The role of teacher capacity and instructional practice in the integration of educational technology for emergent bilingual students

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ABSTRACT

This mixed methods study examines the extent to which the use, and intensity of use, of educational technology is associated with improved academic outcomes for English language learners (ELLs) in both English/Spanish bilingual and traditional English-only classrooms. We also explore the role of teacher capacity and practice in integrating educational technology by student population and instructional setting across six schools serving a student population of predominately low-income ELLs. Building on limited prior work on technology integration with elementary school ELLs, the analysis draws on district administrative data, teacher surveys, classroom observations, and teacher interviews. In econometric analyses of academic outcomes associated with exposure to varying intensities of technology use, we identified positive associations of technology use in reading, starting at around 40 min of weekly use in bilingual classrooms versus 1 h of weekly use in traditional classrooms. While the average reading effect size topped out at 0.20 for students with 2 h of weekly technology use in reading in traditional classrooms, the reading effect size continued to rise in bilingual classrooms to over 0.50 for students in classrooms using technology for 3 h a week in reading. We also found that technology use in reading—where teachers were observed more frequently using blended instructional strategies—was more effective for students in bilingual classes than technology use in math. Our findings suggest that alignment of technology with constructivist teaching strategies, which connect student learning to culturally relevant experiences and provide opportunities for interactivity and collaboration, is key to transforming the learning process and outcomes of emergent bilingual students.

1. Introduction

Twenty-two percent of all elementary school students in the United States speak a language other than English (Davis & Bauman, 2013), with 13 percent of kindergarten through sixth-grade students across the country identified as English Language Learners (ELL) (U.S. Department of Education, 2016). Of those students identified as ELL, 77 percent speak Spanish, although the proportion of Spanish-speaking students classified as ELL is much larger in some states such as California, Texas, and New Mexico (U.S. Department of Education, 2016). National trends indicate rapid increases in the percentage of bilingual and Spanish-speaking individuals living in the United States since the 1980s (Ryan, 2013). At the same time, the achievement gap between ELL and non-ELL students in fourth-

grade reading is larger than the achievement gap between students qualifying for free/reduced lunch and students who do not qualify, with similarly sized gaps in math scores (U.S. Department of Education, 2015a).

With sufficient teacher capacity and appropriate instructional practice, educational technology can play a role in mitigating these gaps in achievement and the underlying learning experiences that contribute to them. At the same time, *how* technology is integrated into classroom instruction matters. Social constructivism asserts that empowered language learning occurs when students actively construct their own meaning, often through shared social experiences and interactions (Cummins, 1986; Kaufman, 2004; Vygotsky, 1978). Theory and research evidence suggest that to support emergent bilingual students in their language learning, educators should strive to integrate collaborative participation, reciprocal and interaction-oriented pedagogy, and authentic learning experiences within an additive cultural and linguistic framework (Au, 1998; Cummins, 1986). The use of instructional technology with emergent bilingual students[2] holds the potential to augment these best pedagogical practices for language learning, and in turn, enhance student engagement, encourage independent learning, and build language confidence among students (Lacina, 2008; Maduabuchi & Emechebe, 2016; Yunus, Nordin, Salehi, Embi, & Salahi, 2013).

At the most basic level, constant, easy access to a dictionary when reading fosters vocabulary development (Maduabuchi & Emechebe, 2016; Yunus, Nordin, Salehi, Embi, & Salehi, 2013). Teachers can also use technology to improve student learning by facilitating interactivity, collaboration, and group work (Chen, 2016; Foulger & Jimenez-Silva, 2007; Lacina, 2004). These types of interactivity can facilitate opportunities to learn not just grammar and vocabulary, but also cultural norms (Chen, 2016) and the application of knowledge in a meaningful manner (Lacina, 2004). Further, by opening new channels of communication, technology use can reduce English learning anxiety, providing students an opportunity to experiment with language use and build confidence (Foulger & Jimenez-Silva, 2007; Hwang, Hsu, Lai, & Hsueh, 2017; Lacina, 2004). Lacina (2004), for instance, reported that allowing students to communicate online anonymously decreased student anxiety about being judged and allowed students to review what they typed before posting.

Strategies that are effective for integrating technology to support the learning of emergent bilingual students are distinct from those employed for other student populations. Teachers in bilingual classrooms and instructing students with limited English proficiency require knowledge of and access to technological resources that cater to the needs of these particular student population (Almerich, Orellana, Suárez-Rodríguez, & Díaz-García, 2016; Lacina, 2004). Thus, consistent with Snodgrass, Israel, & Reese's (2016) call for additional research to expand understanding on the implications and demands of technology integration across student populations, this study identifies effective technology integration practices and predictors of student academic success in schools serving emergent bilingual students.

1.1. Study aims

In this study, we explore how teacher capacity and practice requirements for technology integration vary based on student ELL status. We examine how intensity of technology use across varying instructional practices in English/Spanish bilingual and traditional English-only classrooms is associated with the extent to which instructional technology supports learning among low-income, emergent bilingual students. Drawing on a sample of predominately Hispanic, Spanish-speaking bilingual students, our study also speaks to the larger body of literature on resource and schooling inequalities in the United States. Researchers have a responsibility to ensure that school leaders and policymakers have access to information that not only reflects the current technological environment in schools but also the changing populations of students toward whom the integration and use of technology are being directed. For educational technology to serve as a mechanism for the reduction of racial and socioeconomic gaps in student achievement, it is critical that educators and schools have knowledge specific to technology use with our nation's most vulnerable populations (Author, 2016; Zheng, Warschauer, Lin, & Chang, 2016).

Toward these aims, we address the following research questions in a mixed methods research study:

(1) To what extent is the use, and intensity of use, of educational technology associated with improved academic outcomes for ELL students in both English/Spanish bilingual and traditional English-only classrooms?
(2) How do the roles of teacher capacity and practice in integrating educational technology vary by student population and instructional setting?

Our results can inform the design, implementation, and evaluation of school-based technology initiatives geared toward emergent bilingual student populations. We begin below by summarizing what researchers know about the role of teacher capacity and instructional practice in the implementation of education technology initiatives, citing studies specific to ELLs when possible. We then identify gaps in knowledge on and applicability to emergent bilingual students that we address through our study.

1.2. Literature review

At the most basic level, teachers require training and support on the logistics of integrating technology, including the capacity to

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[2] Emergent bilingual student refers to students learning a second language, in this context English, while maintaining native language fluency (Garcia, 2009). Because their secondary language is not replacing their native language, these students will become bilingual upon gaining fluency in English.

address daily technology issues, minimize off-task time, and support students' technology use (Almerich et al., 2016; Holland, 2001). Training and support to implement new organizational strategies are often also necessary to mitigate improper device use and digital distractions (Author, 2016; Halvorsen, 2017). Without training and support to address common technical issues and develop a positive classroom environment, access to technology may detract from rather than enhance student learning. Accordingly, basic technical competencies and strategies for managing technology integration are important for all teachers, but especially for teachers of bilingual classrooms who may need to make additional accommodations for students (Maduabuchi & Emechebe, 2016; Yunus et al., 2013).

