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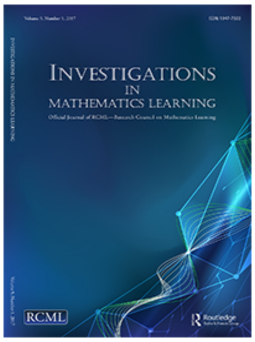

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INVESTIGATIONS IN MATHEMATICS LEARNING
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Online Resources for Mathematics: Exploring the Relationship between Teacher Use and Student Performance

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ABSTRACT

Adoption of online resources to support instruction and student performance has amplified with technological advances and increased standards for mathematics education. Because teachers play a critical role in the adoption of technology, analysis of data pertaining to how and why teachers utilize online resources is needed to optimize the design and implementation of similar tools. The present study explores how Algebra Nation (AN), an online resource aligned with an Algebra I statewide exam, was utilized by teachers and what usage components influenced student achievement. A survey of teacher use was conducted and analysis implies that online resources should provide multiple incorporation methods including supplementation, assessment, and remediation. Results suggest that teacher logins, trainings, and workbook usage contribute to increased passing rates.

KEYWORDS
Technology; algebra; student achievement

Introduction

Since the introduction of the No Child Left Behind act and the development of academic standards, pressure to improve student achievement and to compete globally has intensified. Standardized testing in core subjects like mathematics is often used to evaluate a school's quality of education, which can result in punitive changes in funding, administration, or faculty. In response to the demands of high-stakes standardized testing, educators have sought classroom resources and professional development opportunities aimed to enhance classroom instruction and increase student achievement. Technological tools have been shown to support instruction and enhance student learning in mathematics (National Council of Teachers of Mathematics [NCTM], 2000, 2014), but not all technology is adopted by mathematics teachers or significantly impacts student achievement equally. In an age of high-stakes testing and accountability, the need for continued exploration of the intersection of teacher, student, technology, and content is necessary to promote effective use of online resources in the classroom. This article aims to investigate how teachers utilized one online mathematics resource, an algebra tutoring platform, in their classrooms and the relationships between classroom use and student performance on a standardized algebra assessment.

Literature review

Mathematics is a challenging subject for many students, yet it is considered to be an essential component of K–12 education and a prerequisite to postsecondary success (Bakia et al., 2013). In particular, completion of high school algebra has been found to correlate with college access, graduation rates, and higher career incomes (National Mathematics Advisory Panel [NMAP], 2008). Because of the significant role mathematics plays in future achievement, standardized tests in mathematics

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have become a critical component of today's educational landscape—tracking the achievement of students, evaluating teacher effectiveness, and comparing educational outcomes nationally and internationally. Continued concern over poor student performance in mathematics has led many educators to seek instructional tools that might develop strong mathematics content knowledge and reasoning skills. Strategic use of technology provides an effective way to support mathematics teaching and learning (Dick & Hollebrands, 2011; Rakes et al., 2010) and can provide students "richer opportunities to investigate mathematical ideas at a deeper level" (Kurz, 2011, p. 260), but not all technologies are implemented effectively nor garner teacher buy-in. In fact, the rapidly expanding field of technology has resulted in a significant range of instructional tools available to classroom teachers. While technology can include hardware like calculators or software like word processors, the present study primarily focuses on what we have termed online mathematics resources—web-based computer technology focused on educational mathematics content. Research demonstrates that online mathematics resources are utilized in multiple ways in the classroom with mixed outcomes on student performance. The following sections will present a summary of relevant studies regarding technology and its impact on student performance and teacher use in mathematics classrooms.

Technology and Student Performance

Research studies on the relationship between computer technology and mathematics achievement are abundant, yet the differential impact of how and what technology is implemented on the relationship with mathematics performance continues to be a pervasive theme. During the early years of technology adoption in the classroom, Wenglinsky (1998) found the use of computers for engaging students in higher-order thinking to be positively associated with academic achievement in mathematics. However, when computers were used for lower-order skills the relationship to mathematics achievement was negative—providing early evidence that the ways in which technology is used is critical to its impact on mathematics performance. The kind of technology being implemented in the classroom was one critical factor impacting the magnitude of the effect size. Over the past 20 years, numerous studies have since examined the relationship between the use of technology in the classroom and student performance. In particular, secondary-mathematics achievement has garnered significant interest by researchers as evidenced by several recent meta-analyses on the impact of technology on student performance (Cheung & Slavin, 2013; Li & Ma, 2011; Rakes et al., 2010; Slavin et al., 2009).

One of the first meta-analyses to systematically look at the effects of technology on secondary-mathematics achievement was conducted by Slavin et al. (2009). This analysis was aimed at determining best practices among multiple programs for teaching secondary mathematics, including mathematics curricula, computer-assisted instruction (CAI), and instructional process programs. In the analysis, CAI was defined as "programs that use technology to enhance mathematics achievement" (p. 842), which included providing extra instruction and/or practice in computer labs, replacing teacher instruction with self-paced modules (core) and computer-based progress assessments (computer-managed learning systems). Out of the 100 studies reviewed, 38 experimental studies using CAI were included with small but positive overall effect size (+0.10). However, the authors further distinguished among the differing types of CAI by examining three subcategories of use: supplemental, core, and computer-managed learning systems. Supplemental CAI included online resources that were used to support regular classroom instruction, such as PLATO and Jostens/Compass Learning, and were found to have the greatest weighted mean effect size of +0.19. Core CAI studies included the use of online resources, such as Cognitive Tutor, to provide primary instruction with the classroom teacher serving as support and resulted in a minimal effect size of +0.09. Computer-managed learning systems included studies on the online progress-monitoring software, Accelerate Math, which resulted in another minimal weighted mean effect size of –0.02. The results of this meta-analysis provide evidence that the ways in which one uses online mathematics resources may influence student achievement in mathematics.

Li and Ma (2011) found similar results when analyzing 46 studies on the impact of computer technology on elementary and secondary students' mathematics achievement. When looking across all included studies, a moderate and positive average effect size (+0.28) was found for the use of computer technology. Similar to Slavin et al. (2009), the authors further analyzed effect sizes by the type of technology and characteristics of implementation and found that not all approaches led to better student performance. In this case, analyzing effect sizes based on the type of technology (e.g., tutorial, communication media, exploratory environments, tools), there was no significant difference in mathematics achievement such as was found by Slavin et al. (2009). However, how the technology was being implemented resulted in significant effect sizes. When integrated with a constructivist teaching approach versus a traditional approach, larger effect sizes were found. In addition, the researchers found that shorter periods of implementation of computer technology (less than six months) resulted in greater effect sizes.

More recently, Cheung and Slavin (2013) identified issues in previous meta-analyses with the inclusion of studies with methodological designs that may have resulted in inflation of effect sizes. Once applying improved standards for the inclusion of studies in their meta-analyses, the authors identified 75 studies that included online resources and other computer technologies such as interactive whiteboards. Overall, use of educational technologies resulted in a moderate, positive overall weighted effect size of +0.15 on mathematics achievement. Grade level, intervention type, program intensity, and level of implementation were features of included studies concerning which the authors looked at respective effect sizes in greater detail. Unlike in previous studies, there were no significant differences between effect sizes in elementary and secondary studies. However, similar to the findings by Slavin et al. (2009), significant differences were detected when analyzing effect size by type of technology. When comparing studies that incorporated computer-managed learning (e.g., Accelerated Math), comprehensive models (e.g., Cognitive Tutor), and supplemental CAI (e.g., PLATO), most studies fell into the supplemental CAI category with the largest effect size of +0.18. When analyzing program intensity and level of implementation, higher frequency of use (at least 30 minutes per week) and greater program implementation also resulted in larger average effect sizes.

