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Evaluating Pedagogical Practices in Science Classrooms: A Randomized Controlled Trial Study on Teacher Virtual Professional Development with Virtual Mentoring and Coaching

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Abstract

In this randomized control study, we evaluated science teachers' pedagogical practices via classroom observations following ongoing, intensive, and structured instructional support sessions. These sessions included virtual professional development (VPD) and virtual mentoring and coaching (VMC) that accompanied a literacy-infused science curriculum. Using a low-inference observational instrument, we explored the direct impact of VPD and VMC on fifth-grade science teachers' observed time allocation in a randomized controlled trial (RCT) validation study. The observations were collected three times during science instruction from 121 teachers in 68 schools from 35 public school districts in the U.S. state of Texas, during the 2017-2018 school year. Preliminary findings revealed pedagogical differences in time allocation among teachers between treatment and control classrooms. We identified improved instructional practices within treatment classrooms, which suggests the intervention had a positive effect by enhancing the quality of pedagogy as well as the content-area instruction in science.

Keywords:

Classroom Observation, Evaluation, Randomized Control Trial, Science, Pedagogical Practices, Virtual Professional Development, Virtual Mentoring And Coaching, Emergent Bilingual, Economically Challenged Students, United States

Introduction

Professional development (PD) has long been utilized to support teacher learning and instructional capacity to implement curriculum and instructional strategies (Darling-Hammond et al., 2017; Desimone et al., 2002; Fischer et al., 2018; Fishman et al., 2003; McChesney & Aldridge, 2021; Sancar et al., 2021; Valiandes et al., 2018). Virtual PD (VPD) coupled with the use of virtual tools can provide effective, high-quality teacher learning experiences (Irby et al., 2022; Fishman et al., 2013; Lara-Alecio et al., 2021; Lynch et al., 2021; S. Tang et al., 2022), especially for science teachers in remote or rural areas (Cady et al., 2011; Irby et al., 2021; Quinn et al., 2022).

Although PD can help teachers increase content knowledge and learn instructional strategies, PD alone does not provide teachers the opportunity to implement strategies in the classroom and receive timely feedback on their performance. Providing real-time, remote instructional feedback can improve teacher performance (Sinclair et al., 2020), and utilizing technology to provide such feedback has been found to be both cost-effective and practical in school settings (Rodgers et al., 2019; Schaefer & Ottley, 2018). Researchers have been clear that PD and real-time coaching support teacher instructional capacity. However, little has been reported about how ongoing instructional support sessions, including both VPD paired with virtual mentoring and coaching (VMC), influence elementary science teachers' pedagogical practices.

One measure of teachers' pedagogical effectiveness is classroom observation. When a classroom observation is recorded with a detailed observation protocol, such a record gives the observer a complete and nuanced picture of a teacher's instructional practices minute by minute. This detailed information can be used to understand what the teacher is accomplishing instructionally, as well as what aspects of the instruction that may need improvement. Providing observation-based performance feedback can help reinforce targeted instructional behaviors (Sweigart et al., 2016) and is an important element of effective teacher development (Darling-Hammond et al., 2017; Kettler & Reddy, 2019). Such performance feedback can be shared individually or with small groups of teachers who might have similar instructional needs.

The purpose of this study was to evaluate the pedagogical practices of fifth-grade treatment science teachers who were provided the support of VPD and VMC and control teachers who only received in the typical district PD opportunities and no VMC. These teachers participated in a randomized controlled trial (RCT) validation study implemented in 35 public school districts in the United States in Texas. The VPD and VMC intervention took place in school districts with large numbers of economically challenged (EC) students, inclusive of emergent bilingual (EB) students, and was based on implementation of a literacy-infused science (LIS) curriculum (Lara-Alecio et al., 2016).

Theoretical Framework

Classroom observation data for evaluating teachers' pedagogical practices is important to have in order to improve those practices (Tong, Irby et al., 2019). To better observe classrooms with large numbers of EBs, Lara-Alecio and Parker (1994) and Lara-Alecio et al. (2013) developed a four-dimensional pedagogical classroom observation model that integrates bilingual education theoretical principles to include interrelated dimensions of language content, language of instruction, communication mode, and activity structures. The domain of language content is grounded in Cummins' (1986) language acquisition theory that distinguishes between Basic Interpersonal Communication Skills (BICS) and Cognitive Academic Language Proficiency (CALP). The pedagogical model further separates BICS and CALP in four language content levels: (a) social routines, (b) classroom routines, (c) light cognitive language, and (d) dense cognitive language. The language of instruction domain draws from the bilingual threshold hypothesis and the use of the first heritage language (L1) and second language (L2) during content-area instruction (Cummins, 1986; Krashen, 1981). The pedagogical model includes both language(s) used by the teacher and students in the following categories: (a) content is presented in L1, (b) L1 is used to introduce L2, (c) L2 is supported and clarified by L1, and (d) content is presented in L2. The domain of communication is informed by the reciprocal interaction model (Cummins, 1986) and the context-specific model (Diaz et al., 1986) to classify students' mode of communication: receptive (listening and reading), expressive (speaking and writing), or some combination of these. The activity structure domain is grounded in Vygotsky's Zone of Proximal Development (ZPD; 1978) and in the work of Brophy and Good (1974) as related to the context of instruction and how teachers structure interactions to enhance student learning. The activity structure domain signifies the teacher's pedagogical activities (e.g., lecturing, observing, evaluating, and asking) and the students' response (e.g., listening, answering, cooperating, and asking).