Once teachers feel comfortable with the logistics of integrating technology, they often need assistance reimagining instructional strategies and teaching philosophies to take full advantage of available digital tools (Barrios et al., 2004; Bebell & O'Dwyer, 2010). Teachers face many instructional and pedagogical choices when integrating technology, such as whether to encourage student or teacher-directed technology use and to what extent (and how) technology should be leveraged to reframe student-teacher and peer communication and relations (Halvorsen, 2017). Teachers with constructivist philosophies and student-centered beliefs are more likely to integrate technology that helps students take ownership of their learning and supports group work (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Hermans, Tondeur, van Braak, & Valcke, 2008). The ability of digital tools to facilitate these types of student-centered, collaborative, active, and critical thinking-based learning is consistent with best practices in teaching ELLs (Bunch, 2013; DiCerbo, Anstrom, Baker, & Rivera, 2014). Programs and tools that facilitate deep learning, place language and literacy within its larger cultural context, and provide opportunities for interactivity can accelerate language acquisition, while technology used for drill and practice or to supplement teacher-driven content delivery is less likely to improve student learning (Bunch, 2013; DiCerbo et al., 2014). Thus, capacity building efforts should address not only issues of technical but also pedagogical competences and alignment (Almerich et al., 2016; Røkens & Krumsvik, 2016).

Research demonstrates that linking technology enactment to content-specific instructional practices increases technology use and effectiveness (Boschman, McKenney, Pieters, & Voogt, 2016; Janssen & Lazonder, 2016). Providing teachers exposure to digital programs and tools aligned with best practices for teaching emergent bilingual students may be particularly important due to the large variability in the utility of available resources for this student population. For instance, access to programs that provide students reading material at their individually-assessed reading level, while useful for any student population, is particularly valuable when teaching emergent bilingual students (Maduabuchi & Emechebe, 2016). Teachers working in schools with a high proportion of ELLs must teach to a wide range of skill levels. Any tool that helps teachers make adaptations for emergent English language acquisition is thus particularly useful (DiCerbo et al., 2014). On the other hand, technology-based programs that assume grade-level reading proficiency, for instance, may not be practical in all settings, discouraging use and effectiveness if these are the only accessible resources.

There is a distinctive opportunity for technology to reframe math versus language instruction, particularly for emergent English speakers. Math instruction, more so than language instruction, is often delivered by a teacher at the front of a classroom; while not ideal for many students, this delivery method poses greater challenge for students less familiar with not only mathematical jargon but English in general (Purpura, Napoli, Wehrspann, & Gold, 2017; Thompson, 2017). Instead, best practices dictate language integration across subjects and core content (Bunch, 2013; DiCerbo et al., 2014). Technical programs and tools that facilitate adaptability to student language needs and encourage active learning, such as group-based problem-solving or student-driven content creation, in place of passive learning thus can improve not only English language acquisition but also overall academic performance (Bunch, 2013; DiCerbo et al., 2014; Purpura et al., 2017).

The research summarized above identifies instructional strategies that enhance the learning of emergent bilingual students (i.e., Bunch, 2013; DiCerbo et al., 2014). Fewer studies examine how elementary teachers of ELLs can integrate digital tools in alignment with these strategies (only Foulger & Jimenez-Silva, 2007; Lacina, 2004, 2008). We update and expand the findings of the existing qualitative studies by explicitly linking instructional technology use with standards for teaching ELLs using rigorous quantitative, as well as qualitative, methods. While some recent quantitative research focused on the effect of a particular digital program (i.e., Chen, 2016; Hwang et al., 2017), we focus on the role of teacher capacity and instructional practices in mediating digital tool effectiveness more generally. We further expand current literature by examining the role of technology integration in math and reading instruction, in line with evidence that language fluency influences learning across content areas (Purpura et al., 2017; Thompson, 2017). In the following section, we describe the details of the intervention we studied and our research methods and materials.

2. Research methods and materials

We employ a sequential, mixed methods research design (Creswell & Clark, 2011), using data collected from district administrative records, teacher surveys, classroom observations, and teacher interviews to investigate the above research questions about the integration and effects of educational technology for emergent bilingual students.

2.1. Study intervention and setting

We examine instructor capacity and related factors influencing technology use in a 1:1 tablet technology pilot program in Dallas Independent School District (DISD). DISD introduced tablets (Kindles/eReaders) in low-resource schools in 2014 with financial and personnel support from the Jiv Daya Foundation. The tablet integration evaluated in this study occurred during the 2015-16 school year. Schools retained access to the tablets but not the same comprehensive support and professional development provided by Jiv Daya in subsequent school years.

Table 1
DISD school-level demographic and achievement information: 2015-16 school year.

	All DISD Schools (%)	Title 1 Schools (%)	Tablet Schools (%)
Percent Native American	0.28 (0.65)	0.27 (0.63)	0.41 (0.81)
Percent Asian	1.16 (4.14)	1.03 (4.11)	0.58 (1.03)
Percent Hispanic	67.63 (27.10)	69.54 (26.18)	88.00 (8.79)
Percent Black	25.22 (26.20)	25.44 (26.29)	7.76 (5.03)
Percent White	5.12 (11.14)	3.25 (5.66)	2.57 (4.19)
Percent Male	52.11 (8.02)	52.03 (7.39)	52.10 (3.31)
Percent English Language Learners	47.91 (21.73)	49.89 (20.56)	63.50 (8.40)
Percent Receiving Special Education Services	8.55 (9.11)	8.44 (8.41)	8.72 (2.77)
Percent Low-Income	90.21 (14.87)	93.37 (6.19)	93.72 (6.51)
Prior Year Math Proficiency	48.54 (28.76)	47.94 (27.82)	51.81 (26.12)
Prior Year Reading Proficiency	46.23 (28.49)	45.77 (27.52)	51.73 (25.12)
N	438	412	21

Standard errors in parentheses.

This initiative, known as the Student eReader Program (StEP) program, aims to provide access to educational technology for under-resourced classrooms, while at the same time supporting instructional staff in integrating the devices into teaching and developing innovative curriculum. Tablets were distributed to classrooms in the 3rd-5th grades in the first "personalized learning" partnership school, and the partnership subsequently expanded to three additional elementary schools in that same academic year. In the following school year (2015–16), three other elementary schools joined the StEP initiative.

In addition to subsidizing 80 percent of the cost of the tablets, the Jiv Daya Foundation provides considerable support for integration, including comprehensive training in technology integration, digital applications, and training for teachers in instructional best practices. A StEP team from the foundation organized training sessions for teachers before the start of the school year and provided support in schools for managing the use of devices, troubleshooting technical problems, and guiding the integration of the tablets into classroom instruction throughout the school year. The initial professional development session began with a discussion of instructional purpose setting, a process of making sure there is alignment between instructional goals and technology integration. The professional development provided teachers information on available, recommended tablet applications, as well as how to access and troubleshoot common programs and device functions. Jiv Daya incorporated opportunities to share information, answer questions, discuss strategies, and show video demonstrations of different uses of technology in the classroom within the structure of the professional development session.