Examining algebra achievement in particular, a meta-analysis by Rakes et al. (2010) also found indicators that computer technology may play a role in improved student performance. When analyzing the results of 82 studies that implemented instructional methods to improve student achievement in algebra, technology curricula and tools were found to have statistically significant weighted average effect sizes of +0.04 and +0.311, respectively. Technology curricula included online resources like Cognitive Tutor and PLATO as platforms for delivering or supporting algebra instruction. Technology tools, on the other hand, was broadly defined to include calculators, computer programs, and interactive applets. Unlike other meta-analyses, the criteria for inclusion and types of achievement measures examined were much broader and the magnitude of reported effect sizes may be misleading. Effect sizes of differing types of technology tools and curriculum were not included, which previous meta-analyses defined as an important distinguishing factor in the effectiveness on student achievement results. In sum, the last two decades have seen numerous studies on the impact of computer technology on student performance in mathematics (see Table 1). Use of online resources to supplement instruction that are implemented on a frequent basis show promise for increased academic achievement; yet, the variations in effect size and continuous advances in technology call for further research on such online mathematics resources.

Table 1. Summary of meta-analyses on the effect of technology on mathematics performance.

Authors	Number of Studies	Overall Effect Size
Slavin et al. (2009)	38	+0.10
Li and Ma (2011)	46	+0.28
Cheung and Slavin (2013)	74	+0.15
Rakes et al. (2010)	36	+0.16

Technology and teacher use

Each of the recent meta-analyses on technology and mathematics achievement found that the type of technology, frequency of use, and approach to implementation are factors that potentially impact students' mathematics performance. At the same time, the inclusion of studies with large sets of mathematics achievement data often resulted in limited description of teacher implementation in mathematics classrooms beyond broad descriptors like "traditional" or "supplemental." In a review of literature on the impact of information communication technology (ICT) on mathematics achievement, Hardman (2019) concluded that there is a "paucity of published studies that investigate variation in pedagogical practices with ICT" (p. 2). In particular, the author notes that Li and Ma (2011) are one of the few meta-analyses that analyzed pedagogy around technology in mathematics classrooms yet still provided limited understanding of what the categories of constructivist and traditional technology use mean.

Looking more closely at research within these meta-analyses provides some insight into the range of teacher pedagogy involved in implementing technology tools. For example, a study by Connell (1998) illustrates how technology might be used to support a constructivist approach to mathematics problem-solving. The study examined student performance in two classrooms with different uses of technology—a traditional approach that utilized technology for computation and presentation and a constructivist approach requiring students to engage with tools for discovery and exploration. Students in the constructivist-technology-use classroom outperformed those in the traditional-technology-use classroom. While both overall teaching approaches to instruction without technology were considered constructivist, the degree to which the technology aligned with the individual teacher's philosophy led to significantly different achievement outcomes. A similar study demonstrating a student-centered, constructivist use of technology was conducted by Shyu (2000). Rather than using the technology as a replacement for teacher-centered lecture, the researcher analyzed the impact of interactive videos that utilized stories with "interesting, realistic contexts that encouraged the active construction of knowledge by learners" (Shyu, 2000, p. 58). In the treatment group, a classroom teacher used the videos as a focal point of instruction, having students watch, discuss problem-solving strategies, and collaborate with peers to solve an authentic problem. When compared to a traditional classroom approach, students using the technology had significantly improved mathematics problem-solving scores.

While this kind of implementation may align more closely with teacher practices described in *Principles to Action* (NCTM, 2014), many studies described teachers using technology to support their instruction with more traditional, transmission models of learning. A study by Hannafin and Foshay (2008) describes the impact of a computer-based instructional course, PLATO, on at-risk students' performance on a state standardized assessment. The classroom teacher in the study used the technology tool in a remedial mathematics course in which students worked independently four days a week on online modules aligned with content in the state standards. Assigning individualized work provided the instructor time to meet one-on-one with students to support their independent learning. At the end of the course, student scores increased significantly between eighth-grade and 10th-grade administrations of the state assessment. A similar study by Carter and Smith (2002) analyzed the impact of an integrating learning system, Learning Logic, on high school students' algebra performance. In their analysis, teacher use of the technology tool was also presented as an alternative to traditional teaching that fully replaced teacher instruction. Students worked individually on their computers for entire class periods but, in this case, students in classrooms using the technology did not outperform their peers in traditional classrooms. However, more students did go on to take Algebra II than in the control group. The differences in outcomes described in similar studies like Hannafin and Foshay (2008) and Carter and Smith (2002) highlight the need for more qualitative research to better understand how teachers implemented the technology and what elements related to teaching approach might account for increased student performance.

Not only are technologies being used for the traditional teaching of mathematics content, but several studies included in the meta-analyses used curriculum-based technology tools primarily for assessment purposes. Ysseldyke et al. (2003) is one study that explored teachers' implementation of a curriculum-based instructional management system, Accelerated Math. Teachers were given access to this tool in conjunction with the Everyday Math curriculum in hopes that the alignment would help support teacher instruction and improve overall student performance. In the study, teachers had the opportunity to use the tool to assign individual problem sets and practice assessments, provide individualized feedback on assessments, and monitor individual and class progress on learning goals. When comparing mathematics achievement in classes with and without the technology, students who used Accelerate Math achieved larger gains in mathematics than students in classrooms that did not use the tool. However, classroom observations concluded that teacher-student interaction times did not increase and instructional tasks selected by teachers were primarily worksheet-based problem sets.

As the wealth of studies on technology and mathematics achievement demonstrate, teacher implementation of technology in mathematics classrooms can vary widely. According to Drijvers et al. (2013), three "crucial" factors impacting the integration of technology in mathematics classrooms includes the design, the teacher, and the context. First of all, the design of the technology tool is an important component of a teacher's decision to implement it in the classroom. Teacher use will vary based on the affordances and constraints offered by the tool and the overall alignment to the teacher's pedagogical decisions and lesson design (Drijvers et al., 2013). Second, teacher perceptions and knowledge about technology play a critical role in the incorporation of technology in the classroom. Teachers are more likely to adopt a technology when they believe that it will enhance student learning and motivation (Hennessy et al., 2005; Pierce & Ball, 2009) or perceive the technology to be useful in their own professional practice (Fishman et al., 2011). In addition to perceptions, the degree to which the teacher feels prepared and knowledgeable about a technology tool, including access to professional development, influences how technology tools are ultimately incorporated into teacher practice (Lawless & Pellegrino, 2007; Zheng et al., 2016). Finally, the educational contexts in which a teacher works can alter the implementation of technology tools. At the most basic level, a school's infrastructure to support the use of technology, including Internet and device access, impact a teacher's ability to integrate technology in the classroom (Njiku et al., 2019). Beyond this, the coherence between the technology and state standards, existing curriculum, school policies and initiatives, and professional development programs are all factors of the educational context that can influence teacher adoption (Drijvers et al., 2013; Fishman et al., 2011). To see the full effects of technology on mathematics achievement, it is essential that researchers consider these elements of teacher use so that effective and sustained implementation might be realized in more mathematics classrooms.

Theoretical framework

Understanding teachers' use of technology in the classroom and its impact on student understanding is a complex endeavor. In mathematics education, the theory of instrumentation (Artigue, 2002; Guin & Trouche, 1999) and instrumental orchestration (Drijvers et al., 2010; Trouche, 2004) has been increasingly used to understand the ways in which students and teachers engage with technology for mathematics learning. Instrumentation theory presumes that students' learning to engage with a technology tool, or artifact, requires a process of *instrumental genesis* whereby the tool is turned into an instrument through the creation of schemes and techniques for using the tool (Drijvers et al., 2010; Trouche, 2004). The ways in which teachers design and enact learning activities around these tools is critical to supporting students' instrumental genesis (Mariotti, 2002), and the teacher's role in guiding student use of technology tools has become known as *instrumental orchestration* (Trouche, 2004). Instrumental orchestration has been defined in the mathematics education field as "the teacher's intentional and systematic organization and use of the various artifacts available in a … learning environment in a given mathematical task situation to guide students' instrumental genesis (Drijvers et al., 2010)

When preparing to teach mathematics with the use of technology, Trouche (2004) defined two critical elements: didactical configurations and exploitation modes. *Didactical configuration* describes the way that the artifacts and classroom environment are arranged. *Exploitation mode* describes the ways that teachers can use the didactical configuration to meet their objectives, or *didactical intentions*. These two elements work together to describe the ways teachers organize their environment and instruction to support students' mathematical learning. For example, a common instrumental orchestration from Drijvers et al. (2010) titled technical-demo describes a scenario wherein a teacher projects the tool on the screen to the whole class (didactical configuration) and uses a selected example (exploitation mode) to provide a step-by-step explanation of how to use the technology tool for the class (didactical intention). In fact, several common types of orchestrations (see summaries in Table 2) have been identified and, while not yet a complete list, these examples have been useful in describing the different ways technology can be used by teachers to support students' mathematical learning (Drijvers et al., 2010).

