huang, and Lee (2007) conducted a meta-analysis of studies on instructional strategies that positively impact student success in science. The authors identified 61 studies from 1980-2004 that met their inclusion criteria. The authors grouped the strategies represented in the studies:

- Questioning strategies — Teachers pose questions at different points of time and cognitive levels (e.g., providing more wait time, purposely pausing for student responses, or using comprehension questions at the beginning or end of a lesson).
- Focusing strategies — Teachers explicitly call students' attention to the purpose of a lesson (e.g., including lesson objectives, introducing objectives at the start of the lesson, or reiterating them at the end).
- Manipulation strategies — Teachers provide students with physical objects to touch and manipulate (e.g., students building a diorama or model, using real tools, or handling real-life examples).
- Enhanced materials strategies — Teachers revise teaching/learning materials (e.g., developing a graphic organizer, adapting the language of a text, or simplifying instructions).
- Assessment strategies — Teachers vary assessment format, frequency, and purpose (e.g., testing for mastery, portfolio use, or formative/summative assessment).

- Inquiry strategies — Teachers utilize more student-centered learning techniques that are more hands-on (e.g., students participating in science labs or guided-inquiry projects and activities).
- Enhanced context strategies — Teachers connect learning to student background knowledge or interests through the use of the surroundings (e.g., field trips, utilizing school grounds during lessons, or creative classroom decoration/displays).
- Instructional technology strategies — Teachers incorporate technology into lessons (e.g., streaming online video and audio clips, modeling concepts or processes, or students completing internet research).
- Direct instruction — Teachers provide explicit verbal instruction or use step-by-step directions (e.g., leading science experiments or lecturing).
- Collaborative learning strategies — Teachers organize students in pairs or groups for collaborative work (e.g., lab groups, discussions, or group projects). (p. 1445-1446)

The authors then ranked the strategy groups by the magnitude of the effect size on student achievement in science (effect size is in parentheses):

1. Enhanced content strategies (1.48)
2. Collaborative learning strategies (.96)
3. Questioning strategies (.74)
4. Inquiry strategies (.65)
5. Manipulation strategies (.57)
6. Assessment strategies (.51)
7. Instructional technology strategies (.48)
8. Enhanced material strategies (.29). (Schroeder et al., 2007, p. 1452)

While Schroeder et al.'s meta-analysis covered effective instructional strategies for science in general, it is important to note that these strategies are also helpful for ELLs. Some of the same strategies (e.g., collaborative learning and grouping, questioning, use of manipulatives) were also included in Project MSSELL.

Effective ESL Strategies in Science for ELLs

With the increase of ELLs in U.S. schools and entrenched achievement gaps in science, researchers have examined how to make instruction effective for ELLs. Several literature reviews have been completed in this area (e.g., Buxton & Lee, 2014; Janzen, 2008; Lee, 2005; Pearson et al., 2010). Janzen (2008), in her literature review, covered teaching ELLs in the content areas, including science. She reported promising ESL strategies such as hands-on activities, inquiry-based learning, collaborative work, and use of visuals. It was found that ELLs who learned content, with their teachers' integrating such ESL strategies, demonstrated a better performance. Pearson et al. conducted a literature search on literacy and inquiry-based science. They identified a variety of promising integrated inquiry-based approaches, but cautioned that science teachers must first be trained in implementing these approaches through pre-service teacher preparation and ongoing teacher professional development.

Fang (2006) explained the gap between conversational fluency and academic language used in science poses a problem for middle school ELLs. He recommended the following language strategies to assist ELLs: vocabulary building, noun expansion (having students elaborate on simple nouns), sentence completion and paraphrasing exercises, sentence stripping (analyzing how complex sentences are constructed with conjunctions), and developing student awareness of sentence signposts. Lee and Buxton (2013) described a range of ESL strategies that can be used with ELLs and other students in the science classroom, including literacy strategies (e.g., incorporating science texts and trade books; student writing in different genres, such as lab reports and conference posters; expository paragraphs on science concepts or processes; narrative stories on science-related concepts); language support strategies (i.e., hands-on, inquiry-based activities, engaging multiple modes of learning, and explicit science vocabulary instruction); and discourse strategies (i.e., linguistic scaffolding and ongoing, two-way conversations about science topics). Medina-Jerez and colleagues (2007) recommended additional strategies, including collaboration between teachers, especially ESL and content-area teachers; use of alternative assessments; promoting democratic classrooms; highlighting the work of non-Western scientists; and involving parents.