The four-dimensional pedagogical model (see Figure 1) serves as the theoretical basis of the validated observation tool used in this study, the Pedagogical Observation Protocol (POP). The POP integrates observable behaviors and interactions of teachers and students in the classroom and is used in this study to capture science teachers' pedagogical practices.

Literature Review

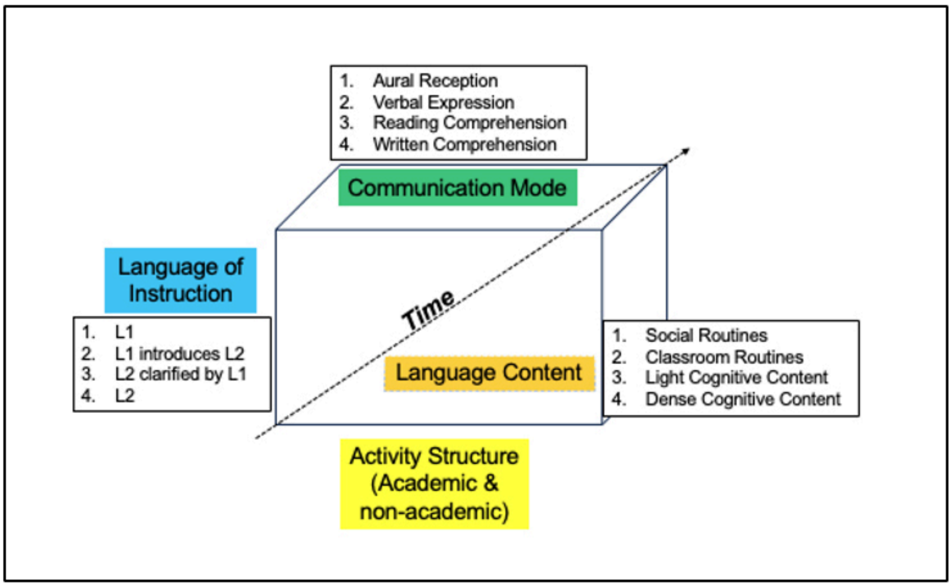
In this section, we present a narrative literature review in four sections. Those are connections between classroom observation and professional development, professional development, virtual professional development, and virtual mentoring and coaching.

Connecting Classroom Observation and Professional Development

The powerful link between classroom observation and PD might not be immediately obvious. Novice and experienced teachers sometimes find classroom observation a stressful or anxiety-producing experience because they associate it with performance evaluation, although observation

Figure 1

Four-dimensional Pedagogical Model (Lara-Alecio & Parker, 1994; Lara-Alecio et al., 2013)



also is an important indicator of educators' PD needs (Aubusson et al., 2007; Borich, 2015; Lasagabaster & Sierra, 2011). O'Leary et al. (2023) noted that one hurdle for Vietnamese schools is moving teachers and educational leaders away from thinking of classroom observation as merely an evaluative tool to utilizing it for teacher PD and learning. They summarized that this shift in thinking requires more of a collaborative approach and building of trust.

The evidence of successful PD may be observed via classroom observations, which can best demonstrate the effectiveness of such PD, and even more importantly, teachers' instructional patterns that influence student involvement in science classrooms and on students' science achievement, especially for EB and EC students (Garza, Huerta, Lara-Alecio et al., 2018; Garza, Huerta, Spies et al., 2018; Jackson et al., 2019). In early observational studies, researchers found that lower-achieving schools often devote less time and emphasis to higher-order thinking skills and cognitively demanding academic language development than do schools serving more advantaged students (Coley & Hoffman, 1990; Padrón & Waxman, 1993). Likewise, Davidson and Koppenhaver (2017) found that low-income and minoritized students were more likely to be placed in remedial coursework, thus receiving less demanding classroom instruction. Similarly, the scarcity of reported practice was found regarding teachers' support in science instruction to engage students in cognitively challenging tasks among students with low-literacy skills (Tong, Irby et al., 2019). Thus, quality PD opportunities should be provided to equip science teachers with tools and resources to serve diverse learners and EC students with science content (Irby et al., 2018; Gamez & Parker, 2018; Jackson et al., 2019; Lee et al., 2023; Meskill & Oliveira, 2019; Vera et al., 2022). The impact of these PD opportunities on teachers' pedagogical practices can be evaluated with a comprehensive observation instrument (Garza, Huerta, Lara-Alecio et al., 2018; Garza, Huerta, Spies et al., 2018).