Because the aim of this study was to understand how teachers implemented a technology tool in mathematics classrooms and its subsequent impact on student learning, instrumental orchestration became a lens for interpreting teachers' reported use of Algebra Nation (AN). In this study, teacher use of AN (e.g., whole-group video projection, individual remediation, small-group centers) describes the didactical configuration of their instrumental orchestrations (e.g., technical-demo, explain-the-screen) used to support student understanding of algebraic concepts. While teachers are presumed to have had various didactical intentions and exploitation modes (Trouche, 2004) when using AN, the scope of this study did not provide enough detail on those elements of their orchestrations.

Context of the study

In this study, we focus on one particular online resource—the AN online tutoring platform. AN was developed to support students and teachers in meeting mathematics state standards required on the Florida Algebra 1 end-of-course (EOC) assessment (Algebra 1 EOC). The Algebra I EOC is a standardized assessment used to measure student achievement of the Florida Algebra I standards and is required for all public-school students enrolled in Algebra 1. The 2013–2014 administration of the exam consisted of 30–35 multiple-choice questions and 20–25 open-ended items to be completed during a 160-minute period. Florida adopted the Common Core State Standards for Mathematics, also known as the Florida Standards, in 2010 and Florida teachers were in at least the third year of implementation of the standards when introduced to AN. Included in the online resource were video lessons by experienced algebra tutors, practice assessments modeled from the Algebra 1 EOC, and a synchronous, interactive wall through which students can converse with other students, teachers, and online tutors about algebraic concepts (see Figures 1 and 2 for samples of the student interface). A workbook with study guides that follow along with the videos was also available for

Table 2. Instrumental-orchestration types from Drijvers (2011).

Orchestration Type	Example
Technical-demo	Teacher demonstrates how to use technology tool by projecting tool on screen and providing technical steps for its use.
Explain-the-screen	Teacher uses technology-tool projection on screen to explain mathematical concept.
Link-screen-board	Teacher makes connections from math using tool to other representations on board to explain mathematical concept.
Discuss-the-screen	Teacher orchestrates discussion of mathematical concept using tool projected on screen.
Spot-and-show	Teacher identifies student work to project with technology tool and initiates discussion about mathematical concept.
Sherpa-at-work	Student uses the technology to share work with the class as teacher directs discussion about mathematical concepts.
Work-and-walk-by	Students work with technology individually on devices as teacher circulates and works one-on-one with students.

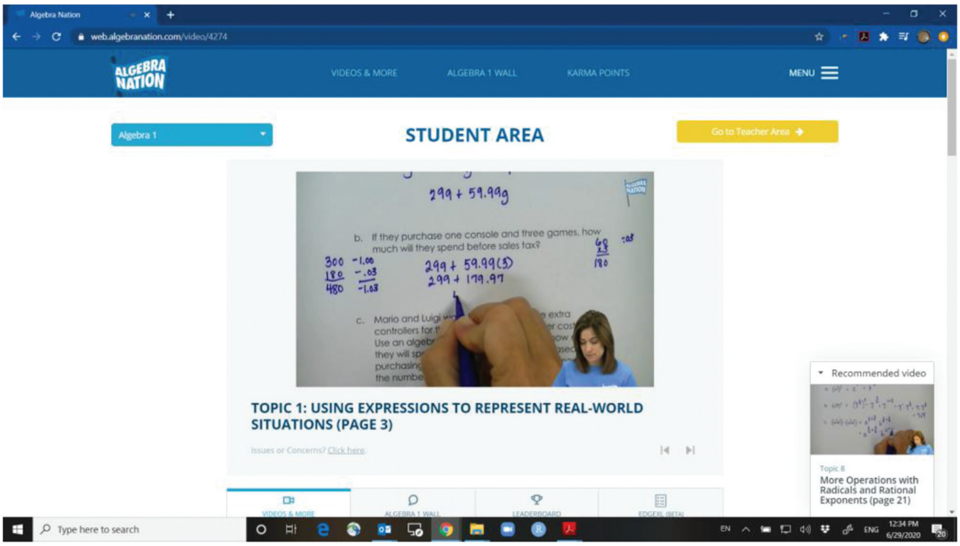
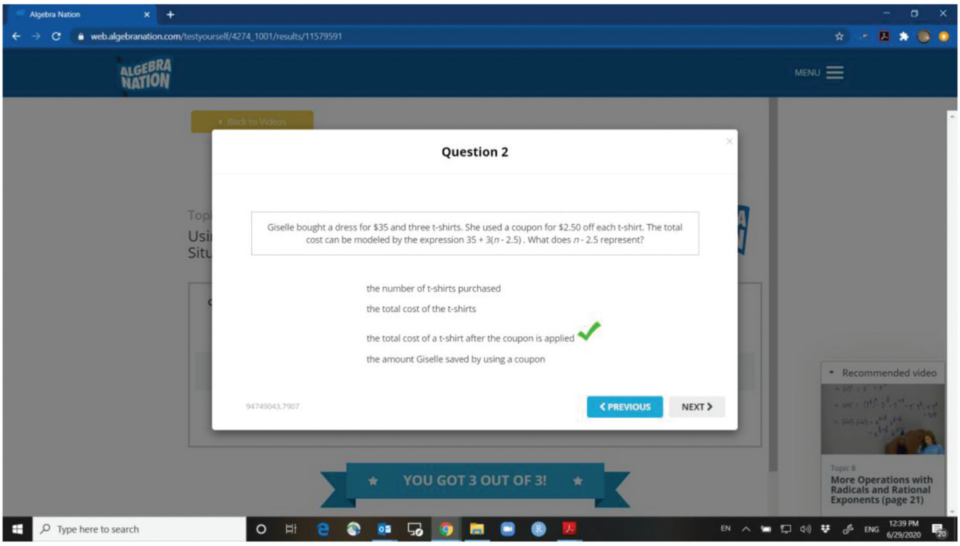


Figure 1. Sample Algebra Nation instructional video.



Question 2

Giselle bought a dress for $35 and three t-shirts. She used a coupon for $2.50 off each t-shirt. The total cost can be modeled by the expression 35 + 3(*n* - 2.5) . What does *n* - 2.5 represent?

the number of t-shirts purchased
the total cost of the t-shirts
the total cost of a t-shirt after the coupon is applied ✓
the amount Giselle saved by using a coupon

94749043.7907

‹ PREVIOUS NEXT ›

★ YOU GOT 3 OUT OF 3! ★

Figure 2. Sample Algebra Nation test-yourself assessment.

teachers and students. Content covered in each of these components was designed to align with the Florida state standards for algebra and was organized according to the following domains: (a) equations and inequalities; (b) exponential functions; (c) expressions; (d) introduction to functions; (e) linear equations, functions, and inequalities; (f) one-variable statistics; (g) quadratic functions; (h) summary of functions; and (i) two-variable statistics.

The design of AN has some similarities to other widely-used online resources, such as Cognitive Tutor, Khan Academy, PLATO, and ALEKS. Each of these online resources provided video tutorials on mathematics content aligned with state standards, as well as opportunities for students to assess their progress through short formative assessment questions. Like AN, Cognitive Tutor provides printed workbooks to students that align with their online content. While each resource contains modules that align to the nine algebraic domains of AN, Cognitive Tutor, Khan Academy, PLATO, and ALEKS offer a larger selection of content including elementary mathematics, geometry, trigonometry, and calculus. Each of these alternative online resources also provides adaptive online learning environments designed to provide individualized instruction, whereas AN is self-guided and does not currently utilize adaptive technology.