The Jiv Daya Foundation also developed resource guides and tailored instructional supports available via the foundation's website (http://www.jivdayafound.org/teac/). These materials include detailed guides on the basics of tablet use for instruction, troubleshooting technical problems (e.g., internet access, locked screens, registration problems), and managing communications via devices. Jiv Daya also provided access to specific content and documents, such as classroom teaching tools and subject-specific instructional resources and applications.

2.2. Study sample

Table 1 presents the school-level demographic characteristics of 3rd-5th-grade students in the seven elementary schools that participated in the tablet initiative in the spring of 2016, six of which agreed to participate in the observational component of our study. The table also compares the school-level averages of treatment schools to all other schools serving 3rd-5th grade students in DISD, as well as to only those 3rd-5th grade students in low-income (Title I) schools. Jiv Daya identified the schools for tablet integration based on the following criteria. All schools must qualify as Title 1, belong to a single school feeder pattern, and serve a high proportion of ELLs. Most DISD schools are Title I-qualifying,[3] including all schools that received tablets. The primary difference between the "treatment" (StEP) schools and those that did not participate was the racial composition of the schools. StEP schools served a significantly higher proportion of students who were Hispanic (88 vs. 68–70 percent) and fewer African-American students. Correspondingly, StEP schools served a significantly larger percentage of students identified as limited English proficiency (64 vs. 48–50 percent). The small baseline (2015) differences in the standardized test pass rates in math and reading among students in StEP and non-participating schools were not statistically significant.

In our analysis, we follow the school district labeling of classrooms in distinguishing between students assigned to classrooms where we observed English/Spanish bilingual instruction and students assigned to classrooms where we only observed English spoken. Across all schools, 455 students (56 percent) received instruction within an English/Spanish bilingual classroom, compared to 364 students (44 percent) who received instruction within a traditional English-only classroom. Students who received instruction within bilingual classrooms identified as Hispanic and as ELLs in the same proportion as students assigned to traditional classrooms.

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[3] Title 1 is a federal program that provides additional financial resources for the education of low-income students in the United States. Schools qualify for Title 1 when at least 40 percent of their students qualify for free or reduced lunch (i.e., students with family incomes within 185 percent of the federal income poverty guidelines) (U.S. Department of Education, 2015b).

Similarly, the district identified both types of classrooms as containing a comparable number of students who were low-income and receiving special education services. However, students in bilingual classrooms scored slightly higher, on average, on the prior year reading standardized test and approximately 0.10 standard deviations higher on the prior year math standardized test.

2.3. Data collection

Classroom observations of tablet use began in February 2016 in six of the partnering elementary schools.[4] The research-based observation instrument asked observers to evaluate the extent to which the instructional session (and integration of educational technology) facilitated quality learning opportunities for students.[5] The observation instrument contained a set of indicators of quality elements that captured interactions occurring between teachers, students, and educational technology (when in use). We recorded ratings of ten core elements of digital and blended instruction (described in Appendix A) on a 0–4 (5-point) scale. Observers also recorded narrative comments and vignettes, total instructional time, whether the format facilitated live interaction between instructors and students around instructional tasks, and the functionality of the technology.

We facilitated training and established interrater consistency for all raters conducting classroom observations. When feasible, observers also conducted interviews with teachers that were recorded, transcribed and then analyzed using thematic coding by more than one rater to ensure consistency (Braun & Clarke, 2006). The data collected in classroom observations were digitized and linked to the survey and administrative data for empirical analysis, although it is important to point out that our classroom observations may not be fully representative of technology use and classroom activities across the entire school year. That said, with between 50 and 300 students observed per school, we feel confident that our measures of central tendency and variance reflect general trends within and across schools.

The Jiv Daya Foundation also administered teacher surveys to classrooms with tablets[6] that collected information on how (and how often) teachers used tablets for instruction, the types of applications accessed, and the challenges and opportunities they presented for student learning. Surveys included both multiple choice and open-ended questions. Of the 1272 students with teacher survey data, 1053 were in observed classrooms.

We removed an additional 234 students missing one or more independent variables, leaving a final sample size of 819 students. Of students in observed classrooms, 145 of the students excluded from the analytic sample (the large majority) were removed because they did not have prior year test score data.[7] Our investigation of missing data patterns showed that students with missing data had significantly lower average prior year standardized math and reading achievement, and significantly fewer students of these students were identified as low-income. Although this is a limitation of our sample that we cannot overcome, there was no statistically significant difference in teacher-reported intensity of classroom technology use for students excluded from the analysis due to missing data.

2.4. Measures

We examined the association between student outcomes (standardized math and reading test scores), the intensity of technology use in our pilot schools, and teacher expertise or capacity, controlling for student and classroom characteristics, such as prior year academic achievement and bilingual instruction, and the classroom environment. Fig. 1 presents a conceptual depiction of the empirical model we estimate.

2.4.1. Test scores
The students in our sample took the State of Texas Assessments of Academic Readiness (STAAR) in May of 2016. We also controlled for prior year (spring 2015) STAAR standardized test scores to account for baseline academic performance.

2.4.2. Intensity of technology use
Our measure of the intensity of technology use is based on teacher survey questions that asked teachers to report the number of days per week and amount of time per class period they typically used the tablets. We combined responses to these questions to create a continuous measure of classroom technology based on the number of minutes a week each teacher reported using technology in reading and math. The mean intensity of technology use was 66.67 (SD = 58.77) minutes a week in reading and 87.29 (SD = 58.47) minutes a week in math. Twenty-four percent of teachers reported no technology use in reading compared to nine percent who reported no technology use in math.

2.4.3. Classroom environment
A key classroom characteristic of interest in our analysis is whether the classroom provided English/Spanish bilingual (vs. traditional English-only) instruction. We also control for teacher capacity measures that influenced whether students had full access to

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[4] One school declined to participate in this component of the study.

[5] One of the authors used the same instrument in a 2016 study.

[6] Copies of the instruments are available from the authors upon request.

[7] We performed sensitivity tests to assess the robustness of our model specifications and analysis to our restricted samples and determined that our results were stable across the samples; the details and findings of these analyses are available upon request from the authors.
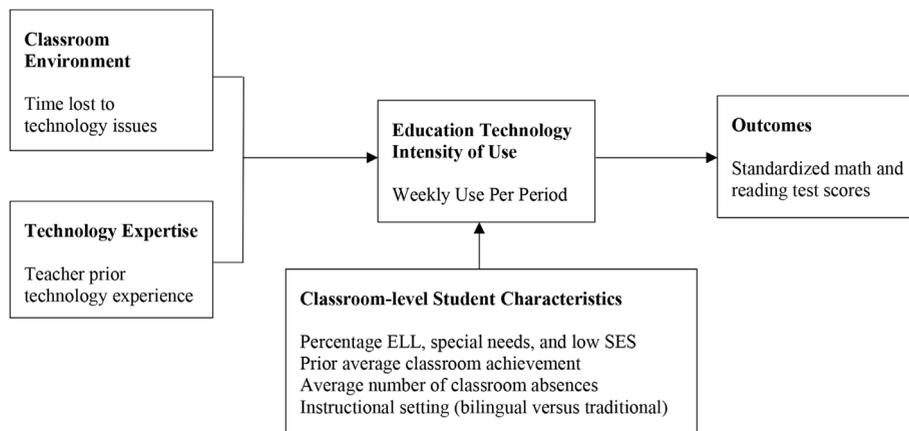
Fig. 1. Conceptual depiction of the empirical model.

classroom technology. We operationalized the classroom technology environment as the percent of instructional time lost due to technology issues using information collected on the amount of time spent addressing technology issues in each observation, which ranged from zero to 92 percent of the observed time (mean = 0.08, SD = 0.18). Time spent resolving technology matters limits the time available for instruction and student learning and allows us to distinguish between the importance of teacher capacity to address technical issues versus technology integration into instruction.