Without direct classroom observation, it cannot be determined if teachers are implementing the strategies and information learned in PD sessions and improving their effectiveness for promoting students' achievement (Joyce & Calhoun, 2010; Tong, Tang et al., 2019). Specifically, reliable, valid, and practical observation protocols can offer a vehicle for observing and exploring how knowledge and skills acquired during the PD can be transferred into hands-on practice in the science classroom to create an environment that is conducive to student learning (Calderón et al., 2011; National Research Council, 2010).

Professional Development

Due to challenges in the recruitment and retention of highly qualified teachers, particularly in the science, technology, engineering, and mathematics (STEM) areas (Fairman et al., 2019; Sutcher et al., 2016; Whitfield et al., 2021), students often have limited access to teachers with content-area expertise (Cardichon et al., 2020; Sexton, 2018). Scholars have concurred that quality PD leads to changes in teachers' knowledge and instructional techniques in mainstream education (Bragg et al., 2021; Darling-Hammond et al., 2017; Germuth, 2018; Kim et al., 2019). Quality PD can also make a difference for content-area teachers (Maeng et al., 2020; Miller et al., 2019). For instance, Maeng et al. (2020) provided a four-week summer institute on reform-based science instruction for elementary science teachers. Utilizing an RCT design, Maeng and colleagues found that treatment teachers who attended the PD demonstrated significantly greater acumen and confidence integrating inquiry, project-based learning, and nature of science into their instruction compared to control teachers. These improvements also were evident in treatment teachers' recorded classroom observations.

Researchers have also linked effective teacher PD with student outcomes (Gupta & Lee, 2020; Llosa et al., 2016). For example, A. Tang et al. (2022) conducted a multilevel mediation analysis of fourth-grade and eighth-grade students and their teachers in Hong Kong. They found that teachers' PD in science pedagogy was significantly and positively related to student outcomes. Tang et al. also showed that teachers' focus on science investigation was a strong mediator at grade 4, but not grade 8. Llosa et al. (2016) found significant, positive science outcomes for mainstream and EB students, following a one-year science curricular intervention with teacher PD. In another study on the effects of a year-long PD for elementary science teachers, Nichol et al. (2018) found no difference in science performance between treatment and comparison students, despite the treatment teachers being absent 20% of the school year for the PD. Moreover, the investigators also examined the long-term impact of the PD by comparing the scores of students who were taught by the treatment teachers the year they received the PD and their students the following year. The latter group significantly exceeded the other group, with a medium effect size of .088. Characteristics of effective teacher PD include: (a) long-term duration; (b) collaboration; (c) voluntary; (d) subject knowledge training; (e) inclusion of outside expertise; (f) coaching support; (g) incorporation of active learning; and (h) reflection opportunities (Darling-Hammond et al., 2017; Sims & Fletcher-Wood, 2021).

Based on a systematic review of 11 empirical studies on teacher professional development for STEM integration in elementary/primary classrooms, Boz (2023) recommended that PD should: (a) be targeted to increase teachers' content knowledge and boost collaborative planning with subject-area specialists; (b) incorporate active learning strategies and provide a range of samples of integrated STEM curriculum; (c) emphasize successful practices of educators implementing integrated STEM activities; (d) be in line with school or district policies and standards, and offer teachers continual support from administrators and parents; (e) focus on assessment of student learning across the subjects integrated into the STEM lessons; and (f) bolster teachers planning and conducting STEM lessons.

Virtual Professional Development

Virtual professional development has gained traction with teachers and school administrators looking to sharpen their skills (Irby et al., 2015.; Irby, Sutton-Jones et al., 2017; Irby, Pashmforoosh, Duery et al., 2022; Tong et al., 2015). VPD for teachers can take a range of forms, such as formal online university courses, professional learning communities (PLCs) hosted through social media or other online platforms, live video conferences and webinars, and informal, just-in-time PD videos. The literature increasingly supports the effectiveness of VPD for teacher learning (Dede et al., 2016; Fishman et al., 2013; Jaber et al., 2018), and comparison studies of online and face-to-face PD have indicated similar learning outcomes for teachers (Fishman et al., 2013; Hathaway & Norton, 2012) and students (Fishman et al., 2013). In a comparison of online and face-to-face continuing PD for Saudi science teachers, Binmohsen and Abrahams (2022) observed that teachers receiving the online PD were as effective, and in some cases, more effective than the face-to-face teachers, based on classroom observations; the online teachers also reported more satisfaction with the PD. Rigorous empirical research as well as theory-building studies on online PD remains scarce, and scholars have called for more investigation (Dede et al., 2009; Moon et al., 2014). The Community for Advancing Discovery Research in Education (CADRE, 2017) noted the need for more research that:

- "targets specific program features or combinations of features and their connections to teacher learning;
- examines impacts on teacher practice and student learning; and
- invokes a range of formative and summative methodologies…." (p. 15)

With an increased government, industry, and business focus on STEM, it is crucial for science teachers to have strong PD opportunities to strengthen their knowledge and skills. VPD can fill this need, especially for science teachers serving in rural or remote schools (Cady et al., 2011). Moreover, VPD provides teachers in geographically remote areas with the same opportunities and access to quality PD (Irby, 2015; Irby, Tong et al., 2021; Quinn et al., 2022). Binmohsen and Abrahams (2022) observed that online PD has benefits in countries where social and religious customs prohibit direct interaction between men and women. Through VPD, teacher educators can build and enhance teachers' science content knowledge and pedagogical beliefs and skills. For example, Gosselin et al. (2010) reported on the creation of Laboratory Earth, three sponsored, online graduate courses, considered online PD, for K-8 educators designed to improve teacher content knowledge and teacher attitudes about science. The scholars found significant increases in both science content knowledge and sense of self-efficacy and enjoyment in teaching science among teachers who participated. In 2011, the National Science Teachers Association (NSTA) launched the PD Indexer, a valid and reliable tool that helps teachers self-assess their content knowledge and then, based their results, points them to relevant PD resources within the NSTA's online portal (Buyers et al., 2011).

The body of literature on VPD continues to increase, especially in terms of best practices for PD instruction and facilitation, and general design principles. In their case study of a year-long science VPD for in-service elementary and middle school teachers in a rural Massachusetts district, Watkins et al. (2020) emphasized the need to understand how online instructors can better support teachers' science engagement. They suggested that within an asynchronous online environment, instructors should practice responsive facilitation in three essential ways: (a) tailor prompts and assignments to teachers' needs and context, (b) encourage teachers to engage in discipline-specific critical-thinking, and (c) focus on the individual's scientific thinking. Yoon et al. (2020) stressed the need for online learning environments that support teachers in creating social connections, cultivating participant trust through sharing, engaging in collaborative "sense making" (p. 10), and connecting with other teachers and specialists.

Cavanaugh and Dawson (2010) suggested that following best practice design principles contributed to the success of their online Exploring Florida Science project, which was implemented to increase content knowledge for secondary science teachers and provide science digital media for student project-based learning. They highlighted the following principles: (a) VPD environments included engaging media to increase teacher participation; (b) teacher materials were content standards aligned in order to make them more relevant; (c) materials included personal stories to make it easier for teachers to relate to science practitioners; and (d) resources for teachers to incorporate student project-based learning were included. Based on feedback from researchers from across 11 National Science Foundation education projects, CADRE (2017) identified three significant design principles for online and blended teacher PD in K-12 STEM: (a) encouraging and supportive engagement that increases knowledge and furthers professional goals; (b) building opportunities for collaborative learning for teachers, and (c) promoting teacher reflection on content and practice. Interestingly, Luz et al. (2018) found that it was external factors (i.e., heavy workloads and technology issues) that most commonly drove Brazilian science teachers to drop out of online PD courses.

Virtual Mentoring and Coaching

Over the past 10 years, research has been expanded in the arena of online or virtual mentoring and coaching (Irby, Lynch et al., 2017; Irby, Pashmforoosh, Lara-Alecio et al., 2023; Irby, Pashmforoosh, Tong et al., 2022) — sometimes also called e-mentoring — especially for science teachers (Bang, 2013; Bang & Luft, 2014; Lee et al., 2018; Melton et al., 2019; Nugent et al., 2016). Several different models of online mentoring are present in the literature. For example, there are asynchronous, dialogue-based mentoring models that utilize discussion boards and/or private chat rooms, such as that described in Bang and Luft's (2014) case study. They reported on the mentoring dialogues of two first-year secondary science teachers located in the American Southwest who participated in a nationwide online mentoring program, and they analyzed the threaded messages of the teachers (mentees) and teacher educators (mentors). These messages, focused on science teaching, were posted privately and asynchronously in a virtual chat room three to four times a week. Bang and Luft suggested that their analysis provided evidence that online mentoring is an effective method for sharing knowledge between experienced and novice teachers and speeding the induction and professional development of new science teachers. A similar online mentoring model was used in Simonsen et al.'s (2009) study, which was derived from a multiyear, multistate National Science Foundation project on science and math teacher induction. This project leveraged both VPD and VMC. Utilizing content analysis, researchers examined private discussion postings between mentor teachers and mentee novice teachers. Content analysis of more than 1,600 posts from 19 mentor-mentee pairs indicated that conversations centered on three types of knowledge: content knowledge, pedagogical content knowledge, and pedagogical knowledge. Simonsen et al. concluded that the use of this medium created a safe space for novice teachers to construct new pedagogical knowledge and talk about sensitive topics with a trusted, experienced mentor.