However, AN has distinguished itself from similar resources for several reasons, including free access for teachers and students, specific alignment to Florida state standards and EOC exams, and onsite professional-development training by knowledgeable educators. The AN trainings are inquiry-based, allowing the teachers to explore the features of AN, including the video lessons, practice assessments, interactive student wall, and workbook. The teachers collaborate and share strategies that they will use to implement the resources in their curriculum. With the instructional videos and workbooks covering all of the Algebra 1 content, there is much focus on how teachers will use that feature in the classroom. Teachers often learn about flipping the classroom (e.g., having students watch the videos at home), using the videos as a coteacher during class, and segmenting the videos and using only portions during class. These strategies always include the students completing the workbook as they are watching the videos.

During the 2013–2014 school year, AN was introduced to all Florida schools as a free resource and was quickly utilized by more than 100,000 students across the state. Since its introduction to Florida schools, numerous trainings and professional-development days were conducted across the state to encourage teacher use. In addition, AN is swiftly becoming more than just an online resource for students and teachers but also a collaborative online community of educators. Similar to the student interactive wall and video tutorials, a professional-development component has been created that provides teachers with opportunities to converse about teaching mathematics and preparing for the Algebra EOC, to share instructional resources, and to view videos of Florida classroom teachers demonstrating mathematical teaching practices.

Purpose of the Study

We aim to understand how teachers are engaging students with one online mathematics resource, AN, and the relationship between classroom use and student performance in algebra. In particular, the following research questions will be addressed:

In what ways is AN being incorporated in instruction?

Is there a relationship between usage of AN at the school level and improved student performance on the Algebra 1 EOC?

Did schools at which teachers attended in-person professional developments, logged into the AN's online learning environment, and ordered student and teacher workbooks differ from schools that did not use AN with respect to mean student scores and the percentage of students passing the Spring 2014 Algebra I EOC?

Methods

Sample

The data used for this study came from four different sources: *How Teachers Use Algebra Nation Survey*, the AN system, the Florida Department of Education (FL DOE) website, and the website of the National Center for Education Statistics (NCES). Research Question 1 (RQ1) was addressed with both quantitative and qualitative data from the survey. The respondents to the survey were all full-time teachers who taught Algebra I in Florida during the 2013–2014 academic school year. The online survey was sent to 1,244 teachers who logged into the AN system at least five times and obtained a 48% response rate (i.e., 596 respondents). In a meta-analysis of 68 online surveys, Cook, Heath, and

Thompson (2000) found that the mean response rate was 39.6% (*SD* = 19.6%). Therefore, the response rate was 0.43 standard deviations above the mean reported in Cook et al.'s meta-analysis.

Data from the AN system was used to answer Research Question 2 (RQ2) and Research Question 3 (RQ3). The AN system collected usage data during the 2013–2014 and 2014–2015 academic years and included over 655,000 logins, 1.3 million video views, over 3 million responses to a 582-question item bank, and over 200,000 discussion-forum entries. Because the Algebra I EOC is required for a wide array of courses (Algebra I, Algebra I Honors, Algebra I-B, Pre-AP Algebra I, Pre-AICE Mathematics I, and IB Middle Years) in Florida, both middle and high school data were examined in this study.

From the FL DOE website, public school–level data on the Algebra EOC was obtained for Spring 2012, Spring 2013, and Spring 2014 and used to address RQ2 and RQ3. The data set included the number of students taking the test for the first time, mean scale score, percentage of students that passed, and the percentage of scores at each level. The NCES website was used to obtain additional school-level covariates, as described in the Measures section below.

To address RQ3, a quasi-experimental analysis was used to evaluate the effects of in-person trainings, logins into AN's online learning environment, and access to student and teacher workbooks on the performance of schools with respect to the mean student scores and percentage of students passing the Algebra I EOC. Conventional estimation of average treatment effects (ATE) is calculated by taking the difference of the means of the control and treatment groups (Rosenbaum & Rubin, 1983). Application of this method to the sample from our quasi-experimental design would not have accounted for uncontrolled factors. Instead, we matched schools in the treated and control groups based on confounding variables before we calculated the mean of the matched pair differences. For RQ3, AN user schools (i.e., the treated group) consisted of 291 schools that received the AN workbooks and had at least one teacher log into the AN system and attend in-person trainings. The control group consisted of 73 schools that were not provided with AN workbooks, whose teachers did not log into the system, and who did not participate in in-person trainings.

Measures

The survey used to address RQ1 was designed to examine the usage of AN by teachers and students for multiple levels of instruction. It included questions about how, where, and with what frequency they used AN videos, workbook, test questions, and a discussion forum. The survey had 39 closed-ended questions with a rating-scale or yes/no format and three open-ended items. Each closed-ended question was designed following the principles for writing effective survey questions presented by Dillman et al. (2009). The principles included avoiding vague quantifiers (such ordinal frequency scales with rarely-sometimes-frequently anchors). Instead, for questions about the usage of each component of AN, we used the more precise frequency anchors: "Not used," "Less than once in every five classes," "One or two times in every five classes," "Three or four times in every five classes," and "In every class".[1] Open-ended items included the following questions: What is the main strength of Algebra Nation? What is the main limitation of Algebra Nation?, and What is the main problem that has prevented you from using Algebra Nation with your students at least once in every two weeks? The survey was pretested using the guidelines presented by Presser et al. (2004) using cognitive interviews, expert reviews, and a pilot study. Fourteen cognitive interviews were performed, with seven as think-aloud interviews and seven as verbal-probing interviews, following the methods for cognitive interviews presented by Willis (1999). The participants of the cognitive interviews were algebra teachers from nine school districts identified by the AN vendor as intensive users of the tool. Expert reviews involved having the survey reviewed by three mathematics education experts and the AN coach who provided training to teachers on how to use the tool. The pilot study consisted of sending the survey to 100 randomly selected teachers from the original sampling frame. From these 42 responded to the survey, for a response rate of 42%. Based on the results of the pretesting methods and

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[1] The complete survey is available by contacting the first author.

the pilot study, questions that had problems, such as unclear wording and low frequency of responses for some options, were revised.

The outcomes of RQ2 and RQ3 are the mean student scores on the Spring 2014 Algebra I EOC assessment and the percentage of students passing this exam. The passing cut-off is defined by the Florida Department of Education and was consistent across all schools. The covariates controlled included the Spring 2013 and Spring 2012 Algebra I EOC exam and the percentages of students passing the exam on these two administrations, the student-teacher ratio, percentage of students eligible for free lunch, percentage of students eligible for reduced-price lunch, and dummy indicators of whether the school was a charter, magnet, or Title I school. The mean scores and passing rates used as outcomes and covariates were obtained from the Florida Department of Education website. The other covariates were measured in 2012 and obtained from the National Center for Education Statistics website.

Analysis

To answer RQ1, frequencies were computed for teacher use of AN instructional videos, use of AN as individual work, use of AN as a remediation tool, use of AN as a homework activity, use of the AN workbook, and use of study questions. To understand what factors influenced teacher use, open-ended survey items were analyzed using a typological analysis approach (Hatch, 2002) according to the type of usage (e.g., instructional videos, individual work) and the open-ended responses indicated. After this initial deductive coding, responses within each type of usage were coded again for alignment with existing orchestration types suggested by the instrumental orchestration framework (Drijvers et al., 2010). For example, the researchers first determined that 48% of the respondents on one of the qualitative questions referred to the use of instructional videos and, in their secondary analysis, found that teachers primarily described an *explain-the-screen* orchestration when using the instructional videos in AN.