2.4.4. Technology expertise

We examined technology expertise through teachers' self-reported prior experience with technology. Teachers selected the response that best described their experience at the beginning of the school year on a 0–4 (5-point) scale, where zero represented no prior experience, 1 "Minimal," 2 "Some," 3 "Extensive," and 4 "Expert." The modal teacher response was "some" prior experience (reported by 40 percent of teachers), followed in frequency by "minimal" prior experience (28 percent), no prior experience (15 percent), "extensive" prior experience (11 percent), and "expert"-level prior experience (5 percent). Based on an analysis of variance and low sample size in the Expert group, we collapsed teacher technology experience into two categories: None/Minimal and Some/Extensive/Expert.

2.4.5. Student characteristics

Lastly, we controlled for student characteristics using DISD administrative data, including: the percentage of low-income students, the percentage of ELL students, the percentage of students receiving special education services, the average number of classroom absences, and prior year student achievement (by school and grade).

2.5. Research design and methodology

Our mixed methods study incorporates a sequential design (Creswell & Clark, 2011), allowing qualitative findings to inform subsequent analyses. More specifically, data collection followed an iterative process, whereby initial qualitative data collection and analysis informed research question development and ensuing quantitative analyses. After conducting the quantitative analysis, we re-analyzed the qualitative data to clarify classroom practices and assist in the interpretation of quantitative findings. The teachers interviewed, and the students observed in the classroom, were also included in administrative data and the data from survey respondents.

2.5.1. Model specifications and methods of analysis

We employ an econometric modeling framework for estimating the effects of different levels of exposure to treatment when selection into treatment is non-random and the treatment measure is continuous (Cerulli, 2012). We simultaneously estimate two functions, one for the untreated (whose intensity of technology use is zero, $w = 0$) and one for the treated, whose exposure to tablet use is continuous (conceptualized as minutes per week teachers reported using tablets in each reading and math), allowing for the possibility of heterogeneous treatment responses:

$$w = 1 \rightarrow \quad y_1 = \alpha_1 + g_1(x) + h(t) + e_1$$

$$w = 0 \rightarrow \quad y_0 = \alpha_0 + g_0(x) + e_1$$

In the above submodels, α is the intercept, $g(x)$ a function of all independent variables; $h(t)$ is the response function to the level of treatment for those using tablets, and e the error term (Cerulli, 2012). In our specification, $g(x)$ includes measures of the percent of time lost to technology issues and whether teachers had some or more past technology experience. Controls for student characteristics include the percentage of students identified as low SES, percent ELL, percent receiving special education services, prior year

academic achievement, and the number of absences.

Cerulli (2012) presents a proof showing that under the conditional mean assumption, a model for identifying responses to various levels of treatment exposure can be estimated via regression as follows:

$$E(y|\boldsymbol{x}, w, t) = \mu_0 + \mathbf{x}\boldsymbol{\delta}_0 + wATE + w[\mathbf{x} - \overline{\mathbf{x}}]\boldsymbol{\delta} + w[h(t) - \overline{h}]$$

where $wATE + w[\mathbf{x} - \overline{\mathbf{x}}]\boldsymbol{\delta}$ is the average treatment effect conditional on x, and the exposure term, $[h(t) - \overline{h}]$, may be specified as linear, partial linear or a polynomial. In the specification presented above, we hypothesize (and specify) a nonlinear response to intensity of tablet use. However, because we do not claim to satisfy the conditional mean assumption, as there might be unobserved (and potentially endogenous) variables that explain both intensity of treatment and student outcomes, we do not interpret our estimated effects as causal (but rather, as associations). All models employ robust standard errors to account for clustering of data at the school and grade-level.

2.5.2. Qualitative analysis

Lastly, we supplemented these statistical analyses with analyses of qualitative data from observation vignettes, open-ended survey responses, and teacher interviews to provide context and triangulate findings. Survey and interview responses were coded thematically, and a second rater double coded all responses to ensure inter-rater reliability. The research team collaboratively refined the inductive codes and developed the focused codes upon which we base our qualitative findings.

3. Results

3.1. Student achievement

Employing the econometric model specified above (conceptually depicted in Fig. 1), we found higher math and reading scores in classrooms using tablets after controlling for prior year performance and instructor capacity, as shown in Figs. 2 and 3. The average treatment effect size of 0.07 standard deviations in reading and 0.29 standard deviations in math corresponded with an 11 percent reduction in the reading achievement gap by English proficiency status and a 66 percent reduction in the math achievement gap based on fourth-grade NAEP scores (U.S. Department of Education, 2015a). Although increased intensity of tablet use was generally associated with improved student outcomes, the average effect (in response to a given level of intensity) differed for students in English/Spanish bilingual versus traditional English-only classrooms. We saw positive effects of technology use in reading starting at around 40 min of weekly use in bilingual classrooms and 1 h of weekly use in traditional classrooms. In traditional classrooms, the average reading effect size topped out at 0.20 standard deviations for students with approximately 2 h of weekly technology use in reading. In bilingual classrooms, the reading effect size continued increasing with intensity to an effect size of over 0.50 standard deviations for students in classrooms that used technology for 3 h a week in reading.

Although we observed larger average treatment effects in math than reading overall, the rate of gains in math reaped by students in traditional English-only classrooms outpaced those of students in English/Spanish bilingual classrooms, who scored substantially lower on the end of year math exam across the range of treatment (technology) exposure in math instruction. There was, however, a more pronounced drop-off in average math effect starting at around 2 h of weekly use in math for students in traditional classrooms, whereas we observed a relatively small drop-off among students in bilingual classes starting at 2 h of weekly use in math.

Negative treatment effects in math among students in English/Spanish bilingual classrooms diverged from the generally positive treatment effects observed in bilingual classrooms in reading. A large part of this difference may be attributable to variations in the tools and features available in the math and reading applications offered to teachers. Few math applications provided language translation options, while reading/language arts applications included online book libraries, interactive games, and formative comprehension assessments available at various levels in both English and Spanish. Many reading/language arts applications also integrated auditory as well as visual language tools.

