Implementing an adaptive intelligent tutoring system as an instructional supplement

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Implementing an adaptive intelligent tutoring system as an instructional supplement

Blended learning is an instructional model that combines teacher instruction with online or digital learning. It can also help to enable more personalized approaches by freeing some of the teacher's time, which otherwise would have been used to provide whole-class instruction, so they can focus on individual students while other students are using technology (Pane et al., 2017). Some empirical evidence suggests that technology-based curricula can help personalize students' learning experiences and facilitate the development of mathematical skills (Koedinger et al., 2000; Ritter et al., 2007; Schacter, 1999; Wenglinsky, 1998). A meta-analysis conducted by Means et al. (2010) estimated that interventions combining online and face-to-face instruction in a blended-learning approach appeared to produce more positive effects than either online or face-to-face instruction alone. Subsequently, more evidence has been emerging from rigorous studies on learning systems operating in classroom settings, and the evidence of efficacy has been mixed (Morgan & Ritter, 2002; Pane et al., 2010; 2014). These studies highlighted some of the challenges implementing the systems in classrooms, which may contribute to a lack of consistent positive effects on student learning.

Literature on blended learning stresses the importance of (1) intentional integration of the two modalities to create an integrated learning experience and (2) effective professional development on how to divide the instructional role between teacher and technology (Bailey et al., 2013; Bowyer & Chambers, 2017; Ferdig & Kennedy, 2014; Patrick et al., 2013; Watson et al., 2013). Yet, robust research on blended learning implementation is sparse, with some authors calling on future research to develop better ways to measure implementation. Both Karam et al. (2016) and Snodgrass, Rangel et al. (2015) identified the need to investigate dosage (how much of the intervention is needed to have an effect) and fidelity (whether the intervention is implemented as intended) as important aspects of blended learning implementation. Karam et al. (2016) extended this by suggesting that, irrespective of implementation fidelity, it is important to understand how the intervention changes instructional practices. Bowyer and Chambers (2017) and Baily et al. (2013) echo the importance of examining teaching, learning, and instructional design. Others discuss the importance of learning analytics (data collected by the software) to gain a deeper insight into the implementation of digital innovations and their effects on teaching and learning. Learning analytics can enable evaluators to examine how a user interacts with various components and weigh this along with dosage to gain insight into student engagement with the technology and the impact of specific components (Snodgrass Rangel et al., 2015). The present study builds on many of these recommendations to help enrich the field's understanding of blended learning implementation.

Present study

This article studies the implementation of ALEKS (Assessment and LEarning in Knowledge Spaces) in a blended-learning model. ALEKS is an intelligent tutoring system for mathematics designed to be integrated with existing curricula. This is the first rigorous experimental evaluation of ALEKS in K-12 in-school settings, and the first to gather extensive implementation data. We selected ALEKS for this study because it was in widespread use in high school classrooms and had shown promise for improving student achievement but was not yet subjected to a rigorous test of efficacy for that use.

Prior research on ALEKS generally relied on non-causal methods or examined its use in other contexts. Encouraging effects have been reported for K-12 students in afterschool programs; for post-secondary students; and for adult learners (Ahlgren & Harper, 2009; Baxter & Thibodeau, 2011; Carpenter & Hanna, 2006; Craig et al., 2014; Hu et al., 2012; Hu et al., 2013; Huang et al., 2016). Craig et al. (2013) examined the relationship between student mindset and engagement with ALEKS. A study by the developers found that the system showed promise in improving algebra readiness (ALEKS Corporation, 2011) but did not focus on implementation. Two middle school studies by Sullins et al. (2013) found positive correlations between usage and student achievement, although it is unclear how online and traditional learning were blended in that implementation.

Our study examined the use of ALEKS as a supplement to an existing high school algebra curriculum, as part of a randomized controlled trial studying its efficacy for improving achievement. Approximately 2,500 students were randomly assigned to use ALEKS as a supplement to the district's algebra curriculum, or a control group that just used the algebra curriculum. The details of the study design and results of the outcomes study will be reported in a separate publication. Briefly, the study found no significant effect on an end-of-course algebra exam. The focus of this article is to address gaps in the research literature on implementing intelligent, adaptive learning systems in a blended learning environment (Bailey et al., 2013; Bowyer & Chambers, 2017; Karam et al., 2016; Snodgrass, Rangel et al., 2015). As such, it focuses on the classrooms in the experiment that were assigned to use ALEKS.

The implementation study is guided by the following research questions: (1) What models did teachers use to integrate ALEKS into instruction? (2) To what extent did implementation adhere to the core aspects of the ALEKS design? and (3) To what extent did blended use of ALEKS enable personalized instruction?