Another model of online mentoring involves synchronous meetings between mentor and mentee, and the video recording of the mentee teacher delivering classroom instruction (e.g., Carson et al., 2019; Gaudin & Chaliès, 2015). In Carson et al.'s (2019) study, they detailed their model, which follows the Standards for Professional Learning (Learning Forward, 2011), for coaching rural math teachers in New York and Arizona. First, the mentor and mentee met online through a video conferencing app, such as Zoom, to discuss a lesson that the teacher had planned — all lesson materials were in a shared Google folder. Then the teacher video recorded him/herself implementing the lesson, made annotations on part of the recording for the mentor to watch, and shared the recording with the mentor. Next, the mentor also annotated a section of the video. Lastly, the mentor and mentee again met in the video conferencing app to debrief and discuss student work the teacher had uploaded to the Google folder following the lesson. Unver et al. (2023) presented a similar e-mentoring model, which involved Turkish teachers submitting videos of recorded classroom instruction and mentors providing feedback. They followed an iterative mentoring process. The authors concluded that the online mentoring model, supported by scientific inquiry as part of a professional development program, improved teachers' classroom instructional practices, regardless of their years of professional experience or the grade level they taught. Carson and Choppin (2021) used a video-based online coaching model. Their model incorporated both synchronous and asynchronous modes for planning, teaching, and reflection in math content-area teacher learning with a subject-area-focused approach, and enabled rural teachers to have access to experienced coaches with no geographical constraints.

Yet another online mentoring model is completely synchronous, including the streaming video capture of classroom instruction and live, instantaneous mentor feedback. For example, ong et al. (2015) described another online mentoring model as a VMC-RTF model implemented with teachers of EBs to improve students' English oral language, literacy, and/or science outcomes. In this VMC-RTF model, the coach/mentor observed the classroom teacher remotely over the internet at a pre-scheduled time and provided instant feedback to the mentee teacher via a bug-in-the-ear bluetooth device (with a wireless microphone and earbud) as the teacher delivered instruction uninterrupted. A web-accessible video camera placed in the classroom captured teacher and student activities during the coaching session. At a later time, the mentor and teacher reconvened virtually using a video-conferencing platform to discuss ways to improve student learning and engagement, as well as complete a pedagogical reflection using the Brown and Irby Reflection Cycle (2001) in which teachers concluded with the transform stage — transforming their next-step practice.

Research Question

The research question for this study was: When fifth-grade treatment science teachers are provided with VPD and VMC, to what extent do they differ on observed pedagogical practices from fifth-grade control teachers who were not provided VPD and VMC?

Methods

Research Design and Context

This study was derived from a longitudinal RCT funded by the U.S. Department of Education: Literacy-Infused Science Using Technology Opportunities (LISTO; PR/Award Number U411B160011). The purpose was to validate literacy-infused science instructional and curricular innovations in order to increase instructional capacity of teachers and to improve students' science and reading/writing literacy achievement in rural and non-rural schools for EC students, inclusive of EBs. Project personnel recruited 35 Texas public school districts that had more than 50% of students classified as EC. A goal of Project LISTO was to recruit 66% rural campuses to support schools that have limited resources. An external evaluator randomly assigned 68 participating campuses to treatment (n = 33) and control (n = 35) conditions, with 66% (45

Table 1

Chi-square Test Results on Science Teachers' Demographic Data by Condition

Variable			Condition: Control	Condition: Treatment	Chi-square	Cramer's V	*p*
Gender	Female	n	50	43	0.099	0.029	0.753
		%	75.8%	78.2%			
	Male	n	16	12			
		%	24.2%	21.8%			
Route to certification	Alternative certification	n	26	27	1.840	0.123	0.399
		%	39.4%	49.1%			
	University teaching	n	39	28			
		%	59.1%	50.9%			
Highest degree	Bachelor's degree	n	35	37	4.913	0.202	0.178
		%	53%	67.3%			
	Bachelor's degree with some graduate hours	n	8	5			
		%	12.1%	9.1%			
	Master's degree	n	19	13			
		%	28.8%	23.6%			

out of 68) of the schools from rural areas. Fifth-grade science teachers from each campus were invited to participate. For this study, 121 fifth-grade science teachers (66 in treatment, 55 in control) participated. Teachers in treatment campuses implemented LISTO curriculum and received ongoing instructional support sessions, including VPD and VMC. Control teachers implemented district-typical science instruction. The data used in this study came from the first year of Project LISTO, which was the 2017-2018 school year.

Participants

Teachers' demographic information was collected via a participant survey that included gender, route to certification, and highest education level. A chi-square test of homogeneity was conducted to determine whether treatment and control teachers differed on the demographic variables of gender, route to certification, and education level. Results indicated no statistically significant difference between treatment and control teachers regarding these variables, which meant that treatment and control teachers shared similar demographic characteristics, teaching qualifications, and education level before the intervention started (see Table 1).