In the following section, we discuss five ESL strategies and their application in literacy-infused science instruction as related to Project MSSELL. The five specific ESL strategies we share are: (a) hands-on activities, (b) cooperative learning and strategic grouping, (c) dialogic and questioning strategies, (d) scaffolded learning, and (f) integrated technology.

Hands-on activities. Hands-on activities have long been used in teaching ELLs and can encompass a wide variety of activities, such as science experiments and lab work, the creation of models and dioramas, and interactive demonstrations (Lee et al., 2006). Lee et al. (2006) argued that hands-on instruction makes scientific understanding more accessible for ELLs and helps them acquire scientific knowledge by lowering the language demands for meaningful participation. In this case they were comparing hands-on science investigation with more text-based, linguistically-demanding science learning activities. Hands-on science activities combined with collaborative inquiry can help ELLs develop their scientific language in an authentic way.

Hands-on science activities for students were an important component of a professional development intervention for elementary teachers in an urban school district (Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008). Researchers developed curriculum units for grade 3 and provided science supplies for the classrooms. Lee et al. (2008) found statistically significant differences in science outcomes between treatment and control students. There were no statistically significant differences in the science achievement gains made by current ELLs and ELLs who had been exited from or never were in a language program (Lee et al., 2008).

Science lessons for ELL students should include activity-based lessons with all students having hands-on access to materials (Gibbons, 2008). When content-area vocabulary and concepts are presented using realia, picture files, and hands-on activities, students will have the opportunity to use all of their senses to learn about a subject. Using concrete objects in the classroom creates cognitive connections with vocabulary, stimulates conversation, and builds background knowledge (Walqui, 2006). Laboratory equipment, measurement tools, rocks, plants, or any real object that relates to the language objective of a lesson can be used as realia (Nation, 2005). Using these types of multiple representations of information can engage ELLs and lead to better comprehension of the academic content (Moughamian, Rivera, & Francis, 2009).

Cooperative learning and strategic grouping. Cooperative learning and grouping strategies involve putting students into pairs or small groups based on student needs, lesson objectives, or other factors. For example, an ELL with low English proficiency might be paired with an ELL with high English proficiency. This strategy encourages students to learn from each other, and many ELLs prefer to work collaboratively. Brooks and Thurston (2010) studied the probability of middle school ELLs engaging in academic tasks based on how they were grouped with other students in content-area classrooms. They found that ELLs were more likely to participate in academic tasks in small groups and one-on-one pairings. González-Howard and McNeill (2016) highlighted the possibilities for ELL science learning in classroom communities of practice, where students practice scientific argumentation.

Shaw et al. (2014) included collaborative inquiry as an instructional strategy taught to pre-service teachers in an intervention. Pre-service teachers attended a modified science methods course and then delivered science instruction during their first year of teaching in grades 3-6. In addition to collaborative learning, the intervention's framework consisted of the following instructional strategies: science talk, literacy in science, scaffolding and development of language in science, contextualizing science activities, and promoting complex thinking. The findings showed that ELL gains in science concepts, writing, and vocabulary were similar to their non-ELL counterparts (Shaw et al., 2014). There were differences in vocabulary gains across ELL proficiency levels.

Questioning strategies. A number of scholars have emphasized the potential of dialogic and questioning strategies (e.g., Huerta & Jackson, 2010; Li, Lara-Alecio, Tong, & Irby, 2017; Moje et al., 2001; Pappas, Varelas, Kokkino Patton, Ye, & Ortiz, 2012; Rosebery & Ballenger, 2008; Taboada, 2012). Dialogic/discourse strategies center on establishing an interactive discussion of content. Questioning strategies involve teachers prompting students to elaborate on answers and explain ideas. Because these strategies require a verbal response, they facilitate ELLs' oral language development.