Basic overview of the ALEKS experience for students and teachers

Upon first entry into the ALEKS system, the student takes a diagnostic (or placement) assessment that seeks to uncover what the student already knows or does not know. The result of this assessment is displayed to students. Students view the algebra topics already mastered and those not yet mastered. ALEKS curates a customized path of "ready to learn" algebra topics for the student because they have mastered the necessary prerequisites. The student can choose any topic from among the ready-to-learn topics for the ALEKS course. The ALEKS algebra course includes more than 350 topics, some of which reflect prerequisite algebra topics. This mechanism thus implements a mastery-based approach to progression through the software, while still giving students some choices of what to work on.

Theoretically, this ready-to-learn, mastery-based strategy could be beneficial compared to typical classroom instruction where all students cover material at the same pace regardless of whether they understand key prerequisites. Using this strategy, students can fill in gaps of understanding, work a zone of proximal development (Vygotsky, 1930–1934/1978), experience success, and build a better foundation for learning more difficult topics. This can potentially lead to more robust learning. However, if students spend a substantial amount of time filling in prerequisite gaps, their learning, even if substantial, might not align with the algebra curriculum—thus posing a tension known as the mastery versus coverage dilemma (Slavin, 1987). Implementing ALEKS as a supplement may ease the tension somewhat because teachers can cover the required course content and standards while ALEKS provides students with personalized instruction to support increased mastery.

ALEKS personalizes student experiences using an algorithm based on the Knowledge Space Theory. The main instructional activity within ALEKS is solving problems in a constructed-response environment that uses realistic input tools and avoids multiple-choice questions to help ensure that the student demonstrates mastery. The student receives immediate feedback and has access to step-by-step explanations (essentially, worked examples) of how to solve problems. Mathematical terms and concepts that appear in the problems and explanations are hyperlinked to a central glossary. After learning a topic, the student returns to an updated ALEKS pie to choose the next topic to learn. Periodic progress assessments are used to confirm retention, and if the student no longer demonstrates mastery of a previously-completed topic it is returned to the "need to learn" portion of the pie. The student continues to participate in this process of learning and assessment until they reach their learning goals. The assumed learning goal in ALEKS is 100 % completion of the course, but instructors can set intermediate goals for their students.

For teachers, ALEKS provides a learning management system to support class administration, instruction, customizing course content, and progress monitoring. Various reports can be used as part of a data-driven, decision-making process to guide their work, both during whole-class instruction and for small group or individualized instruction while other students are using the software. For example, ALEKS can identify topics that require additional focus for the whole class or identify groups of students who are all ready to learn the same topics. Teachers can work with these groups or assign them to work collaboratively using ALEKS-generated worksheets. Teachers can also use the software to create homework assignments and quizzes.

Methods

Study Design and Participants

The study was implemented in a large, urban school district in the mid-Atlantic region, where levels of mathematics proficiency measured by the 2014 state algebra I assessment were well below state averages, with performance gaps by race/ethnicity. Nine high schools participated in the study for two consecutive school years, with different cohorts of algebra students each year, but, the same teachers to the extent possible given teacher turnover. The two-year implementation allowed for possible improvement in implementation after teachers gained experience with ALEKS. The study actually took place over three years because some schools entered the study later.

Table 1 summarizes characteristics of the participating schools. Five offered open admission to students coming from middle schools within a feeder region; students from outside the feeder region could apply for admission. The other four schools required all students to apply, with admission criteria related to attendance, punctuality, behavior, grades, and standardized test scores.

The vast majority of students enrolled in study classes were non-white and about half of the students in study classes were female (Table 1). Most students (66%) were economically disadvantaged. Fourteen percent of students had an Individualized Education Plan and very few students were limited English proficient. The vast majority of students enrolled in study

Table 1 Characteristics of participating students by study school

School	Participating School Years	School Admissions Criteria	Number of Students	Non-white (%)	Female (%)	Economic Disadvantage (%)	Disability (%)	Limited English Proficient (%)
S01	2014-15 2015-16	Yes	208	99	56	77	16	2
S02	2014-15 2015-16		209	100	36	71	36	2
S03	2014-15 2015-16		487	85	43	62	7	9
S04	2014-15 2015-16		291	100	45	71	14	1
S05	2014-15 2015-16	Yes	243	89	58	53	5	3
S06	2014-15 2015-16	Yes	214	99	33	71	23	2
S07	2015-16 2016-17		354	75	44	66	9	10
S08	2015-16 2016-17	Yes	280	80	59	51	8	2
S09	2015-16 2016-17		208	99	56	80	24	16
Overall			2494	90	47	66	14	1

classes were enrolled in 9th or 10th grade. On the of 8th grade state mathematics assessment—the assessment used as a pretest—the average study student scored at about the 23rd percentile statewide.