Intervention at Teacher Level: Instructional Support Sessions with VPD and VMC

This study was implemented in 35 statewide school districts in Texas; therefore, it was prudent to alter the traditional face-to-face PD and traditional mentoring and coaching to virtual professional development and virtual mentoring and coaching. Teachers participated in a series of 15 ongoing instructional support sessions that included synchronous VPD and live VMC using the Applied Pedagogical eXtra Imaging System (APXIS), which consisted of (a) a laptop computer, (b) external video camera, (c) a video-conferencing platform, and (d) a scheduling platform that we built and adapted for mentoring and coaching. Ongoing group VPD sessions were conducted bi-weekly for 90 minutes per session and focused on student learning, instructional strategies, building capacity for science teaching, previewing upcoming lessons, viewing modeling videos, and reflection on student learning and teaching practices. Teachers were encouraged to engage in the VPD using voice, chat logs, polls, and webcams. Each session was recorded, and links were sent out to participants so they could have access to go back and review the VPD sessions. The VPD included embedded VMC. Trained coaches provided VMC utilizing the APXIS platform to virtually observe treatment teachers' instruction and offer support and immediate real-time feedback; thus, that process we called VMC-realtime feedback (VMC-RTF). VMC-RTF was augmented with interactions via bug-in-the-ear (earbuds). In addition to the VMC-RTF within the 15 VPD sessions, coaches provided two additional VMC-RTF sessions lasting approximately 30 minutes and conducted follow-up, one-on-one reflective sessions allowing teachers to review their recorded instruction and reflect on implementation of LIS curriculum and instructional strategies.

Instrumentation

The four-dimensional pedagogical theory (Lara-Alecio & Parker, 1994) is the basis of the Pedagogical Observation Protocol (POP) (Lara-Alecio et al., 2009), which was originally the Transitional Bilingual Observation Protocol (TBOP) (Lara-Alecio & Parker, 1994; Lara et al., 2009). TBOP has been applied in a previous literacy-infused science RCT for examining how professional development sessions support science teachers' quality of instruction with diverse learners (e.g., Garza, Huerta, Lara-Alecio et al., 2018; Garza, Huerta, Spies et al., 2018; Tong, Tang et al., 2019). Therefore, POP was adopted in the current study to investigate the impact of instructional support sessions on scaffolding teachers' pedagogical practice.

POP includes four domains: activity structure, language of instruction, language content, and communication mode. A fifth and sixth domain (physical grouping and instructional strategy) were later added when the theory was validated (Bruce et al., 1997). This instrument has been adopted and validated for evaluating teachers' instructional practices (e.g., Garza, Huerta, Lara-Alecio et al., 2018; Garza, Huerta, Spies et al., 2018; Lara-Alecio et al., 2009; Tong et al., 2020; Tong, Irby et al., 2019; Tong, Tang et al., 2019).

The POP domain of activity structure is defined as a combination of (a) teacher instructional practice (e.g., lecturing, directing, evaluating, asking) and (b) student response behavior (e.g., listening, cooperating, discussing, answering). For example, when a teacher asks a question, and students answer the question, the activity structure is thus coded as ask/answer (ask/ans). A few classroom activity structures (e.g., transitions between classes, student behavior feedback) are considered non-academic and are coded non-academic-transition (NA-tran) or non-academic-feedback (NA-feedback). In the domain of language content, four levels are included: social routines (e.g., greetings, social exchanges), (b) classroom routines (e.g., handing in assignments, handing out materials), (c) light cognitive content (e.g., reviewing previously introduced content, repetitive drills), and (d) dense cognitive content (e.g., new content-area information, critical thinking). In the domain of language of instruction, four categories are adopted for describing teachers' or students' use of (a) first language, (b) second language, (c) L2 supported and clarified by L1, or (d) L1 to introduce L2. The categories in the domain of communication mode denote students' use of one or a combination of two receptive models (aural, reading) and two expressive modes (verbal, writing). English as a second language (ESL) strategies are included in POP as one of the minor domains, so that teachers' application of effective instructional strategies, such as academic language scaffolding, cooperative/collaborative learning, or manipulative and realia use, are recorded. Physical grouping, the second minor domain, includes four categories to document whether the instructional interaction between teacher and students occur in (a) whole class instruction, (b) large group instruction, (c) teacher working with pairs of students, or (d) teacher working with an individual student.