In a descriptive study, Pappas et al. (2012) illustrated how dialogic strategies in read alouds of English science texts impacted a second-grade bilingual classroom with Spanish-speaking ELLs. Emphasis was placed on prompting student explanations and reasoning, creating intertextual connections prior to class discussions, encouraging understanding of new concepts, and supporting learning of science terms. Pappas et al. suggested that with the aid of these dialogic strategies, classrooms discussions were more authentic because both the students and teacher could contribute their perspectives on concepts covered in the text.

Huerta and Jackson (2010) argued questioning strategies help ELLs improve their level of thinking and consequently their content understanding. Therefore, open-ended questions are more effective than close-ended questions because open-ended questions prompt ELLs to develop higher and deeper levels of thinking and improve their levels of understanding (Huerta, & Jackson).

Academic language scaffolding. The concept of “scaffolding refers to providing contextual supports for meaning through the use of simplified language, teacher modeling, visuals and graphics, cooperative learning and hands-on learning” (Ovando, Collier, & Combs, 2003, p. 345). Two main scaffolding strategies that have been empirically supported in the literature are visual scaffolding and academic language scaffolding. Adopting Herrell and Jordan’s (2004) definition, visual scaffolding refers to an approach in which language used in instruction is made more understandable by displaying visuals such as photographs that allow students to hear a word or concept and connect it with visual images displayed. Academic language scaffolding refers to an approach that supports the development of CALP by supporting students’ participation in content-area instruction (Herrell & Jordan). In doing so, instruction becomes cognitively demanding. Using a qualitative methodology, Gersten and Jimenez (1994) conducted an analysis on teachers’ observations to explore effective instructional strategies in reading among ELLs, particularly those who face reading difficulties. In their study, Gersten and Jimenez observed, for a period of two years, three ESL teachers at grades 3-5, which according to the authors were grades of crucial academic transition. Third grade is a pivotal point in that students at that grade level have learned to read adequately so that as they move to fourth grade, they are more able readers who can take a reading passage and begin to analyze it and build their vocabularies through the reading materials (O’Brien, 2008). Gersten and Jimenez reported that the optimal and scaffolded instructional strategies were those that challenge students without leading to the point of frustration. These strategies included vocabulary development, academic language scaffolding, visual scaffolding, and strategy instruction. It was found that experienced teachers incorporated scaffolding in their instructional practices with ELLs by providing support to students and building on and clarifying student input. Hmelo-Silver, Duncan, and Chinn (2007) defined scaffolding learning and a problem-based environment as the methodology in which students learn self-directed skills, content, and learning strategies through: (a) solving scientific problems collaboratively with their peers; (b) connecting the new scientific content with their life experience; and (c) engaging ELLs in self-directed inquiry. Therefore, Hmelo-Silver et al. asserted that scaffolding, as well as inquiry-based and problem-based learning environments, give ELLs opportunities to engage in complex tasks and make these complex tasks more accessible.

Scaffolding language development can take many forms. For example, Allen and Park (2011) described a life science lesson produced for sixth-grade ELLs of varying language proficiencies. The lesson incorporated multiple scaffolding techniques, including sentence frames and visual materials, as well as peer interpreters and alternative assessment, such as paragraph writing, drawing, and student interviews.

Integrated technology. Integrating technology tools including computers, digital microscopes, multimedia, and data collection software in science classrooms helps ELLs engage in science knowledge acquisition actively and effectively (Guzey & Roehrig, 2009). According to Warschauer, Grant, Del Real, and Rosseau (2004), computers and the Internet provide ELLs with opportunities for expanded reading and writing, support for language scaffolding, and the chance for research and developing multimedia presentations. However, based on their multi-case study of secondary science teachers, Guzey and Roehig argued that teachers need continuing professional development to help acquire technology integration competence in the classroom in order to be able to present content effectively.

Johnson (2011) reported on a multimodal, inquiry-based science intervention he implemented with seventh- and eighth-grade ELL and refugee students in an urban school district. In addition to a range of ESL strategies, Johnson incorporated technology into his science instruction, including digital probes, online research, streaming video, and virtual globe software. He noted that his ELL students were less likely to engage with computer simulations and other technology components unless student-student interaction was included (Johnson, 2011).

Terrazas-Arellanes, Knox, and Rivas (2013) used collaborative online projects with middle school ELLs to increase science learning. The online projects incorporated warm-up activities, pictures and videos, interactives and games, vocabulary and definition features, and a toggle option to switch between Spanish and English on the webpages. Based on pretest and posttest assessments, ELLs had a statistically significant increase in their science content learning.