To answer RQ2, two analyses were performed—the first focusing on the relationship between AN use indicators and student performance across the entire group of schools and the second focusing on classifying schools into multiple discrete groups based on AN usage and then comparing these groups with respect to student performance. Both analyses used a data set created by aggregating the AN data to the school-level and merging with the FL DOE data set. For the first analysis, an ordinary least squares multiple regression model was fitted to the data in R (R Core Team, 2020). The regression tested the relationship between the percentage of students passing the Algebra EOC in the 2013–2014 academic years with the following variables: (a) the number of teacher users, (b) total video views per teacher user, (c) whether teachers received training, (d) use of workbooks, (e) participation in AN challenges, and (f) whether teachers and students were able to log into AN with their school ID. The regression model controlled for the school passing rates in the two previous years and the number of student test takers. This model included two- and three-way interactions between teacher variables.

For our second analysis addressing RQ2, a latent profile analysis (LPA; Muthén, 2001) was used to classify schools into discrete groups according to six AN usage variables: (a) average number of student logins, (b) average number of student videos viewed, (c) average number of teacher logins, (d) average number of teacher videos viewed, (e) ratio of total videos viewed and the number of ordered workbooks, (f) ratio of total number of logins and the number of ordered workbooks. The last two indicators use the number of ordered workbooks as a proxy to the number of students in the school preparing for the Algebra I EOC. Because there was no cost associated with ordering workbooks, we assumed that each teacher ordered as many as needed for each student to have his/her own workbook. Indicators 1 through 4 were selected to measure volume of AN use in schools, while the ratios used for Indicators 5 through 6 measured intensity of use. The first step of the LPA was to identify the number of classes. We fit latent profile models with two, three, and four classes. These models were compared based on a set of fit indices (Nylund et al., 2007): Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), the Vuong-Lo-Mendell Rubin adjusted likelihood ratio test (LMR), and entropy. The distal outcome for this analysis is the school-level Algebra I EOC assessment passing rate, which ranged in this sample from 3% to 99%. Estimation of the effect of latent classes on the distal outcome was conducted using Vermunt's method (2010). We used the 7.31 version of MPLUS (Muthén & Muthén, 2013) to conduct each step of the LPA.

To answer RQ3, we implemented a propensity score analysis (PSA) in R (R Core Team, 2020). PSA has two major stages: (a) a design stage wherein covariate distributions are balanced between treated and untreated groups without any use of outcomes and (b) an analysis stage wherein treatment effects on outcomes are estimated without any use of covariates (Rubin, 2007, 2008). The separation between covariates and outcomes eliminates assumptions between functional forms of relationships between covariates and outcomes and simplifies statistical models used to analyze outcomes (Ho et al., 2007).

Our PSA was conducted in four steps: (a) propensity score estimation, (b) propensity score method implementation, (c) covariate balance evaluation, and (d) treatment effect estimation. PSA refers to the use of propensity scores, which are predicted probabilities of receiving a treatment given covariates, to achieve baseline equivalence of covariate distributions between treated and untreated groups (Leite, p. 6). We estimated propensity scores given the 10 covariates described earlier. The propensity score method implemented in this study, a genetic algorithm (Diamond & Sekhon, 2013), was used to perform one-to-one matching with replacement of the treated and control schools with respect to the 10 covariates. The matching procedure aimed to establish baseline equivalence between the treated and control groups. Covariate balance was evaluated by comparing the standardized mean difference between the two groups after matching on the covariates. Following the guidelines to meet What Works Clearinghouse (WWC) standards with reservations (U.S. Department of Education, Institute of Education Sciences & What Works Clearinghouse, 2013), we considered covariate balance to be acceptable without additional regression adjustment if the standardized mean difference between groups was less than 0.05 standard deviations and acceptable with regression adjustment if the standardized mean difference was less than 0.25 standard deviations. After we performed matching and checked covariate balance, we estimated the average treatment effect (ATE) on the two outcomes of interest as the average difference between outcomes of the matched pairs, with standard errors obtained using the Abadie-Imbens method (Abadie & Imbens, 2002, 2006) with regression-based bias adjustment for the covariates that met the 0.25 cutoff for equivalence but not the 0.05 cutoff.

Results

The survey results for RQ1 showed that teachers reported taking advantage of all components of AN in a variety of ways to improve their students' preparation for the Algebra I EOC. From the teachers surveyed, 76% used AN in their classroom at least once in every two weeks. Most commonly, AN videos were used in the classroom as a second delivery method in both whole-group and individual configurations. For example, 56% of teachers projected AN instructional videos for their students as a group at least once a week. Most frequently, this use of AN in the classroom aligned with a teacher-centered didactical configuration focused on a specific algebraic concept, such as explain-the-screen and discuss-the-screen orchestrations. Teachers reported that the videos "provide[d] a different medium for the students to learn from" and appreciated being able to "play a video and move around the room" as well as "pause it and talk about [the mathematics]." Many reported that they felt confident that projecting the videos to the class provided "clear and concise instruction, illustration, and practice in Algebraic concepts" that they could use as a jumping-off point for their own explanations of mathematical content. The results also indicated that 60% of the teachers asked students to work individually on the AN website during class time. From these teachers, 79% asked students to log into AN using computers in the classroom, but teachers reported using more than one method, such as computer labs, cell phones, and tablets. Using the AN website for student-centered, individualized didactical configuration in the classroom more closely aligned with the *work-and-walk-by* orchestration for learning. Teachers noted the importance of AN providing the "ability for students to work independently" as this provided teachers with opportunities to "roam around class to check for understanding." While teachers circulated to work with students, they said they felt that AN provided the rest of the class with the "feel of a one-on-one with a teacher" and provided flexibility for students to "learn independently at their own pace." In addition, the results showed that 34% of teachers created centers using AN—another variation of work-and-walk-by whereby teachers could monitor students working independently or in small groups using the AN website.

Results of the survey also found that AN usage frequently extended outside of traditional classroom instruction spaces. The results showed that 79% of teachers used AN as a remediation tool. From these, 56% of teachers assigned AN videos to students at risk as homework, which was the most common strategy. The second most common strategy was to provide before or after school tutoring while using AN as a resource, which 48% of teachers said they did. Also, 51% of teachers assigned AN videos and 46% assigned AN study questions as homework at least once a week. Teachers said they felt the strength of AN was "the availability to students to use for review, remediation, or if they miss my class" and that AN even served as an "excellent tool for flipping the classroom as well as providing differentiated instruction to the students." While use of AN as remediation or homework outside of class required an individual didactical configuration, responses of teachers regarding this approach did not provide enough detail to align with or identify a new orchestration type.

Finally, 86% of teachers surveyed had access to the AN workbook aligned with the online content. Workbook practice problems were most commonly used for openers for lessons, assignments for groups, and diagnostic tools. The AN study questions were most commonly used as an assessment after a lesson and homework assignments. While not a stand-alone technology tool, the workbook and study questions acted as supplementary tools for video instruction representing alternate teacher-centered and student-centered exploitation modes of explain-the-screen, discuss-the-screen, and work-and-walk-by orchestrations. Many teachers noted that this was because the videos, study questions, and workbook were strongly aligned and designed to go "hand in hand." Teachers did not use the discussion forum frequently, but one who did said he appreciated the "homework help that students receive through the Algebra Wall."

For the first analysis addressing RQ2, the results of the school-level multiple regression indicated the predictors explained 66.1% of the variance ($R^2 = 0.661$) of the percentage of students passing in the spring of the 2013–2014 academic year. Table 3 displays the parameter estimates from the multiple regression. The intercept $\beta = 46.4$ ($SE = 2.188$, $p < .01$), indicating that the percentage of students in schools passing was 46.4%, for schools with zero teacher users, no training or workbook, and that students and teachers could not log into AN with their school IDs. Schools whose algebra teachers ordered workbooks had 6.78% ($\beta = 6.78$, $SE = 3.09$, $p < .05$) higher passing rates than schools that did not order workbooks. For schools at which teachers and students were able to log in with their school ID and teachers received AN training, for each teacher user of AN, there was a predicted increase of 4.26% ($\beta = 4.26$, $SE = 1.71$, $p < .05$) in the percentage of students passing the Algebra EOC assessment. For schools at which teachers received training and participated in preparation challenges, each teacher user of AN corresponded to a predicted increase in percentage passing of .009% ($\beta = .009$, $SE = .004$, $p < .05$).