Data Collection and Analysis

Classroom observations were collected virtually using APXIS installed in each classroom. Three rounds of virtual classroom observation were conducted at the beginning, middle, and end of the 2017-2018 school year. The recorded lessons were then rated by trained personnel via POP. During the coding process, raters recorded the presence of teacher instructional practices based on the POP rubric that contains four major domains (i.e., activity structure, communication mode, language content, and language of instruction) and two minor domains (physical grouping and instructional strategies; for details see Tong, Irby et al., 2019). In each domain of POP, raters coded over multiple 20-second intervals of recorded lessons. We established the initial inter-rater reliability (IRR) and monitored IRR at the beginning of each round. IRR at the domain and cross-domain levels was established and continuously monitored to ensure the fidelity of the rating procedure with AC1> 0.6 across three rounds of observation (Gwet, 2008). Gwet's AC1, a rigorous indicator of inter-rater reliability, is suitable for multi-domain-response rater instruments such as POP (Tong, Tang et al., 2019). The magnitude of such IRR corresponds to a substantial level of IRR per Landis and Koch (1977). Given that the POP yields non-parametric frequency data, a chi-square test was employed to identify if the proportion of each category under every domain was homogenous between treatment and control conditions.

Results

Preliminary analyses were performed based on the ratings of the three rounds of observations collected at the beginning, middle, and end of the school year after 15 VPD sessions. The average length of classroom observation was 70 minutes for treatment teachers and 55 minutes for control teachers, respectively. Observations in both conditions were coded over four 5-minute intervals evenly distributed during their observation time, with 20-second coded video clips. In this study, a total of 13,620 twenty-second video clips were recorded and observed. Statistically significant differences were identified regarding teachers' time allocation in the following domains between treatment and control teachers: instructional strategies ($\chi^2(9) = 205.016$, $p < 0.001$, Cramer's V = .123), physical grouping ($\chi^2(4) = 258.628$, $p < 0.001$, Cramer's V = .138), activities structure ($\chi^2(20) = 273.611$, $p < 0.001$, Cramer's V = .142), communication mode ($\chi^2(17) = 241.546$, $p < 0.001$, Cramer's V = .133), language of instruction for teacher ($\chi^2(3) = 35.64$, $p < 0.001$, Cramer's V = .051), and language of instruction for students ($\chi^2(3) = 25.496$, $p < 0.001$, Cramer's V = .043). No significant difference was identified in the domain of language content between the treatment and control teachers.

Pedagogical Practices

In the POP domain of instructional strategies, the visual scaffolding strategy was observed to be the most frequently used technique (21.9% in control, 27.1% in treatment, $p < 0.05$). It was observed that control teachers employed manipulatives and realia strategies more often than treatment teachers (13.2% in control, 8.4% in treatment, $p < 0.05$), while treatment teachers employed cooperative/collaborative strategies (14.1% in treatment, 11.3% in control, $p < 0.05$) and asked students leveled questions (5.8% in treatment, 3.5% in control, $p < 0.05$) more often than the control teachers.

In the POP domain of physical grouping, teachers tended to deliver instruction to the whole class in both conditions (69.2% in control, 68.0% in treatment). It was also observed that treatment teachers provided more opportunities for student pairs to collaborate (7.0% in treatment, 1.7% in control, $p < .05$). In the domain of activity structure, it was observed that lecture/listen (17.1% in control, 16.8% in treatment) was the most frequently observed instructional practice in both treatment and control conditions. It was also observed that control teachers monitored students' performance on academic tasks more often than the treatment teachers (12.6% in control, 8.9% in treatment, $p < 0.05$), while treatment teachers evaluated student understanding by providing the opportunity for students to respond to leveled questions (19.1% in treatment, 15.8% in control, $p < 0.05$) more often than the control teachers.

In the POP domain of communication mode, the following student communication behaviors were the most frequently observed in both conditions: aural (32.3% in control, 32.6% in treatment), and in combinations of verbal and aural communication (41.5% in control, 42.6% in treatment). No significant difference was identified in these communication modes. In the domain of language content, teachers in both conditions were observed to spend the majority of their instructional time delivering dense content (76.7% in control, 77.2% in treatment). In the domains of language of instruction for teacher and students, second language (i.e., English) was observed to be the most frequently used by teachers in both conditions (86.3% in control, 89.0% in treatment). Thus, as a mirror of teachers' behavior, students most commonly utilized English (47.0% in control, 50.7% in treatment).

Limitations

This study has a few limitations that researchers should bear in mind. First, the research we presented solely focused on the science teachers' instructional practices in classrooms that included EBs and ECs; therefore, we did not report student level data and outcomes in this study. This could be one avenue for possible study in the future — research that links observable pedagogical behaviors to specific student outcomes, especially in science. Second, this study centered on one aspect of teachers' observed pedagogical behaviors. Because this study was focused on classroom observation measuring pedagogical practices in the content area of science, we did not explicitly measure changes in teacher content knowledge and/or attitudes/perspectives about teaching science. This would also merit further study. Other possibilities for future research include increasing the amount of time that teachers receive VMC and VMC-RTF. While teachers received fifteen 90-minute VPD sessions with embedded VMC, they only had two 30-minute VMC-RTF sessions during the intervention due to delays resulting from Hurricane Harvey which occurred in August 2017, the first year of implementation. VPD and VMC-RTF activities were originally planned to start in September that year, but did not occur until October, as 17 of the treatment teachers (29.8%) in six school districts were adversely affected by the hurricane. It is possible that more frequent VMC-RTF would result in further pedagogical change. In a future study, researchers might utilize mixed methods to interview and survey teachers on their perspectives of the VPD and VMC.