With one exception, all participating teachers were veteran, with more than 5 years experience teaching mathematics. Of the 38 teachers, three had limited exposure to ALEKS prior to the study. No teachers implemented personalized learning previously; a few teachers occasionally used software or applications to supplement the district curriculum.

The implementation model in this study involved using ALEKS as a blended learning supplement to those existing district materials, including a scope and sequence plan. Teachers received the initial training from ALEKS staff—employees of the software developer focused on training and supporting implementation—prior to implementing the software. Training provided an overview of the software features for students and teachers, and covered guidelines on implementation, including specific information on how long and how often students should be working in ALEKS. It also provided instruction in how to read ALEKS reports to find key indicators of strengths, weaknesses, and progress, and best practices. In the 2015–16 and 2016–17 school years, teachers received monthly in-person visits from ALEKS staff.

Data collection

The research team conducted three site visits per year to all classes in the study. The visits collected information on instruction, student engagement and ALEKS implementation. The first site visit occurred in the fall, approximately one month after schools deemed course enrollment stable. The third site visit generally occurred in the weeks before the state assessment, and the second visit was about halfway between the other two. Each site visit included observations of instruction and teacher interviews.

We designed classroom observation and teacher interview protocols, informed by an implementation checklist used by ALEKS staff for their implementation support visits, material covered during teacher training sessions, and protocols used in previous studies (e.g. Augustine et al., 2016; Karam et al., 2016). The checklist covers several points the company believes are important for the software to work effectively in a blended environment, such as ensuring the algebra curriculum is appropriate given the student's preparation, use by students of notebooks, and use by teachers of reporting features to monitor progress and make instructional decisions. At teacher trainings, ALEKS staff recommended each student use the software for at least two hours per week, or at least 60 hours over the school year. Teachers were encouraged to consider a variety of models for how they might integrate ALEKS into their course to accomplish usage and blended learning guidelines. An online repository contributed to by teachers who had used ALEKS previously also offered some possibilities.

Observation domains included time on task, student engagement, indicators of general instructional quality, and indicators of quality for implementation of ALEKS. We reviewed the instrument with ALEKS staff and piloted it in classes that did not participate in the study. During the pilot, we refined the protocol and established inter-rater agreement of 100% on each item. When two raters did not initially agree, we discussed the item and arrived at consensus. Raters continued to observe classes until achieving 100% agreement in an observation. After each observation of a study class, one rater reviewed the running record of instruction and ratings for agreement. The interview protocol covered curriculum, planning, instructional practices, and support received for implementing the algebra I curriculum and ALEKS. Interviews were semi-structured and conducted in-person.

ALEKS provided student-level logs of software usage. In this paper we summarize usage time (in hours) for students enrolled in ALEKS classes, and classroom level medians of usage. Other, more complex analyses of the log data are planned for other publications.

Analytic approach

Given the flexibility offered to teachers in how to use ALEKS, as well as lack of prior research on ALEKS implementation, we developed a framework for analyzing implementation (Dane &

Scheider, 1998; Dusenbury et al., 2003; Carroll et al., 2007) in relation to the three research questions, reiterated here: (1) What models did teachers use to integrate ALEKS into instruction? (2) To what extent did implementation adhere to the core aspects of the ALEKS design? and (3) To what extent did teachers use key features of ALEKS to facilitate personalized instruction? We specified these research questions to address the gaps in literature on implementation in a blended learning environment, which include adherence to the core components of an intervention, dosage, and designs for blending instruction. The research questions were also intended to identify the components that may be essential to the intervention if ALEKS was found to have a positive effect on student outcomes. Analysis made use of data gathered from observations, interviews, and software logs. Themes were identified through an iterative process, using Dedoose software to assist with coding the data and identifying implementation themes. The analytic approach for each research question follows:

Implementation models for integrating ALEKS into instruction. We examined teacher-developed implementation models and plans for how both teacher and software would deliver instruction. We conducted a thematic analysis to identify contextual factors that affected enactment of the model.

Adherence to core aspects of the ALEKS design. Using information from teacher trainings, interviews with ALEKS implementation staff, the implementation checklist, and software logs, we developed a rubric for capturing four key aspects of the ALEKS design, shown in Table 2. We rated adherence to using a 3-point Likert scale of no adherence (0), partial adherence (1), or full adherence (2) for each of the four key aspects of the ALEKS design. There was a total possible score of 8 for adherence to the core aspects of the ALEKS design.