As we continue in this paper, we describe how the aforementioned five ESL strategies were incorporated into science instruction to support student learning, and conduct a comparison on such incorporation between sixth-grade science teachers in treatment and control classrooms in Project MSSELL. As noted earlier, our overarching research question is: Is there a significant difference between treatment and control classrooms on teachers' implementation of ESL strategies?

Project MSSELL

Project MSSELL (DRL-0822343) was a longitudinal (fifth to sixth grade) research study funded by the National Science Foundation. The project, designed to improve science and literacy for ELLs and economically-challenged students, was located in a large urban school district in southeast Texas.

Design and Participants

A randomized control trial, Project MSSELL was implemented in four intermediate schools randomly assigned to treatment or control (typical science instruction) conditions. In order to avoid contamination of the intervention, ELLs and economically-challenged non-ELLs at the same school received the same condition. The district serves a large number of Spanish-speaking ELLs (over 45%), and the majority of students in the district (85%) qualify for free or reduced-cost lunches. For the purposes of this research, we focused only on the sixth-grade level since this would be the second year of continuous work with the same cohort of students in the longitudinal program. The teachers were different from grade level to grade level. Within each school, teachers were randomly selected for participation. For sixth grade, there were four treatment teachers and four control teachers, with an average of 8.4 years of teaching. In this group, there were also two novice teachers. The fifth-grade student sample consisted of 248 ELLs (166 in treatment and 80 in control) and 288 English speakers (94 in treatment and 194 in control). Of these students, 160 ELLs (105 treatment; 55 control) and 116 non-ELLs (48 treatment; 68 control) completed the intervention through sixth grade. The overall project was experimental at the school level, and quasi-experimental at the student level, which is in accordance with Texas law (Texas Education Code [TEC], 1995) since randomization at the student level is a violation of the TEC. Specifically, for this component we analyzed sixth-grade data.

MSSELL Teachers and Curriculum

Treatment teachers participated in ongoing bi-weekly professional learning sessions taught by research coordinators specializing in science and second language development for one year. Delivered after school, the face-to-face sessions lasted 90 minutes and covered upcoming lessons and ESL strategies used in the pre-scripted, project specific, researcher-developed lessons. These lessons embedded literacy by focusing on expository text features, pre-teaching academic science vocabulary using student-friendly definitions, and pronunciation and decoding of challenging words selected from the text. Expository text was strategically selected by the MSSELL researchers from a published science curriculum (not used by the district) and from other science literacy resources. In the treatment classrooms, students received 85 minutes of daily literacy-infused science instruction. This instruction followed a highly-structured, scripted curriculum aligned to state and national science and reading standards. The treatment literacy-infused science curriculum was developed by the researchers and was used in lieu of the district curriculum. We also addressed the following topics in the professional learning sessions: (a) integrated science content reading, (b) science vocabulary instruction, (c) oral and written language development in science, (d) student engagement through questioning strategies, and (e) second language acquisition ESL strategies, including visual and language scaffolding, manipulatives, realia, content connections, literacy development, cooperative learning, grouping, and technology integration. Elaboration on the ESL strategies implemented in Project MSSELL follows.

Hands-on activities. The daily hands-on lessons included the 5E's (Engagement, Exploration, Explanation, Elaboration, and Evaluation) from the 5E Instructional Model (Bybee, 1996) and included daily writing, speaking, ESL strategies, hands-on science activities, and reading practices with science content. At least three of the 5E's were used in the lessons each day. Students collaborated for partner reading and in small collaborative learning or partner groups for hands-on science activities related to each day's lesson. This provided hooks for language development for the children. Rupley and Slough (2010) indicated that "what children learn in science is dependent not only on curriculum and standards, but also by how they are engaged in the science curriculum; the experiences they have extend, reinforce, and stimulate them to engage in deeper processing of scientific concepts" and more specifically, that "multiple inputs (seeing, doing, and hearing)" are powerful for ELL students' vocabulary development (p. 109). In MSSELL, along with the tactile engagement in science, multiple inputs, such as direct instruction of vocabulary, including pronunciation, definitions, and visuals, were used by teachers. Students kept science notebooks, where they recorded vocabulary, predictions, and observations; completed foldables; and produced genre-based science writing (e.g., narratives, reflections, and newspaper articles). Throughout instruction, teachers implemented multiple ESL strategies that had been modeled in the professional learning sessions and were systematically included in the scripted curriculum materials.