Discussion and Conclusions

The current study was focused on a comprehensive examination of science teachers' pedagogical practices after they have received intensive virtual training and support to enhance their instruction. Specifically, the purpose of this study was to evaluate the pedagogical practices of fifth-grade treatment teachers who were provided the support of VPD and VMC, and control teachers who only received in the typical district professional development opportunities and no VMC. We have highlighted the variation in teachers' time allocation in instructional strategies, content, instructional language, communication mode, and activity structure. We identified pedagogical differences in time allocation between teachers in treatment and control conditions. We proffer that such differences are due to the effective, ongoing, and structured VPD and VMC provided. Our findings are in line with previous studies conducted by Garza, Huerta, Lara-Alecio et al. (2018) and Garza, Huerta, Spies et al. (2018), as well as Tong, Irby et al. (2019) that ongoing structured PD improves teachers' instructional capacity in a challenging content area, science, and such improvement can be accurately documented via a comprehensive observation instrument, like POP. The positive findings in observed activity structures within treatment classrooms implies that with support there can be better implementation of effective instructional practices, such as providing students with leveled questions and using cooperative/collaborative instructional strategies. We found that the POP is a flexible and comprehensive classroom observation protocol instrument that can be effectively used in the science classroom that is inclusive of EBs and ECs. It (a) provides an objective, reliable, and valid picture of science teachers' instructional patterns and their interaction with students and (b) allows researchers to evaluate how intervention factors influence teachers' quality of pedagogy.

More specifically, we found that both VPD and VMC resulted in the treatment group of science teachers engaging students in reasoning, comparing, and predicting — all of which are higher-order thinking skills. This finding was supported by the results in the domain of instructional strategies, as we found that treatment teachers applied more questioning strategies. In the domain of activity structure, we reported that treatment teachers more often asked students questions, compared to control teachers. Treatment teachers were also grouping and pairing students for collaborative work and sharing ideas with peers. Moreover, treatment teachers provided students with visual scaffolding to support their science content learning. Similar patterns of pedagogical improvement were also evident in Lara-Alecio et al. (2009).

These results indicated that the treatment teachers, through their exposure to the intervention VPD and VMC, were learning and adopting new pedagogical behaviors (or modifying existing ones) that are in line with best practice. The combination of the group VPD created a community of professional learners and the individual VMC allowed teachers to practice new skills in a safe, comfortable space, similar to Simonsen et al. (2009). The VPD+VMC blend of instructional support targeted a range of professional learning needs for the science teachers. It is important to note that the VPD and VMC were aligned with the three significant design principles for online and blended teacher PD identified by CADRE (2017). These design principles included: (a) supporting teacher engagement to increase knowledge and advance professional goals; (b) incorporating opportunities for collaborative learning; and (c) encouraging teacher reflection on content and practice. Therefore, we conclude that high-quality, ongoing VPD and VMC inclusive of VMC-RTF can support and enhance teacher implementation of classroom science intervention — thus providing EB and EC students with elevated science learning opportunities.

We observed how science teachers allocated instructional time in the critical components of language content, communication mode, language of instruction, activity structure, physical grouping, and instructional strategies. Observing how teachers use their instructional time can provide valuable insights into teaching effectiveness. Additionally, we conclude that such teaching effectiveness, which cannot be guaranteed by simply more instructional time but specifically by the quality of instruction within the available instructional time as also noted by Tong, Irby et al. (2019). The differences between treatment and control teachers in the critical components of language content, communication mode, language of instruction, activity structure, physical grouping, and instructional strategies, as observed in the current study confirmed that classroom observation is a comprehensive and reliable approach to examine teacher instructional quality.

This study is particularly impactful in rural schools, since the majority of the participating teachers taught in rural school districts. We want to emphasize that because these instructional supports were provided online, these important resources have the potential to be available to science teachers everywhere, regardless of their location. This consideration is especially important for rural or isolated school districts, where it can be challenging to recruit science teachers or to provide current in-service science educators with sufficient content-specific PD (Cady et al., 2011). Therefore, we conclude that rural districts can take advantage of VPD opportunities for their teachers.

Important to note, there had been no large-scale RCT studies as we could determine that were focused on curriculum-based training for science teachers with EBs and ECs in their classes and with a year-long intervention that incorporated ongoing instructional support sessions, including VPD, VMC, and/or VMC-RTF. To address this issue, we implemented a rigorous RCT design in which we supported science teachers via 15 bi-weekly instructional support sessions throughout the school year to implement literacy-infused science curriculum. We conclude that continuous quality instructional support via VPD and VMC, including VMC-RTF is worthwhile for improved science instruction in rural classrooms inclusive of EBs and ECs.

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