Extent to which ALEKS enabled personalized instruction. As discussed earlier, the literature on blended and personalized learning says that teacher and computer-led instruction should provide an integrated learning experience. We identified five discrete domains after

Table 2 Rubric for adherence to core aspects of ALEKS design

Item	Data Sources	No adherence (0)	Partial adherence (1)	Full adherence (2)
Student Placement in the Correct ALEKS Course	Teacher interviews; classroom observations	Few students are placed in the correct ALEKS course	Most students are placed in the correct ALEKS course	All students are placed in the correct ALEKS course
Use of ALEKS problem-solving tools only	Teacher interviews; classroom observations	Students almost always used tools other than those intended by ALEKS	Students sometimes used tools other than those intended by ALEKS	Students used only tools provided by ALEKS
Use of student pathways in ALEKS determined by the algorithm	Teacher interviews	Overrode the personalized student pathway majority of year	Overrode the personalized student pathway for a portion of the year	Students used the ALEKS personalized student pathway exclusively
Hours of usage of ALEKS	Software logs	0-29 hours	30-59 hours	60 or more hours

Table 3 Rubric for extent to which ALEKS enabled personalized instruction

Domain	Not at all integrated (0)	Somewhat integrated (1)	Integrated (2)
Use of ALEKS Performance Data	Teacher did not look at ALEKS data	Teacher looked at student or class-level reports of usage and/or progress	Teacher used student or class-level ALEKS data when planning instruction (e.g., shortening or skipping instruction where the majority of students demonstrated mastery)
Incorporation of ALEKS in Course Grade	ALEKS was not part of the course grade	Student usage hours drove students' ALEKS grade	Student growth or progress drove students' ALEKS grade (i.e. mastery-based grade)
Integration of Instructional Content	Students selected ready-to-learn topics without guidance from the teacher	Teacher directed students to ready-to-learn topics that aligned with teacher-led instruction	Teacher used customized materials to deliver small group or personalized instruction to students; teacher prioritizing ready-to-learn topics related to classroom instruction
Differentiated Instructional Practices	Teacher used the same practices and resources as non-ALEKS classes to differentiate instruction	Teacher used ALEKS data to create small groups or identify standards for individual instruction but used the same resources as non-ALEKS classes	Teacher used customized ALEKS materials to deliver small group or personalized instruction to students
Monitoring Student Progress	Teacher did not engage when students used ALEKS	Teacher walked around the room; directed students to complete problems or stay on task; met with students one-on-one when they had questions; students used ALEKS Notebook	Teacher reviewed reports of active student engagement while students used ALEKS; met with students one-on-one to assess understanding of ALEKS problems; teacher reviewed ALEKS notebook

reviewing ALEKS implementation documents, participating in trainings, and reviewing implementation strategies submitted to an online repository by teachers where ALEKS provided opportunities to inform teacher-led instruction (Table 3). Opportunities for teachers to inform ALEKS instruction were constrained by the fact that most ALEKS instructional decisions are shaped by internal software analytics. In each domain, the scale illustrates practices that are either not integrated (0), somewhat integrated (1), or integrated (2). Ratings for each domain were summed to reach an overall score for personalized instruction, with maximum of 10.

Limitations

The study relies on classroom observations and teacher interviews, which have a variety of limitations. We observed classrooms only three times during the year, offering just a glimpse of teachers' everyday instructional practices. In interviews teachers reported on their practices between classroom observations to help fill in the gaps. Although the two sources corroborated each other, both are vulnerable to biases. Teachers knew in advance when we would appear and may have acted differently those days. Self-report data from interviews can suffer from a variety of problems, including poor recall or social desirability bias. Our observation rubrics were used for the first time in this study and not previously validated.

Results

We describe implementation for each element: (1) Implementation models for integrating ALEKS into instruction; (2) Adherence to core aspects of the ALEKS design; and (3) Extent to which ALEKS enabled personalized instruction.

Implementation models for integrating ALEKS into instruction

Implementation and integration. Table 4 summarizes the variation in implementation by identifying three broad implementation models: (1) Integrated—teacher integrated ALEKS into instruction, (2) ALEKS— teacher taught using ALEKS only, or (3) Teacher-led—teacher did not integrate ALEKS at all. The study anticipated use of an integrated model where teacher delivered instruction with ALEKS but 38% of classes used only one modality. In nine (23%) classes, teachers