Questioning strategies. Project MSSELL lessons included scripted, leveled questions, and question statements with cognitive verbs (e.g., “Define energy”; “Give an example of energy transformation in your home”; “Hypothesize what would happen if energy did not transform”). Students responded to these questions, which were strategically placed in the lessons and included higher order questions, through a variety of simultaneity techniques, which allowed all students to respond in some manner through choral response, Think-Pair-Share, visual cues (thumbs up/thumbs down), or writing or illustrating their answer. Individual students were then randomly called on to answer before the whole class. If a student did not respond or gave an incorrect response, the teacher provided wait time, which is time for students to think and formulate a response. If needed, then the teacher coached by rewording the question, offering clues, and giving students time to conference with peers. Teachers provided students with cognitive and affective feedback, for example: “Great job giving an example of energy transformation.”

Academic language scaffolding (MSSELL included visual scaffolding, manipulatives/realia, and grouping). Teachers supported student use of academic language through identifying and directly teaching academic vocabulary. Science vocabulary words were taught using student-friendly definitions, visuals, and sentences using vocabulary words in context. Science concept vocabulary posters helped students make connections and see relationships between words and science concepts. Teachers also scaffolded academic language when modeling academic language during instruction. Teachers modeled language by pronouncing words correctly, speaking clearly and in complete sentences, and repeating and restating ideas using academic vocabulary. Students were encouraged to use academic vocabulary when speaking and writing, and reminded to speak in complete sentences.

Teachers also supported academic language through visual scaffolding and hands-on learning using manipulatives and realia. Visual images, photographs, drawings, and video clips, were incorporated into MSSELL instructional materials. Teachers purposefully called attention to the visual images to help support student understanding of science academic vocabulary and concepts. Students interacted with manipulatives, small objects that could be touched and moved, while conducting investigations. Students built background knowledge and connected vocabulary and concepts to the real world through their senses by using realia, such as microscopes, thermometers, plants, soil, or representations of real objects like toy cars and science models.

Students had multiple opportunities for verbal interaction and peer-scaffolding while working in cooperative groups and through partner work. Students had assigned roles as they worked together to conduct investigations, gave pair-sharing responses to leveled questions, and completed partner reading in strategically matched pairings. Teachers monitored group work and clarified misconceptions, while modeling and encouraging use of academic language.

Integrated technology. Science concept development was supported through the integration of technology in the classroom. Science standards-based educational software (e.g., EduSmart) supported student understanding and application of science concepts through the use of graphics and animation. Our research team added higher level questions to the EduSmart science. As related to the focused science standard(s), segments of the software animations and simulations were projected via a projector. MSSELL lessons provided supplementary, leveled questions for students and teachers to discuss during strategic stopping points to check for comprehension. Technology integration also included student use of technology, such as conducting Internet research on energy resources and other curricular topics.

Control Teachers and Curriculum

Teachers in the control condition followed the district's typical practices in science instruction and science curriculum. This included district-supported science workshops to meet the state's requirement of 30 hours of professional development. Control teachers implemented the standards-based, district-adopted science curriculum and accompanying lessons that covered one 5E in a science lesson per day, per week. Based on classroom observations, typical lessons involved independent reading of the science text, answering questions, vocabulary instruction through word walls and students writing definitions, some use of science notebooks, and varying utilization of ESL strategies. Control teachers varied their lessons and strictly followed the district curriculum.