We also detected differential effects by the percentage of ELL students and classroom type. For reading outcomes, we observed a lower average effect of technology use in traditional English-only (vs. English/Spanish bilingual) classrooms with a larger percent of students identified as ELLs; all classrooms, except those with the lowest percent of students identified as ELL, exhibited negative effects (see Fig. 4). In contrast, in bilingual classrooms, we observed the opposite trend, with more positive effect estimates of technology use in classrooms with a larger percentage of emergent bilingual students. This finding points to the greater potential utility of technology integration strategies in bilingual classrooms for students identified as ELL, particularly when using applications with special tools and features designed to facilitate language acquisition. Prior research corroborates that the adaptability facilitated by technology use in reading may be particularly helpful in classrooms with more students learning in more than one language (DiCerbo et al., 2014; Maduabuchi & Emechebe, 2016; Yunus et al., 2013). In these contexts, something as small as easy access to definitions, all the way to personalized reading prompts, expands student access to quality learning experiences. Bilingual instructional techniques in reading may also lend themselves to technology integration strategies that are more effective with emergent bilingual students. For instance, teachers may differ in exposure to or experience with the constructivist teaching philosophies associated with larger, positive outcomes from technology integration (Ertmer et al., 2012; Hermans et al., 2008).

While we observed larger reading treatment effects in English/Spanish bilingual classrooms with more students identified as ELLs, the opposite trend materialized in math, with larger treatment effects in traditional English-only classroom settings. In both bilingual and traditional classrooms, the average math treatment effect increased as the percentage of students identified as ELL in the class rose, indicating that the use of technology in math may reduce language barriers in classrooms in classrooms where ELL students are
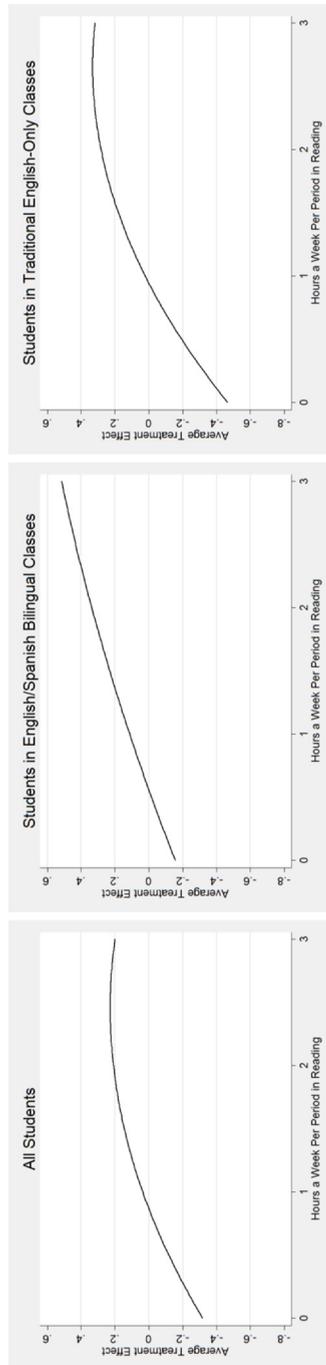
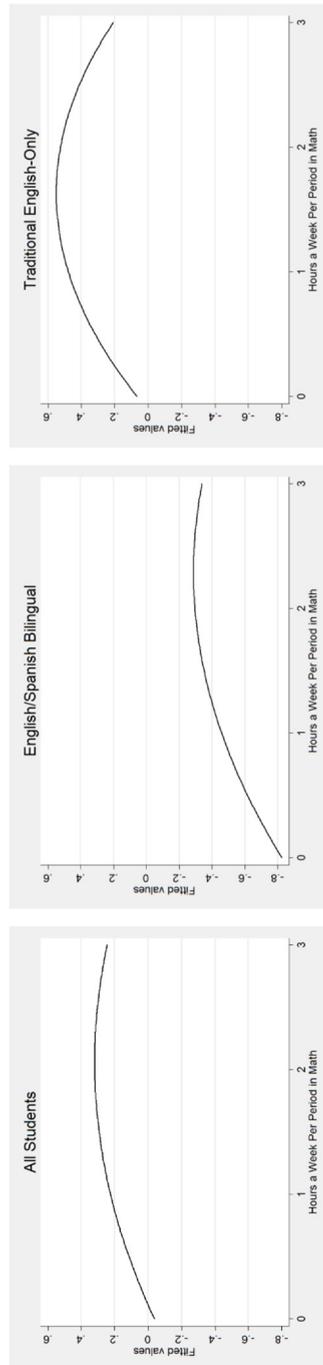**Fig. 2.** Reading average treatment effect by intensity of technology use (hours a week per period).

Fig. 3. Math average treatment effect by intensity of technology use (hours a week per period).
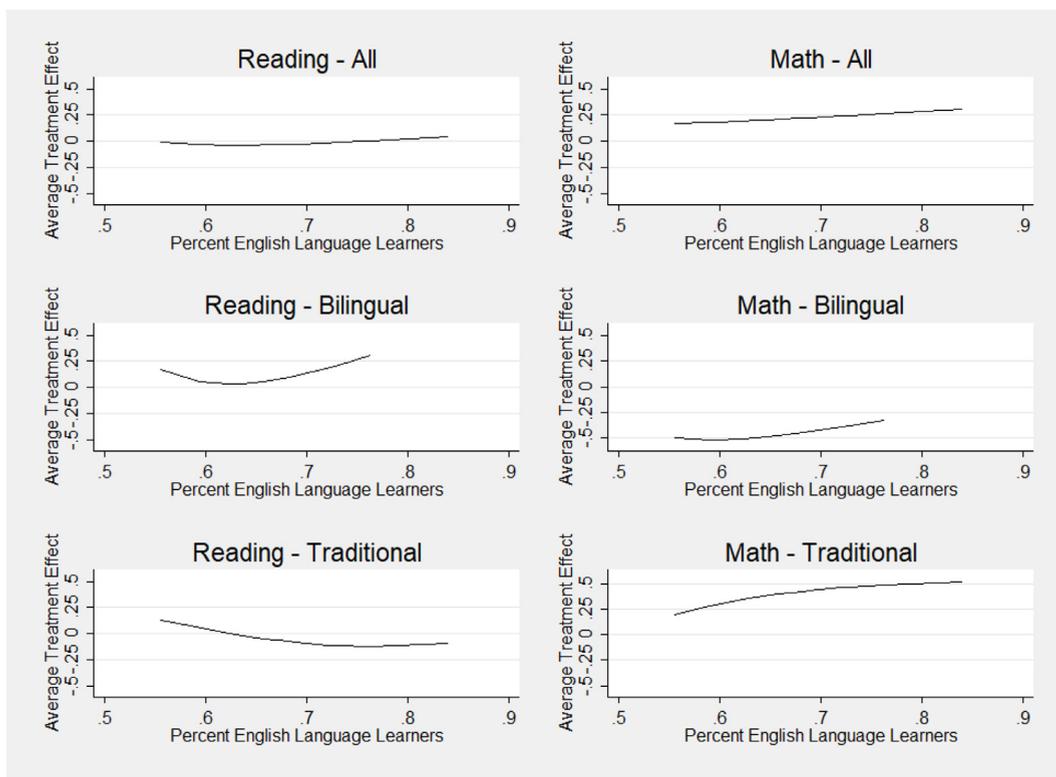
Fig. 4. Average effect of technology use by percent ELL students and classroom type.

taught in English. Below, we examine the contributions of teacher capacity and instructional practice in explaining these disparate findings across subject and classroom type.