Table 4 Implementation models and integration approach, and usage by class

Study Year	Class	Implementation Model	Integration Approach	Median Usage
1	S01_C01	ALEKS		41
1	S01_C02	ALEKS		41
1	S02_C03	Teacher-led		3
1	S02_C04	Integrated	2-3 days per week	10
1	S03_C05	Integrated	2-3 days per week	30
1	S03_C06	Integrated	ALEKS only for several months; 2-3 days per week	24
1	S03_C07	Integrated	ALEKS only for several months; 2-3 days per week	19
1	S03_C08	Teacher-led		2
1	S04_C09	Teacher-led		0
1	S04_C10	Teacher-led		0
1	S05_C11	Integrated	2-3 days per week	12
1	S05_C12	Integrated	Outside of class	14
1	S06_C13	ALEKS		26
1	S06_C14	ALEKS		22
2	S01_C15	Teacher-led		9
2	S01_C16	Teacher-led		2
2	S09_C17	Integrated	3-4 days per week	6
2	S09_C18	Integrated	2-3 days per week	1
2	S07_C19	Teacher-led		0
2	S07_C20	Integrated	2-3 days per week	0
2	S02_C21	ALEKS		18
2	S02_C22	Integrated	2-3 days per week	6
2	S03_C23	Integrated	2-3 days per week	21
2	S03_C24	Integrated	2-3 days per week	15
2	S03_C25	Teacher-led		3
2	S03_C26	Integrated	2-3 days per week for a month; teacher-led remainder of year	24
2	S04_C27	Teacher-led		0
2	S04_C28	Integrated	2 days per week	17
2	S05_C29	Integrated	2 days per week	18
2	S05_C30	Integrated	Daily small group teacher-led instruction	75
2	S06_C31	Integrated	2-3 days per week	24
2	S06_C32	Integrated	2-3 days per week	21
2	S08_C33	Integrated	When time allowed	11
2	S08_C34	Integrated	2-3 days per week	17
3	S09_C35	Integrated	1 day per week	0
3	S09_C36	Integrated	2 days per week	3
3	S07_C37	Integrated	2 days per week	5
3	S07_C38	Integrated	2 days per week	4
3	S08_C39	ALEKS		79
3	S08_C40	Integrated	When time allowed	12

S School, *C* Class

assigned students to complete the diagnostic assessment in ALEKS but almost never assigned subsequent use; instruction focused only on the existing algebra curriculum. At the other end of the spectrum, six (15%) classes used ALEKS almost exclusively to deliver instruction. Teachers in five of these six classes identified the low levels of readiness for algebra I as a primary reason. According to one teacher, “The highest level of mastery [on the ALEKS diagnostic] was 11%. This really shows students are not ready for algebra. They need as much time as possible in ALEKS. I’m using [ALEKS] to build up their basic skills so that they’ll be at a higher level of readiness [for the algebra curriculum].” Nearly all teachers using this model planned to eventually deliver an integrated learning experience but never accomplished that goal.

In the other 25 (63%) classes, teachers implemented an integrated model where students received instruction from both the teacher and software. Approaches for implementing the integrated model varied. In two of the 25 classes, teachers reported using ALEKS in class when time allowed, largely when teacher-led instruction ended early. One teacher assigned nearly all ALEKS use to occur outside of class and supported such usage by offering students access to computers before school daily and during homeroom twice per week. The majority (88%) of teachers using an integrated model assigned ALEKS 2 to 3 days per week in class.

Challenges to integrated usage models. Across all three models, teachers identified two key barriers to implementation. First, as illustrated in Table 5, class length ranged from 42 to 90 min. Teachers felt there was insufficient time to cover the algebra course prior to the state end-of-course exam, describing the scope and sequence as aggressive and ambitious for the most prepared students in the district. Teachers of classes shorter than one hour (26 of 40) were most concerned about instructional time. Second, teachers of the majority of classes (36) described students as largely unprepared for algebra. Students reportedly struggled with foundational mathematics skills (i.e. decimals, regrouping). Even though teachers sometimes incorporated remedial instruction in their algebra lessons, they did not “give up” much instructional time to deliver remedial instruction. They viewed allocating class time to ALEKS as "giving up" time for algebra instruction.

Table 5 Instructional minutes by school and study year

School	Average length of class (minutes)	Average instructional minutes per week	Recommended ALEKS usage per week	Remaining in-class instructional minutes per week
S01	45	225	120	105
S02	90	450	120	330
S03	54	270	120	150
S04	47	235	120	115
S05	47	235	120	115
S06	89	445	120	325
S07	90	450	120	330
	45	225	120	105
S08	80	400	120	280
S09	42	210	120	90

Several teachers suggested that an additional math class would provide sufficient time to integrate both modes of instruction. A review of implementation strategies submitted to the ALEKS repository by teachers revealed that most integrated models relied on additional instructional time to implement ALEKS, either by adding a supplemental math class for the year or several times per week.

Adherence to core aspects of the ALEKS design

According to ALEKS staff, four key aspects of the ALEKS design are important to optimize its ability to maximize learning: (a) Placing students in the correct ALEKS course; (b) Restricting the use of problem solving tools (e.g. calculators) to those offered within the ALEKS system; (c) Allowing the ALEKS algorithm to determine student pathways through material; and (d) Sufficient use of ALEKS, or dosage. Analysis of adherence to these principles excludes classes that did not use ALEKS and thus reflects observations and interviews of 31 classes. Table 6 presents item-level and overall adherence scores for each class. We rated adherence to using a 3-point Likert scale of no adherence (0), partial adherence (1), or full adherence (2).