Observation of ESL Strategies with the Transitional Bilingual Observation Protocol

In Project MSSELL, the Transitional Bilingual Observation Protocol (TBOP) was used as a fidelity check to capture teachers' pedagogical delivery, and to compare such delivery between treatment and control classrooms. This protocol is based on a four-dimensional pedagogical theory developed by Lara-Alecio and Parker (1994). Originally designed for transitional bilingual classroom settings, this protocol has been successfully used as an observation tool in structured English immersion and dual language environments (see Lara-Alecio, Tong, Irby, & Mathes, 2009; Tong, Luo, Irby, Lara-Alecio, & Rivera, 2017). TBOP incorporates four pedagogical domains and the component of ESL strategies in the web-based tool, which was incorporated as a tool modification in previous studies (e.g., Irby, Tong, Lara-Alecio, Meyer, & Rodriguez, 2007; Lara-Alecio et al., 2009). Although there is a range of different aspects of the teaching captured in the observation protocol via four domains, for the purposes of this paper, we only analyzed the data related to ESL strategies present during science instruction. Trained observers with interrater reliability of $a = .95$ recorded the occurrence of instructional events within all domains and ESL strategies every 20 seconds.

Results

For sixth grade, a total of 1,380 rounds of observation were conducted in both experimental and control classrooms during science instruction, with an average of 54.5 minutes per teacher (for more specific information on fifth-grade implementation and results, see Garza, Huerta, Lara-Alecio, Irby, & Tong, 2016a; Garza, Huerta, Lara-Alecio, Irby, & Tong, 2016b; Tong, Irby, Lara-Alecio, Guerrero, Fan, & Huerta, 2014). Because of the frequency nature of the data, a chi-square test of homogeneity of proportion was employed to identify if the proportion of each category under every domain of TBOP was homogenous across condition.

Cramer's V is reported below as type of effect size (Rea & Parker, 1992). The data collected from teachers with ELLs and non-ELLs were aggregated because (a) in some classrooms/rotations, ELLs and non-ELLs were placed in the same science block; and (b) treatment teachers received the same professional development. The chi-square test was significant ($p < 0.001$), with a Cramer's V of 0.46, indicating there was a statistically significant difference among teachers' time allocation in the ESL strategies between the two conditions, and the magnitude of such difference was strong, with treatment teachers demonstrating more ESL strategies than the control teachers during the observed time periods.

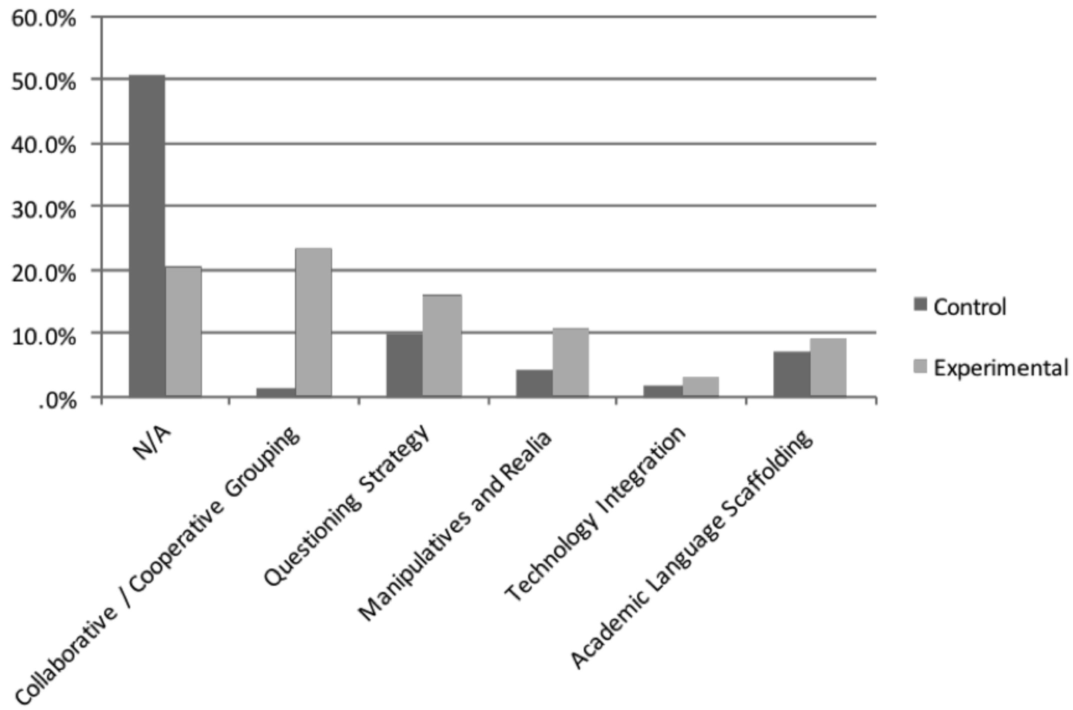

Figure 1. ESL strategies by condition – sixth grade. N/A: ESL strategies in the observed time allocation were not demonstrated.