3.2. Teacher capacity and instructional practice

In examining average effects of tablet use on student achievement, it is important to establish how variation in teacher capacity and instructional practice affects student access and outcomes. We first examined two types of technical capacity: (1) ability to address technical issues and (2) the contribution of technical knowledge to improved instructional practices through technology use. We operationalized the second type of technical capacity as the remaining association between improved outcomes and prior technology experience after controlling for the percent of time lost to technology issues. We also integrated qualitative excerpts from classroom observations to further illustrate the technical capacity and technology-based instructional practices that were present or occurring in classrooms.

At the most basic level, the percent of time lost to technical issues was negatively associated with student achievement, particularly for students in traditional classroom settings, as seen in Table 2. Across models, the negative association between time lost to technical issues and lower achievement ranged from 0.19 to 0.91 standard deviations lower test scores when teachers spent the full class period addressing these issues. During a class period where a teacher spent half the class period addressing technical issues, we would expect 0.10 to 0.46 standard deviations lower test scores. Consistent with prior research, this finding suggests that the benefits of technology use are reduced by the loss of instructional time due to technology problems (Almerich et al., 2016; Holland, 2001; Maduabuchi & Emechebe, 2016; Yunus et al., 2013). Thus, additional training in this area to assist teachers struggling with daily technology challenges may enhance the benefit of technology integration for emergent students.

The past technology experience of a student's teacher also mediated gains in math but not reading achievement from technology use, particularly in English/Spanish bilingual classrooms. Teachers with some or more prior technology experience used blended instructional strategies more often ($p < 0.001$). Blended learning requires the integration of technology and face-to-face instructional techniques simultaneously, as shown in the second excerpt below from observation notes of a blended science class. In contrast, the first excerpt from an observation in a technology-driven math class typifies the instructional expectations observed in most math classrooms.

Excerpt 1: Technology-driven math instruction. The teacher is working with two students at the back of a bilingual classroom. Materials are in English and Spanish. The teacher instructs the students, "If you are stuck in personal math trainer, do not talk to your neighbor. This is your own work. If you are stuck, ask the program. I don't want to hear any talking. This is your own work."

Table 2
OLS student-level regression, dependent variables: Standardized reading scores.

	Spring Reading Scores (Std.)			Spring Math Scores (Std.)		
	All	Bilingual	Traditional	All	Bilingual	Traditional
Tablets Used in Subject	−0.022	0.105	−0.026	0.209	−0.467	0.387***
	(0.040)	(0.057)	(0.085)	(0.113)	(0.228)	(0.089)
Hours of Weekly Use Per Period in Subject	0.445**	0.293	0.600*	0.348*	0.470*	0.593
	(0.135)	(0.246)	(0.249)	(0.127)	(0.190)	(0.322)
Hours of Weekly Use Per Period in Subject Squared	−0.091*	−0.023	−0.113	−0.085*	−0.103	−0.182
	(0.038)	(0.090)	(0.081)	(0.033)	(0.052)	(0.086)
Percent Time Lost to Technology Issues	−0.345	−0.302	−0.914**	−0.192	−0.767*	−0.211
	(0.191)	(0.386)	(0.277)	(0.159)	(0.341)	(0.229)
Some or More Past Tech Experience	−0.024	−0.023	−0.011	0.070	0.171*	0.113
	(0.049)	(0.090)	(0.073)	(0.064)	(0.068)	(0.070)
Percent English Language Learners	−0.074	−1.970	0.257	−0.882	−0.300	−0.701
	(0.909)	(2.013)	(0.677)	(1.328)	(2.394)	(0.800)
Percent Special Education	2.547	3.824	6.570*	3.134	0.248	1.615
	(3.037)	(3.569)	(2.915)	(3.147)	(4.443)	(2.182)
Percent Low SES	−1.811	−3.908*	0.186	0.001	−0.620	0.735
	(1.589)	(1.689)	(1.380)	(1.826)	(1.654)	(1.918)
Same Subject Prior Year Achievement (Std.)	0.162	0.137	0.219	0.126	0.011	0.227
	(0.175)	(0.215)	(0.169)	(0.133)	(0.141)	(0.107)
Number of Absences	−0.048	−0.136	−0.067	−0.152	−0.141	−0.080
	(0.078)	(0.091)	(0.073)	(0.084)	(0.092)	(0.087)
Constant	1.838	5.254	−0.462	0.941	1.898	−0.283
	(1.987)	(2.653)	(1.510)	(2.475)	(2.658)	(2.202)
Observations	819	455	364	819	455	364
R^2	0.39	0.47	0.64	0.35	0.39	0.74
F	20.47	2619.27	83.22	200.87	1920.48	204.42

Notes: Standard errors in parentheses.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
Estimated using the STATA ctreatreg routine.

Excerpt 2: Blended science instruction. The teacher reads the question in Spanish to students, who must submit their individual answers via e-readers to Kahoot. A female student discusses why she answered her question and how does water get into the plant. She explains in Spanish that the water came from the roots in the ground. The teacher responds with another question (in Spanish) for the students, "How would the chemicals affect the ground and water since chemicals get into the dirt? Do the chemicals affect the plant?" The teacher asks the students to explain their answer in Spanish or English … The teacher proceeds with a review. She asks students, "What have learned this week?" In Spanish she says, "Properties of dirt, the color of water, which water-water from the hose." She continues in Spanish, "What are some of the properties of dirt? It holds water. What can we learn from touching the dirt? What are we investigating, what is it called? How does it feel? Texture." The teacher says in Spanish, "Now–we will be planting today. Students put away your Kindles. Teacher re-directs students to the next plant activity.

In the first excerpt, the teacher discourages interaction or help-seeking, shifting all responsibility for instructional delivery to the tablets. In the second excerpt, the teacher encouraged interactivity. Students submitted their answers using their eReaders, allowing the teacher to gauge quickly all students' level of understanding. Even though the lesson topic is not reading or language arts specific, the teacher actively encouraged communication. The teacher in the first excerpt made accommodations for ELLs in her class by providing materials in both English and Spanish. In contrast, the teacher in the second excerpt aligned technology use with best practices in educating emergent bilingual students, providing students opportunities to practice language skills in a face-to-face instructional setting and using technology as a tool to engage students not yet comfortable speaking up in class. We found that teachers with greater technology expertise used blended instructional strategies more often in both bilingual and traditional classrooms. The use of blended instead of solely technology-driven instruction may be one mechanism through which prior technology experience facilitates higher student achievement in elementary school settings.

As suggested above, the increased importance of teacher capacity in math may be in response to lower average rates of blended instruction in math compared to reading. We observed that digital math programs accessible to teachers often consisted of drill and practice program-generated math problems, requiring greater teacher commitment and technical expertise to adapt or modify available tools to fit instructional best-practices. Consider that in the above examples, the only responsibilities of the teacher who asked students to complete technology-based math problems involved minimizing classroom disruptions and addressing any technology issues that arose. In contrast, the teacher in the blended science vignette developed a multiple-choice assessment using Kahoot prior to the lesson, in addition to actively probing for student knowledge during the observation and designing the planting activity the class moved on to at the end of the observation. Technology can be used to save time and minimize effort, but often the integration strategies that most enhance student learning require more, not less, teacher expertise and engagement.