RQ2 was also addressed with an LPA that identified latent classes (i.e., clusters) of schools with respect to AN usage indicators. This analysis followed three steps: First, the number of latent classes

Table 3. Summary of significant predictors of Spring 2014 Algebra I EOC passing rates.

	Estimate	Std. Error	Pr(>|t|)
(Intercept)	46.366	2.188	0.000
Mean-centered passing rates 2012	0.139	0.045	0.002
Mean-centered passing rates 2013	0.687	0.046	0.000
Mean-centered number of students 2014	−0.010	0.005	0.024
Access to workbooks (yes or no)	6.775	3.085	0.029
Trained teachers who participated in TYP challenges	0.009	0.004	0.034
Algebra Nation–integrated schools with trained teachers	4.261	1.707	0.013

Note. TYP = Test Yourself Preparatory.

Table 4. Fit indices for competing latent profile models.

Model	Log-Likelihood	AIC	BIC	Entropy	LMR-A *p* value
2 class	−27,110.020	54,270.039	54,396.977	0.965	<.001
3 class	−26,677.187	53,418.373	53,580.853	0.963	.008
4 class	−26,437.697	52,953.395	53,151.417	0.971	0.117

that best fit the data was selected using fit indices; second, the proportions of schools in each latent class and the classification probabilities of each school were determined; then, the differences between classes in passing rates of the Algebra I EOC assessment were determined. Table 4 shows model fit indices we used to determine the number of latent classes that best fit our data. We compared the fit indices from 2-, 3-, and 4-class models. We only interpreted the 3-class model results because the LMR rejected the 4-class model, and there were slight differences between the fit indices.

Table 5 shows differences in sizes for Class 1: low AN usage (46% of the sample), Class 2: medium AN usage (45%), and Class 3: high AN usage (9%). Schools in the first class had a mean of 3.655 student logins, 3.184 student video views, 9.172 teacher logins, 7.754 teacher video views, a ratio of 0.560 videos viewed per ordered workbook, and a ratio of 0.731 logins per workbook. We characterized schools in Classes 2 and 3 based on their relatively higher AN usage. For example, students from schools in the high AN usage class would log in approximately eight times more than students from schools in the low AN usage class. Table 6 shows the means and variances of usage for each latent class.

In the final step of the LPA, we estimated the difference between school passing rates across classes of AN usage. Figure 3 displays the increases between each interval of student usage. We obtained class average passing rates on the Algebra 1 EOC assessment of 0.633, 0.689, and 0.833 for Class 1, Class 2, and Class 3, respectively. Additionally, a chi-square χ^2 test of independence was conducted to determine whether each class was significantly different from the others. The mean differences between classes were all statistically significant at α = .05. Because Classes 1, 2, and 3 had increasing

Table 5. Class counts and proportions for three-class model.

Latent Classes	Counts	Proportions
1	545.091	.460
2	536.005	.452
3	103.903	.088

Table 6. Latent profile model results.

Latent Class	Indicator	Mean (*SE*)	Variance
1 class	Student logins	3.655 (0.138)	5.595
	Student video views	3.184 (0.178)	9.747
	Teacher logins	9.172 (0.850)	121.735
	Teacher video views	7.754 (1.481)	142.683
	Ratio of video viewed by workbook	.560 (0.070)	0.766
	Ratio of logins by workbook	.731 (0.084)	1.242
2 class	Student logins	10.492 (0.401)	40.402
	Student video views	13.043 (0.648)	117.971
	Teacher logins	41.993 (2.119)	2,321.228
	Teacher video views	73.415 (5.637)	40,374.367
	Ratio of videos viewed per workbook	9.381 (0.626)	153.970
	Ratio of logins per workbook	7.911 (7.911)	150.246
3 class	Student logins	24.656 (1.149)	40.402
	Student video views	38.673 (2.246)	117.971
	Teacher logins	63.672 (6.694)	2,321.228
	Teacher video views	215.482 (45.651)	40,374.367
	Ratio of video views per workbook	47.808 (4.174)	153.970
	Ratio of logins per workbook	31.594 (3.098)	150.246

Note. All means are statistically significant at $p < .0001$.

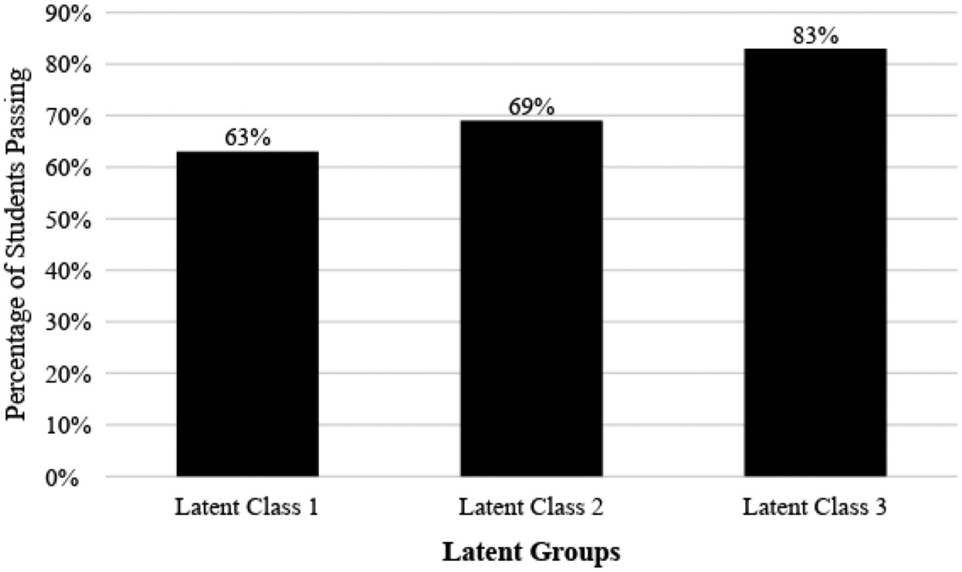

Figure 3. Mean school passing rates for levels of use.

levels of usage of AN, it can be concluded that higher levels of AN usage corresponds to higher passing rates in the Algebra I end-of-course exam.

Results of the school matching with a genetic algorithm to answer RQ3 showed that covariate equivalence with the 0.05 standard deviation cutoff was achieved for eight out of the 10 covariates. The covariates that did not meet the strict criterion were the mean Algebra 1 EOC assessment scale score in 2013 and the percentage of students eligible for free or reduced-price lunch. Following WWC guidelines for quasi-experimental studies, these two covariates were then used for regression adjustment in the estimation of treatment effects of schools receiving the AN workbook and teachers using the AN system. The expected difference in response of AN treatment and control schools matched by our genetic algorithm with the same value of PS was the ATE. The estimated ATE of schools receiving in-person teacher trainings, student and teacher workbooks, and instruction on the AN online learning environment on the Spring 2014 mean scale score was 2.91, $SE = 1.3$, $p = .02$, Hedges' $g = .26$. The effect on Spring 2014 passing rates was 5.46, $SE = 2.28$, $p = .02$, Hedges' $g = .28$. Therefore, the results indicate that, at the school level, teacher engagement with the resources provided by AN produced an increase of both mean scores and passing rates. More specifically, the ATE on the mean scale score indicates that schools whose teachers were AN users obtained student mean scores on the Algebra 1 EOC exam that were 0.26 standard deviations higher than matched schools that did not receive support. The ATE on passing rates indicates that schools whose teachers engaged with AN had passing rates on the Algebra 1 EOC that were 5.46% higher than matched schools that were not users of AN, which corresponds to a standardized difference of 0.28 standard deviations. Therefore, the effects of AN use at the school level are both statistically significant and substantively important according to the criteria of the What Works Clearinghouse (U.S. Department of Education, Institute of Education Sciences & What Works Clearinghouse, 2013).