Table 6 Adherence to the core aspects of the ALEKS design by class

Class	Student placement in the correct ALEKS course	Use of ALEKS problem-solving tools only	Use of student pathways in ALEKS determined by the algorithm	Meets recommended hours of usage of ALEKS	Total adherence
S01_C01	2	0	2	1	5
S01_C02	2	0	2	1	5
S02_C04	2	0	2	0	4
S03_C05	2	0	1	1	4
S03_C06	2	0	2	0	4
S03_C07	2	0	2	0	4
S05_C11	2	0	2	0	4
S05_C12	2	0	2	0	4
S06_C13	0	0	2	0	2
S06_C14	0	0	2	0	2
S09_C17	2	0	2	0	4
S09_C18	2	0	2	0	4
S07_C20	2	0	2	0	4
S02_C21	2	0	2	0	4
S02_C22	2	0	2	0	4
S03_C23	2	0	0	0	2
S03_C24	2	0	2	0	4
S03_C26	2	0	2	0	4
S04_C28	2	0	2	0	4
S05_C29	2	0	2	0	4
S05_C30	2	0	2	2	6
S06_C31	2	0	2	0	4
S06_C32	2	0	2	0	4
S08_C33	2	0	2	0	4
S08_C34	2	0	2	0	4
S09_C35	2	0	2	0	4
S09_C36	2	0	2	0	4
S07_C37	2	0	2	0	4
S07_C38	2	0	1	0	3
S08_C39	2	0	2	2	6
S08_C40	2	0	2	0	4

S School, *C* Class

Placement in the correct ALEKS course. As a standard practice, ALEKS staff monitor diagnostic assessment and progress reports to assess if individual students are placed in the appropriate ALEKS course. ALEKS recommends moving a student to a lower-level course if diagnostic assessment shows less than 15% mastery or if progress is insufficient. In the first study year, ALEKS staff contacted teachers of four classes to discuss moving many of their students to the High School Preparation for Algebra course. Two of the four teachers agreed. The two who declined believed exposure to the algebra content, even if too difficult, would better prepare students for the state assessment.

ALEKS staff conducted a review of diagnostic assessment, usage, and progress data before the second year of the study. They determined the vast majority of students would have benefitted by using the High School Preparation course. As a result, ALEKS staff redesigned the course sequence for 2015–2016 school year. ALEKS placed all students in the High School Preparation course in the first semester and promoted them to the Algebra course once they mastered between 50 and 70% of the High School Preparation content. If they did not meet this criterion, students were promoted in the second semester. Overall, students in 29 of 31 classes (94%) were placed in the correct course.

Use of ALEKS problem-solving tools only. ALEKS assumes that students only use a calculator within the software and only when it is provided by the program, and that otherwise students solve problems on their own. In every class, students used a non-ALEKS calculator. In many classes, teachers distributed graphing calculators and students opted to use them. In interviews, some teachers reported encouraging students to use graphing calculators because they were permitted during the state assessment. In classes where teachers did not distribute graphing calculators, we observed students using calculators available on Chromebooks or smart phones. We also observed individual students using websites to solve ALEKS problems in a few classes each year. Students entered the ALEKS problem, received a solution, then entered the solution into ALEKS. No classes adhered to this core design aspect.

Use of ALEKS student pathways. The ALEKS algorithm personalizes students' experiences within the software and generates printable material (e.g., worksheet) for offline use. ALEKS staff strongly discouraged teachers from overriding this. Yet, teachers of 3 classes reported overriding personalized pathways to assign all students the same problems. Two teachers assigned all students the same content for approximately one month. The third teacher assigned the same content most of the year. Thus, 90% of classes adhered to personalized student pathway designed by ALEKS, two classes partially adhered, and one class did not adhere.

Even though the majority of teachers adhered, many expressed a desire to "override the algorithm" so that work in ALEKS would address the topics covered during teacher- led instruction. Teachers were concerned about the disconnect between the ready-to-learn topics in ALEKS and the current content being covered in the class. If more teachers had the skill to circumvent the ALEKS pathway, they might have done so. Adherence to the pathway was high, but best described as reluctant.

Recommended versus actual ALEKS usage. All teachers that adopted models that included ALEKS usage (ALEKS-only and integrated) aimed to design an implementation approach that met or exceeded the recommended usage. Despite these intentions, actual class-level usage was significantly below 60 h. As shown in Table 4, the median level of usage exceeded 60 h in only two classes (S08_C39 and S05_C30). The next highest median usage was 41 h. Of the four classes with the highest usage levels, three delivered ALEKS-only instruction. In the class meeting recommended usage with an integrated approach, all teacher-led instruction occurred individually or in small groups while the rest of the class used ALEKS. Most classes using an integrated model had less than 30 median usage hours, a level significantly below the recommended 60 h. Table 7 summarizes the number of classes adopting each implementation model, and the resulting levels of ALEKS use, calculated as the average of each class's median student usage hours. Usage was well below the recommended

60 h in each model.