In our analysis of student learning gains, we observed that technology use in reading was more helpful for students in English/

Spanish bilingual classes than was technology used in math. We also observed that teachers used blended instructional strategies more often in English/language arts bilingual classrooms than in math bilingual classrooms. While teachers of bilingual classrooms used blended instructional techniques approximately twice as often as teachers of traditional English-only classrooms, we observed most of that blended instruction in reading. When focusing on observations of math instruction, we alternatively saw teachers in traditional classrooms using blended techniques more often than teachers in bilingual classrooms. Greater emphasis on blended learning bodes well for student learning where it indicates opportunities for interactive, face-to-face work, while purely digital instruction that replaces rather than supplements student-teacher and student-student interactions appears to be particularly in-effective for emergent bilingual students who need opportunities to practice language use (Chen, 2016; Foulger & Jimenez-Silva, 2007; Lacina, 2004).

Variations in the importance of prior technical experience in math versus reading instruction may also reflect the increased importance of instructional versus technical skill sets in reading, even when using digital tools to assist that instruction (Snodgrass, Israel, & Reese, 2016). That does not mean that different instructional techniques might not lead to larger learning gains in bilingual math classes, only that we did not consistently observe them. Often, the role of English fluency in math learning is overlooked, but the techniques that assist emergent bilingual students in learning English are also effective in supporting student learning in math, with ELLs learning more in math when teachers integrate techniques that encourage interactive, active learning (Bunch, 2013; DiCerbo et al., 2014; Purpura et al., 2017). The following excerpt is from one of the rare math observations where the teacher successfully facilitated blended learning and highlights the importance of language in the comprehension of math concepts (Purpura et al., 2017; Thompson, 2017).

> **Excerpt 3: Blended math instruction.** The teacher tells the students in his class, "You are going to have a table. And the table has information, and you are going to organize the information. If I am in my kitchen and I want to bake a cake and I need to triple it and I want to make three cakes – it's adding or multiplying. Read to understand. Pull out the important information and know what is being asked to make sure you are putting the right information in the table. What does it represent? Turn and tell your neighbor." The teacher adapts on the spot to students' needs in small group instruction. Students log into RM City as individual users and record answers in a math journal.

Above, the teacher integrated best practices for educating ELLs by providing opportunities for student collaboration, encouraging discussion, and linking mathematical concepts to real world, culturally relevant situations (Bunch, 2013; DiCerbo et al., 2014). Most teachers used the same program, RM City, for technology-driven instruction where students worked individually at their own pace through program selected content, but in this instance, the teacher possessed sufficient technical capacity to adapt available tools through the integration of teacher-created content. This further demonstrates the need for technical, instructional, and pedagogical competency for the enactment of the most effective instructional techniques for emergent bilingual students. And this is particularly true in math, where available software more often consisted of drill and practice exercises, while in reading, online exercises more often required higher-order thinking and interactivity.

3.3. Study limitations

Any attempts to generalize from these results must recognize the school and program context of our study. First, the schools in our sample served a predominately Hispanic, ELL, and low-income student population. The same initiative implemented in the same manner may perform differently with students identified as ELLs from non-Hispanic or middle-class backgrounds. Other unobserved school characteristics, such as school culture, instructional leadership, and non-technology related educator capacity, may also limit generalizability to other contexts. Conversely, we were unable to control for some key teacher characteristics, such as years of teaching experience, that might explain differential responses to treatment.

Further, specialized knowledge and experience are critical to effectively serving emergent bilingual students regardless of technology access or use. Our study included findings only from the first full year of implementation of the tablets, and classroom walkthroughs conducted in the subsequent school year indicated ongoing tablet use and some improvements in student digital citizenship, as well as in instructor-facilitated implementation of curricular content and structure, instructional model and tasks, and the use of assessments for creating quality learning opportunities with technology. It is possible that the relationships we observed in the first year might evolve with teachers' acquisition of experience and increased capacity for implementing blended learning techniques with the tablets. In addition, the Jiv Daya Foundation played a critical role in providing ongoing training and support to educators in the pilot schools. Any attempt to replicate the results of this study may require comparable ongoing, external invest-ments.

As with any geographic or context-specific intervention, the future examination of similar interventions and outcomes in other settings would be desirable. Our review of the literature identified other proposed mechanisms through which technology might lead to improved outcomes for some students and in some situations that our research design did not allow us to fully investigate. For instance, future researchers might wish to further examine differences in available content, cultural responsivity, and language support features in technological tools across subjects and the role they may play in the experiences and outcomes of emergent bilingual students. Also, although we disaggregated results by English/Spanish bilingual and traditional English-only classroom settings, our quasi-experimental methods identified associations rather than causal effects, and it is possible that other unobserved characteristics of classrooms or students might have influenced responses to treatment exposure. Based on promising associational findings from this study, future research that more plausibly identifies causal treatment effects would be a welcome addition to the literature.

4. Conclusion and implications of findings

The program model for integrating educational technology in our sample of elementary schools suggests the potential for gains in the academic achievement of emergent English/Spanish bilingual students through tablet use. We conclude with a summary of our findings and discussion of their implications in relation to the two major research questions we articulated in the introduction.

4.1. Summary of findings

To what extent is the use, and intensity of use, of educational technology associated with improved academic outcomes for ELL students in both English/Spanish bilingual and traditional English-only classrooms?

Our research findings suggest the potential for technology to improve student outcomes in schools serving a predominately low-income, emergent English/Spanish bilingual student population. We found the intensity of use to be independently associated with student achievement. The average math treatment effect of 0.29 is slightly smaller than the math effect sizes (k = 41, ES = 0.47) from a meta-analysis of technology initiatives in elementary schools, while the average reading treatment effect of 0.07 is substantially smaller than the average language effect size (k = 77, ES = 0.45) from the same study (Chauhan, 2017). Yet as our research shows, intensity of use also matters. With as many of 3 h a week of technology use in reading, the average effect size rose to over 0.50. Classroom type and associated instructional strategies, as well as the student population served, also contributed to differential average effect sizes, with students identified as ELLs achieving larger reading gains in bilingual classrooms, while students attained larger math gains in traditional classrooms.

How do the roles of teacher capacity and practice in integrating educational technology vary by student population and instructional setting?

Teachers mediated the effect of technology use on student learning by deciding how and how often to integrate instructional technology. Teacher expertise further minimized time spent resolving technology issues and the extent to which technology integration aligned with and supported instructional best practices. As found in prior studies, teachers require opportunities for technology-related professional development for effective implementation, including training on how to efficiently address common technical issues to minimize disruptions to classroom learning regardless of student population taught (Almerich et al., 2016; Author, 2016; Holland, 2001; Maduabuchi & Emechebe, 2016; Yunus et al., 2013). Building teacher capacity to use educational technology beyond basic technical skills, though, requires responsiveness to the specific needs of students in a teacher's classroom in both the selection and adaptation of digital tools and alignment of technical integration with instructional best practices.