Discussion

The results of the study found that AN was utilized by teachers in multiple ways to introduce, assess, and reinforce mathematical concepts but did not replace teachers' primary instruction—aligning with recommendations made in the field of mathematics education (NCTM, 2014). When integrating AN into their instruction, teachers' self-reports of use tended to favor both teacher-centered didactical configurations (Drijvers et al., 2010; Trouche, 2004) such as explain-the-screen, discuss-the-screen, and a student-centered work-and-walk-by approach—orchestrations identified in similar studies (e.g., Drijvers et al., 2013; Tabach, 2011). Teachers reported that they felt AN supported student-centered instruction by supplementing classroom instruction with alternative presentations, providing students and teachers with feedback on their progress toward algebra learning objectives and providing access to tools that can be tailored to students' individual needs. The design of AN provided the opportunity for students to engage in more individualized learning, which research has demonstrated to occur when classrooms provide one-to-one devices whereby students can access similar online resources (Zheng et al., 2016). The limited variety of media available on the AN site also supports previous findings that greater variation of media types in educational technology does not always result in significant gains in student performance (Means et al., 2009).

Teacher and student experiences in the present study indicate that online resources for mathematics, such as the one presented in this study, may be beneficial for schools hoping to make academic gains in standardized testing. Increased incorporation of AN into the classroom was related to improved scores on the Algebra I EOC, similar to the positive effect sizes found in several recent meta-analyses on the impact of technology on mathematics achievement (Cheung & Slavin, 2013; Li & Ma, 2011; Rakes et al., 2010). Analysis of teacher usage of AN also revealed the importance of professional development and teacher support on mathematics achievement scores, a frequently cited barrier to effective classroom technology integration (e.g., Penuel, 2006). Higher levels of usage and support at the school level were found to correspond with greater passing rates on the Algebra I EOC. Interactions between using the workbook, being integrated, participating in trainings and practice challenges, and using AN online were associated with higher passing rates on the Algebra I EOC exam —suggesting that schools looking to utilize similar resources might invest in ensuring teacher use over developing intricate features for online sites. These findings support previous studies demonstrating the importance of teacher professional development in the adoption and use of technology in the classroom (Lawless & Pellegrino, 2007; Matzen & Edmunds, 2007; Zheng et al., 2016).

A significant limitation of this study is that the effects of AN usage were estimated at the school level, so no inference can be made about individual students. The design of the study did not allow us to make connections between individual teacher use and student achievement, as the data sets were not connected. In addition, the covariates for eligibility for free and reduced-price lunch and Title I schools included in our propensity score model were included only to remove bias rather than identify relationships between socioeconomic status, teacher use, and achievement. Because they were not included in our research design, the results cannot speak to the ways that economic status may have influenced adoption of the technology. There is a need for research to go beyond a school-level analysis to determine how student achievement relates to the characteristics of the schools, teachers, and students using AN with particular attention to race, class, and socioeconomic status. Inclusion of these variables can create a more detailed picture of which contextual elements may or may not be impacting student achievement, such as how being an English language learner, having failed the Algebra I EOC exam in the previous year, or attending an underresourced school resulted in varied benefits from AN.

Besides focusing on the benefit of online learning environments for students in high-risk populations, future studies could also examine whether specific usage patterns over time (e.g., daily and weekly use and use just prior to the assessment) and type of didactical configurations (e.g., student-centered, teacher-centered) result in different effects on student achievement. The quantity and quality of open-ended items on the survey limited the descriptive detail of teacher usage and we were unable to link them to the Algebra I EOC data. It is possible that additional orchestration types were used by teachers and future studies might include interviews and classroom observations to provide greater insight into teacher practice. Finally, the impact of professional development provided for teachers utilizing AN remains an unexplored feature and future studies could analyze its association with successful implementation of AN in the classroom. This kind of support could potentially explain the sizable adoption rate and regular use of the tool by educators.

Implications

The results of this study suggest several implications for the design and implementation of online resources for mathematics instruction. First, the design of similar resources should provide teachers with various incorporation methods in the classroom including supplementation, remediation, and assessment. Second, teachers should focus on frequent, intentional integration of high-quality online resources that align with the teacher's own instructional objectives but that do not replace primary instruction. Third, school administrators should provide professional development and time to support teachers in understanding the breadth of instructional approaches a resource can offer to ensure it translates to improved mathematical understanding.

Conclusion

As teachers are increasingly asked to implement more technology in mathematics classrooms, it is critical that we understand how that technology is implemented and its impact on student learning. Even when technology tools are found to improve student learning, this is no guarantee that teachers will implement those resources in ways that promote mathematical learning. In this study, increased teacher usage of the online resource AN did relate to improved student performance. Teacher usage included both whole-group and individual instrumental orchestrations around AN that focused on supplementing their primary instruction. While the results are promising for teachers adopting online resources in similar ways, continued research on how to support teachers in orchestrating use of online resources in ways that promote meaningful mathematical activity is needed.

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References

Abadie, A., & Imbens, G. W. (2002). Simple and bias-corrected matching estimators for average treatment effects. *Technical Working Paper T0283*: NBER.

Abadie, A., & Imbens, G. W. (2006). Large sample properties of matching estimators for average treatment effects. *Econometrica*, *74*(1), 235–267. https://doi.org/10.1111/j.1468-0262.2006.00655.x

Artigue, M. (2002). Learning mathematics in a CAS environment: The genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International Journal of Computers for Mathematical Learning*, *7*(3), 245–274. https://doi.org/10.1023/A:1022103903080

Bakia, M., Mislevy, J., Heying, E., Patton, C., Singleton, C., & Krumm, A. (2013). *Supporting K–12 students in online learning: A review of online Algebra I courses*. SRI International.

Carter, C. M., & Smith, L. R. (2002). Does the use of learning logic in algebra I make a difference in algebra II? *Journal of Research on Technology in Education*, *34*(2), 157. https://doi.org/10.1080/15391523.2001.10782342

Cheung, A. C. K., & Slavin, R. E. (2013). The effectiveness of educational technology applications for enhancing mathematics achievement in K-12 classrooms: A meta-analysis. *Educational Research Review*, *9*(2013 June), 88–113. https://doi.org/10.1016/j.edurev.2013.01.001

Connell, M. L. (1998). Technology in constructivist mathematics classrooms. *Journal of Computers in Mathematics and Science Teaching*, *17*(4), 311–338. https://www.learntechlib.org/primary/p/47140/

Cook, C., Heath, F., & Thompson, R. L. (2000). A Meta-Analysis of Response Rates in Web- or Internet-Based Surveys. *Educational and Psychological Measurement*, *60*(6), 821–836. https://doi.org/10.1177/00131640021970934

Diamond, A., & Sekhon, J. S. (2013). Genetic matching for estimating causal effects: A general multivariate matching method for achieving balance in observational studies. *The Review of Economics and Statistics*, *95*(3), 932–945. https://doi.org/10.1162/REST_a_00318

Dick, T. P., & Hollebrands, K. F. (2011). *Focus in high school mathematics: Technology to support reasoning and sense-making*. NCTM.

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2009). *Internet, mail, and mixed-model surveys: The tailored design method*. (3rd ed.). Wiley.

Drijvers, P., Doorman, M., Boon, P., Reed, H., & Gravemeijer, K. (2010). The teacher and the tool: Instrumental orchestrations in the technology-rich mathematics classroom. *Educational Studies in Mathematics*, *75*(2), 213–234. https://doi.org/10.1007/s10649-010-9254-5

Drijvers, P. (2011). Teachers transforming resources into orchestrations. In *From text to 'lived' resources* (pp. 265-281). Springer, Dordrecht.