Table 7 Summary of implementation models and average of classroom median usage by model

Model	Number of classes	Average class median usage hours
Teacher-led	9	2
ALEKS	6	38
Integrated	25	16

Observations highlighted student engagement as a challenge to achieving recommended usage levels. When using computers, the vast majority of students did not consistently stay on task. Most students intermittently worked in ALEKS and engaged in off-task behaviors, such as conversing with peers, or browsing the Internet. In only 2 of 31 classes were the vast majority of students on task across observations. ALEKS distinguishes between simply logging in and "active" engagement. Thus, usage time reflects students' active ALEKS use, and can depart from teachers' allocation of instructional time.

Teachers also identified student attendance as a barrier to robust usage. Most teachers reported that a core group of students regularly attended class and the remainder attended erratically. The size of the core group of students ranged from very small to approximately half of the class. Only one school reported that a majority of students regularly attended. Students with irregular attendance may have missed multiple in-class opportunities to use ALEKS and, according to teachers, were unlikely to use ALEKS outside of class. Observations aligned with teacher reports of low attendance.

Overall, there was mixed adherence to the four core design aspects of ALEKS (Table 6). In the vast majority of classes (94%) students were placed in the correct ALEKS course and progressed according to their ready-to-learn pathway. Adherence was very low in students' use of ALEKS-only tools to solve problems and median usage hours. As shown in Table 8, total adherence scores were the same for both ALEKS-only and integrated models, but there was some variation in adherence of components. Classes with an integrated model had low levels of usage while classes with an ALEKS-only model had partial adherence to usage levels.

Table 8 Average adherence to the core aspects of the ALEKS design by domain and model

Model	Number of classes	Student placement in the correct ALEKS course	Use of ALEKS problem-solving tools only	Use of student pathways in ALEKS determined by the algorithm	Meets recommended hours of usage of ALEKS	Total average adherence
ALEKS	6	1	0	2	1	4
Integrated	26	2	0	2	0	4

Extent to which ALEKS enabled personalized instruction

Our rubric provided ratings for ALEKS classes in five domains derived from ALEKS documents and trainings that related to how integrated instruction can enable personalized learning (Table 9). This analysis included all classes using ALEKS (n = 31).

Using ALEKS performance data. All teachers reported knowledge of the data available in ALEKS and received training in interpreting it. Yet, nearly 30% of teachers whose classes used ALEKS did not review available student or class-level data. Most teachers (59%) did review ALEKS reports at least weekly to assess usage hours, but only 4 (13%) considered ALEKS data when planning their teacher-led instruction, a necessity to get a rating of fully integrated. One of those 4 teachers used data to identify topics that did not require teacher-class instruction, and 3 of them used ALEKS data to create small groups for teacher-led instruction.

Incorporating ALEKS data into course grade. Twenty-nine of 31 teachers incorporated ALEKS data into students' grades, though ALEKS's weighting was not high (10% to 20%) in most classes. Some classes gave extra credit for ALEKS usage and qualified as somewhat integrated. All of the teachers who incorporated ALEKS in students' course grades reported using the Time and Topic report as the primary data source for grading, which implied that usage hours drove the ALEKS portion of grades. No classes met a rating of fully integrated, which required use of mastery and mastery rate goals (e.g., mastered topics per week).

Integrating instructional content. This domain considered the extent to which computer and teacher-led instruction informed each other. Ready-to-learn topics in ALEKS were personalized to students, whereas standards for instruction in the existing curriculum were course wide. In all but two classes, teachers did not integrate the two. Teachers described ALEKS and teacher- led instruction as independent.

Table 9 Extent to which ALEKS enabled personalized instruction by domain and class

Class	Use of student performance data	Incorporation of ALEKS in student grade	Alignment of instructional content	Differentiated instructional practices	Monitoring student progress	Total average integration
S01_C01	1	1	0	0	2	4
S01_C02	1	1	0	0	1	3
S02_C04	0	1	0	0	1	2
S03_C05	1	1	0	0	1	3
S03_C06	0	1	0	0	1	2
S03_C07	0	1	0	0	1	2
S05_C11	2	1	1	2	2	8
S05_C12	0	1	0	0	0	1
S06_C13	1	1	0	0	1	3
S06_C14	1	1	0	0	1	3
S09_C17	1	1	0	0	1	3
S09_C18	0	1	0	0	0	1
S07_C20	1	1	0	0	1	3
S02_C21	0	1	0	0	0	1
S02_C22	1	1	0	0	1	3
S03_C23	1	1	0	0	1	3
S03_C24	1	1	0	0	1	3
S03_C26	0	0	0	0	0	0
S04_C28	0	1	0	0	0	1
S05_C29	1	1	0	0	1	3
S05_C30	2	1	0	2	2	8
S06_C31	1	1	0	0	1	3
S06_C32	1	1	0	0	1	3
S08_C33	0	0	0	0	0	0
S08_C34	1	1	0	0	1	3
S09_C35	2	1	0	0	2	5
S09_C36	2	1	0	0	1	4
S07_C37	1	1	0	0	1	3
S07_C38	1	1	0	0	1	3
S08_C39	1	1	0	0	1	3
S08_C40	1	1	0	0	0	2