Figure 1 illustrates that experimental teachers spent a higher percentage of instructional time utilizing ESL strategies, such as collaborative/cooperative grouping (24%), questioning strategies (16%), manipulatives and realia (11%), and academic language scaffolding (9.3%).

Collaborative grouping provided students opportunities and support for verbal interaction through cooperative learning, partner work (Think-Pair-Share), and partner reading. With the use of manipulatives and realia, vocabulary and concepts were connected to real life through hands-on materials and opportunities to use the senses in learning (i.e., see, feel, hear, and smell objects). It was also observed that teachers in control classrooms did not fully utilize the instructional time to incorporate ESL strategies to support students' learning. In fact, there was a significantly higher percentage of time (over 50%) among control teachers that was not allocated to ESL strategies.

The ESL-engaged activities in science are critical for teachers to include in their lessons because such ESL strategies can assist English learners and economically-disadvantaged students to improve their fluency in academic language in English, a necessary skill for science class. Cross (1999) indicated that students need "time to talk, write, reflect, and otherwise engage in activities" (p. 10), because "academic language can be confusing when first encountered because of terms that sound similar to everyday conversational English but have different meanings (e.g., periodic *table*, animal *class*, autonomic *response*) (Carrier, 2005, p. 6). Therefore, it is important for teachers to employ ESL strategies in their lessons so that the students have the "tools to engage in social interactions with other students in the classroom" (Carrier, p. 10). Thier (2002) stated that "language and its skills are the lenses that focus students' thinking, the catalysts that help students turn facts into knowledge that they can retain long past their school careers and apply in their own lives" (p. 27). Therefore, we advocate for focused instructional time engaging ESL strategies that promote academic language in science.

Discussion

In this paper, we described how ESL strategies were incorporated into science teaching by sixth-grade teachers in a randomized control research study. Results underscored the difference between treatment and control teachers in utilizing some of the specific ESL instructional strategies to enhance their students' science and literacy growth. More specifically, the following ESL strategies, i.e., collaborative/cooperative grouping, use of manipulatives, academic language scaffolding, realia, and questioning strategies, were found to be more frequently implemented in the treatment classrooms. For ELLs, these strategies can help to make content more accessible. Researchers have also suggested the integration of ESL strategies into content-area teaching for English-speaking students, especially those coming from economically-challenged backgrounds, who might benefit from an emphasis on academic language development (Palumbo & Sanacore, 2009; Tong et al., 2014; Watkins & Lindal, 2010).

Although student data are not analyzed in this paper, in other writings we have reported positive student gains from the first year and second year of implementation in fifth and sixth grade in that treatment students outperformed control students on curriculum-based tests of science and reading and on standardized assessments of science, reading, and English reading fluency (see Lara-Alecio, Irby, Tong, & Guerrero, 2013; Lara-Alecio et al., 2012; Tong et al., 2014). Those student achievements and the findings in this paper imply a promising intervention effect is related to the intensive and strategy-incorporated professional learning provided to treatment teachers as was reflected in their classroom instruction, particularly as the teachers employed ESL strategies. Similar findings in other scholars' research on science teaching and learning for ELLs also indicated increased student academic achievement tied to the use of a variety of ESL strategies (e.g., August, Branum-Martin, Cardenas-Hagan & Francis, 2009; Lee et al., 2008; Shaw et al., 2014; Terrazas-Arellanes et al., 2013).

Based on these findings, we recommend that middle school science teachers implement a variety of ESL instructional strategies frequently and for periods of at least 60% of their instructional minutes in order to make content more comprehensible and engaging for ELL students, as well as economically-challenged English-speaking students, who are often placed in the same classroom with their ELL peers. Professional learning for middle grades science teachers needs to support them in becoming more comfortable with ESL strategies and using them in content-area instruction to promote academic achievement and English language proficiency for ELLs and economically-challenged students. Lastly, we encourage school administrators to consider ongoing, targeted professional learning opportunities on appropriate ESL instructional strategies for their middle grades science (and other content-area) teachers.

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