4.2. Implications

With many technical programs and tools developed by external vendors, districts, schools, it is important for teachers to take an active role in selecting and adapting those tools to best meet the needs of their student population. Specifically, educators should consider the importance of language comprehension in student learning across subjects and incorporate programs that provide language adaptations not just in reading but across content areas (Bunch, 2013; DiCerbo et al., 2014; Purpura et al., 2017; Thompson, 2017). For instance, we observed that the math programs available for teacher use were less student-centered than those in English/language arts. Math programs provided fewer opportunities for interactivity and fewer accommodations, such as translation assistance or text in Spanish, for students learning in more than one language. District, school, and teachers can lessen this concern to some extent by selecting digital tools and programs that provide necessary adaptations and supports for emergent bilingual students. Market availability, though, is dictated largely by vendors, who may not realize the market size and demand for programs designed specifically to minimize language challenges that prevent ELL students, specifically those taught in bilingual classroom settings, from learning math digitally.

Particularly for emergent bilingual students, teachers (and school or district-provided professional development) should emphasize the importance of interactivity and group work within a culturally responsive framework (Bunch, 2013; Chen, 2016; DiCerbo et al., 2014; Foulger & Jimenez-Silva, 2007; Lacina, 2004). Blended learning appears particularly effective in creating these types of quality learning opportunities for emergent bilingual students. We found that bilingual instructional strategies complemented technology integration in reading, while ELLs in traditional classrooms gained more from technology integration in math than ELLs in bilingual classrooms. While the use of blended instructional strategies in and of itself may explain some of this discrepancy, the use of blended learning strategies also appears to be associated with the technical and instructional capacity of a students' teacher. Thus, to expand the use of blended learning, capacity building efforts will likely need to provide training and support for both components.

As previously stated, technology use is most effective when paired with pedagogical expertise. While technology may make tasks such as tracking student progress in a math program or providing individualized reading prompts easier for teachers (Maduabuchi & Emechebe, 2016), the benefits of technology use depend on how teachers integrate those tools within their larger teaching toolbox. With appropriate technology-based tools integrated in instructions informed by best practices in teaching emergent bilingual students, teachers can provide increasingly student-centered instruction, improving language comprehension and use, as well as subsequent learning trajectories.

Lastly, if the primary purpose of technology use in these schools is to improve student achievement and reduce educational inequalities, our findings point to several possible levers to accomplish these goals. First and most basically, our findings suggest that building teachers' technical capacity or providing assistance to address technical issues when implementing a one-to-one technology initiative should lead to improved outcomes (Almerich et al., 2016; Holland, 2001). Specific to teachers of emergent bilingual

students, selecting technical tools that provide language support and adaptions not just in reading but across content areas may go a long way toward creating quality learning opportunities (Almerich et al., 2016; Lacina, 2004). At the same time, technology is not designed to replace pedagogical knowledge when teaching ELLs. Rather, it is through the alignment of technology with constructivist teaching strategies, which connect student learning to culturally relevant experiences and provide opportunities for interactivity and collaboration, that technology can transform the learning process and outcomes of emergent bilingual students (Bunch, 2013; DiCerbo et al., 2014).

Acknowledgments

Appendix A. Summary of Digital Instructional Tools Observational Instrument

We use a standardized observation instrument to evaluate the nature of digital tools themselves and their implementation, as well as the quality of learning opportunities in digital and blended instructional settings within the instructional core and the elements that contribute to quality. The instrument is based on existing research on the integration of technological tools into classrooms, as well as indicators of quality elements in the instructional core in general and for digital instruction in particular (see sources below). Specifically, the rubric evaluates the extent to which the instructional session facilitates quality learning opportunities for students using a set of indicators or dimensions described below, rating the entire learning experience. Thus, a blended "session" includes ratings of both online and face-to-face elements.

The observation instrument is fully qualitative in nature, mapping instruction in a way that is more nuanced than in highly-prescribed tools, and yet the data can be digitized (entered into an online survey data collection program). This instrument addresses an important gap in existing instruments for evaluating digital instruction, as it focuses on the K-12 context, the entire instructional setting and core, and opportunities to learn in practice, and also because it was developed in a research context independent from the online learning industry. Here we summarize the various dimensions of digital and blended instruction (and the settings in which the tools are being used) that we capture in the observation instrument:

- Physical environment: How and where students access the instructional setting, including the technological setting and any associated limitations, and who else in the same physical environment as the student could assist with technological problems and support learning;
- Technology and digital tools: How students access instruction, including internet connectivity, hardware and software in use, and the safety, operability and accessibility of the technology;
- Curricular content and structure: Content and skill focus, who developed it and where it is located (e.g., software loaded onto a tablet, paper workbook), stated learning objectives, sequence and structure, level of rigor or intellectual challenge, and ability to meet and adapt curricular content to student needs;
- Instructional model and tasks: Role of instructor and software in instruction (what drives instruction); purpose or target of instruction; student/instructor ratio and grouping patterns, multimodal instruction; order of thinking required and application of technology in instructional tasks, and ability to meet/adapt instructional model and tasks to student needs;
- Interaction: How much interaction with a live person, and does the technology affect the ability of the instructor or student to positively interact with one another and the instructional resources?
- Digital Citizenship: Is technology being used responsibly by students, as intended by the instructor and/or instructional program?
- Student engagement: Overall student engagement levels (passive or active), level of student self-regulation and persistence, and level of community within the instructional setting;
- Instructor engagement: Overall instructor engagement levels (passive or active) and instructor efforts to encourage engagement;
- Alignment: Alignment of instruction and curriculum to state or district standards and to other instructional settings, and alignment of instruction and curriculum to stated learning objectives (including within the session and between in-person and digital instruction);
- Assessment/feedback: Who develops and manages the assessment (instructor, provider via software), structure, and whether it is individualized to student learning and relevant to stated learning goals.

Ratings of the ten core elements of digital and blended instruction listed above are on a 0–4 (or 5-point) scale. The instrument also records narrative comments and vignettes, total instructional time and total time on task; total time a student interacts with a human instructor; whether the format facilitates live interaction between instructors and students around instructional tasks, and the functionality/operability of the technology or device. The instrument is designed to capture instructional opportunities and the use of digital tools in fully digital, face-to-face and blended settings, as well as for various units of analysis within an instructional setting

(i.e., individual student, small group of students, or whole class). The complete instrument is publicly accessible here: https://my.vanderbilt.edu/digitaled/files/2016/08/Observation-Instrument.pdf.

Theoretical foundations and existing instrumentation consulted in the development of the observation instrument.

- Digital Bloom's Taxonomy by Andrew Churches http://www.techlearning.com/techlearning/archives/2008/04/AndrewChurches.pdf
- Framework for 21st Century Learning (http://www.p21.org/overview/skills-framework)
- iNACOL standards for online courses (http://www.inacol.org/resources/publications/national-quality-standards/)
- Smythe (2012) Toward a Framework for Evaluating Blended Learning (use of rubrics in blended learning environments)
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- Technology Integration Observation Instrument from TPACK (http://elvistheteacher.wikispaces.com/file/view/TPACKObservationInstrument.pdf)
- CLASS observation instrument for student teacher interactions (http://www.teachstone.org/about-the-class/)
- Quality Matters K-12 Online rubric of standards (http://www.uwex.edu/disted/conference/Resource_library/proceedings/29483_10.pdf)
- California State University – Chico, Rubric for Online Instruction (http://www.csuchico.edu/roi/the_rubric.shtml)

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