Drijvers, P., Godino, J. D., Font, V., & Trouche, L. (2013). One episode, two lenses. *Educational Studies in Mathematics*, *82*(1), 23–49. https://doi.org/10.1007/s10649-012-9416-8

Fishman, B., Penuel, W. R., Hegedus, S., & Roschelle, J. (2011). What happens when the research ends? Factors related to the sustainability of a technology-infused mathematics curriculum. *Journal of Computers in Mathematics and Science Teaching*, *30*(4), 329–353. https://www.learntechlib.org/primary/p/36145/

Guin, D., & Trouche, L. (1999). The complex process of converting tools into mathematical instruments: The case of calculators. *International Journal of Computers for Mathematical Learning*, *3*(3), 195–227.

Hannafin, R. D., & Foshay, W. R. (2008). Computer-based instruction's (CBI) rediscovered role in K-12: An evaluation case study of one high school's use of CBI to improve pass rates on high-stakes tests. *Educational Technology Research and Development*, *56*(2), 147–160. https://doi.org/10.1007/s11423-006-9007-4

Hardman, J. (2019). Towards a pedagogical model of teaching with ICTs for mathematics attainment in primary school: A review of studies 2008–2018. *Heliyon*, *5*(5), e01726. https://doi.org/10.1016/j.heliyon.2019.e01726

Hatch, J. A. (2002). *Doing qualitative research in education settings*. State University of New York Press.

Hennessy, S., Ruthven, K., & Brindley, S. (2005). Teacher perspectives on integrating ICT into subject teaching: Commitment, constraints, caution and change. *Journal of Curriculum Studies*, *37*(2), 155–192. https://doi.org/10.1080/0022027032000276961

Ho, D. E., Imai, K., King, G., & Stuart, E. A. (2007). Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference. *Political Analysis*, *15*(3), 199–236. https://doi.org/10.1093/pan/mpl013

Kurz, T. L. (2011). Discovering features of web-based algebraic tools via data analysis to support technology integration in mathematics education. *Journal of Curriculum and Instruction*, *5*(1), 85–100. https://doi.org/10.3776/joci.2011.v5n1p85-100

Lawless, K. A., & Pellegrino, J. W. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. *Review of Educational Research*, *77*(4), 575–614. https://doi.org/10.3102/0034654307309921

Li, Q., & Ma, X. (2011). A meta-analysis of the effects of computer technology on school students' mathematics learning. *Educational Psychology Review*, *22*(3), 215–243. https://doi.org/10.1007/s10648-010-9125-8

Mariotti, M. A. (2002). Influence of technologies advances in students' math learning. In L. D. English (Ed.), *Handbook of international research in mathematics education* (pp. 757–786). Lawrence Erlbaum.

Matzen, N. J., & Edmunds, J. A. (2007). Technology as a catalyst for change: The role of professional development. *Journal of Research on Technology in Education*, *39*(4), 417–430. https://doi.org/10.1080/15391523.2007.10782490

Means, B., Toyama, Y., Murphy, R., Bakia, M., & Jones, K. (2009). Evaluation of evidence-based practices in online learning: A meta-analysis and review of online learning studies. *US Department of Education*. https://repository.alt.ac.uk/629/1/US_DepEdu_Final_report_2009.pdf

Muthén & Muthén. (2013). *Mplus (Version 7.0)*.

Muthén, B. O. (2001). Latent variable mixture modeling. In G. A. Marcoulides & R. E. Schumacker (Eds.), *New developments and techniques in structural equation modeling* (pp. 1–33). Lawrence Erlbaum Associates.

National Council of Teachers of Mathematics. (2014). *Principles to action: Ensuring mathematical success for all*. NCTM.

National Council of Teachers of Mathematics (NCTM). (2000). *Principles and standards for school mathematics*. NCTM.

National Mathematics Advisory Panel. (2008). *Foundations for success: The final report of the national mathematics advisory panel*. U.S. Department of Education.

Njiku, J., Maniraho, J. F., & Mutarutinya, V. (2019). Understanding teachers' attitude towards computer technology integration in education: A review of literature. *Education and Information Technologies*, *24*(5), 3041–3052. https://doi.org/10.1007/s10639-019-09917-z

Nylund, K. L., Asparouhov, T., & Muthén, B. O. (2007). Deciding on the number of classes in latent class analysis and growth mixture modeling: A monte carlo simulation study. *Structural Equation Modeling*, *14*(4), 535–569. https://doi.org/10.1080/10705510701575396

Penuel, W. R. (2006). Implementation and effects of 1:1 computing initiatives: A research synthesis. *Journal of Research on Technology in Education*, *38*(3), 329–348. https://doi.org/10.1080/15391523.2006.10782463

Pierce, R., & Ball, L. (2009). Perceptions that may affect teachers' intention to use technology in secondary mathematics classes. *Educational Studies in Mathematics*, *71*(3), 299–317. https://doi.org/10.1007/s10649-008-9177-6

Presser, S., Couper, M. P., Lessler, J. T., Martin, E., Martin, J., Rothgeb, J. M., & Singer, E. (2004). Methods for Testing and Evaluating Survey Questions. *Public Opinion Quarterly*, *68*(1), 109–130. https://doi.org/10.1093/poq/nfh008

R Core Team. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. http://www.R-project.org/

Rakes, C. R., Valentine, J. C., McGatha, M. B., & Ronau, R. N. (2010). Methods of instructional improvement in algebra: A systematic review and meta-analysis. *Review of Educational Research*, *80*(3), 372–400. https://doi.org/10.3102/0034654310374880

Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, *70*(1), 41–55. https://doi.org/10.1093/biomet/70.1.41

Rubin, D. B. (2007). The design versus the analysis of observational studies for causal effects: Parallels with the design of randomized trials. *Statistics in Medicine*, *26*(1), 20–36. https://doi.org/10.1002/sim.2739

Rubin, D. B. (2008). For objective causal inference, design trumps analysis. *The Annals of Applied Statistics*, *2*(3), 808–840. https://doi.org/10.1214/08-AOAS18

Shyu, H. Y. C. (2000). Using video-based anchored instruction to enhance learning: Taiwan's experience. *British Journal of Educational Technology*, *31*(1), 57–69. https://doi.org/10.1111/1467-8535.00135

Slavin, R. E., Lake, C., & Groff, C. (2009). Effective programs in middle and high school mathematics: A best evidence synthesis. *Review of Educational Research*, *79*(2), 839–911. https://doi.org/10.3102/0034654308330968

Tabach, M. (2011). A mathematics teacher's practice in a technological environment: A case study analysis using two complementary theories. *Technology, Knowledge and Learning*, *16*(3), 247–265. doi:10.1007/s10758-011-9186-x

Trouche, L. (2004). Managing the complexity of human/machine interactions in computerized learning environments: Guiding students' command process through instrumental orchestrations. *International Journal of Computers for Mathematical Learning*, *9*(3), 281. https://doi.org/10.1007/s10758-004-3468-5

What Works Clearinghouse. (2013). Procedures and standards handbook (Version 3.0). Washington, DC: U.S. Department of Education. Retrieved from http://ies.ed.gov/ncee/wwc/Docs/referenceresources/wwc_procedures_v3_0_standards_handbook.pdf

Vermunt, J. K. (2010). Latent class modeling with covariates: Two improved three-step approaches. *Political Analysis*, *18*(4), 450–469. https://doi.org/10.1093/pan/mpq025

Wenglinsky, H. (1998). *Does it compute? The relationship between educational technology and student achievement in mathematics*. Educational Testing Service.

Willis, G. B. (1999). Cognitive Interviewing: A "How To" Guide. Research Triangle Institute.

Ysseldyke, J., Spicuzza, R., Kosciolek, S., Teelucksingh, E., Boys, C., & Lemkuil, A. (2003). Using a curriculum-based instructional management system to enhance math achievement in urban schools. *Journal of Education for Students Placed at Risk*, *8*(2), 247–265. https://doi.org/10.1207/S15327671ESPR0802_4

Zheng, B., Warschauer, M., Lin, C. H., & Chang, C. (2016). Learning in one-to-one laptop environments: A meta-analysis and research synthesis. *Review of Educational Research*, *86*(4), 1052–1084. https://doi.org/10.3102/0034654316628645