S School, *C* Class

One way for teachers to integrate modalities is to direct students to a list of ready-to-learn topics that are "relevant" to standards being covered during teacher-led instruction. We observed only one teacher who regularly did this. According to the teacher, "Students would [experience] better growth if they worked on topics that supported standards covered in class and homework. They would get more out of both [instructional modalities]." Students could choose topics, but the teacher aimed to align content from both instructional modalities.

At the end of each year, the majority of teachers requested more support in integrating ALEKS with the algebra scope and sequence. According to teachers, the disparity between each student's ready-to-learn topics and algebra standards was too vast. Teachers knew what standards they addressed during their instruction and could see the ready- to-learn topics, but mapping between the two was challenging. A few teachers suggested this was difficult because they did not know which ready-to-learn topics would most closely align with the algebra standards covered in class.

Differentiating instructional practices. ALEKS generated personalized materials on demand that teachers could use when delivering small group or individualized instruction to students. The majority of teachers (94%) did not use these resources. The two teachers who used them did so while the rest of the class used ALEKS, as intended.

Monitoring student progress. Most teachers (78%) monitored progress as students used ALEKS. Twenty of the 24 teachers who did this used a somewhat integrated approach, walking around the classroom and periodically observing students' screens as they solved problems. A small group of teachers, 4 of 24, implemented an approach rated fully integrated by conducting one-on-one meetings with students to assess students' understanding of the content. ALEKS intended for students to have a dedicated notebook to solve the program's open-ended free response questions and for teachers to use as a tool to help monitor student progress. Though ALEKS staff distributed notebooks, they were rarely in evidence in our observations and teachers rarely reported using them.

In summary, the overall extent to which teachers enacted personalized instruction with support from ALEKS was low. The total possible score was 10 and the median score was 3. Two teachers received a score of 8, meaning they somewhat or fully integrated ALEKS with their instruction in each domain. These ratings did not vary across models (Table 10).

Table 10 Average extent to which ALEKS enabled personalized instruction by domain and model

Model	Number of classes	Use of student performance Data	Incorporation of ALEKS in student grade	Alignment of instructional content	Differentiated instructional practices	Monitoring student progress	Total average integration
ALEKS	6	1	1	0	0	1	3
Integrated	26	1	1	0	0	1	3

Discussion

In this final section, we discuss implementation factors specific to this study that may present challenges to other implementations of technology in a blended, personalized model, and considerations for future research.

Implementation factors

Of the 31 classes that used ALEKS, only one class met recommended usage levels and demonstrated high levels of personalized instruction. There was insufficient dosage and very little personalization of instruction in the vast majority of classes that used ALEKS. Teachers identified a number of implementation challenges for both dosage and personalization. These factors hindered overall implementation and were consistent with prior implementation research (Ely, 1990, 1999; Fixsen et al., 2005; Damschroder et al., 2009; Bertram et al., 2015).

Teachers in the majority (36 of 40) of classes described students as largely unprepared for algebra and in need of extensive remedial instruction. On the 8th grade state mathematics assessment—the assessment used as a pretest—the average study student was 0.75 standard deviations below the state mean, or at about the 23rd percentile statewide. By and large teachers reported ALEKS met a “critical need” because it delivered remedial instruction in foundational skills the standard algebra curriculum did not and described the curriculum, which did not address gaps in foundational mathematics, as unsatisfactory. There was strong buy-in and support for ALEKS, critical factors for successful implementation (Damschroder et al. 2009; Ely 1990, 1999), because it could improve students' performance in mathematics (Datnow & Stringfield, 2000; Newmann et al., 2001; Honig & Hatch, 2004).

Yet, the majority of teachers expressed a tension in allocating instructional time to the use of ALEKS at the recommended levels. Teachers felt there was insufficient time to cover the algebra course prior to the state end of course algebra assessment, describing the scope and sequence as aggressive and ambitious for the most prepared students in the district. Even though teachers incorporated remedial instruction in their algebra lessons as a standard practice, they did not perceive themselves as "giving up" much instructional time. In contrast, ALEKS required 2 h per week, which was nearly half of the instructional time for teachers of classes with less than 5 h per week of instructional time (26 of 40 classes). Teachers reported a tension between remediation and simultaneous preparation for the high-stakes algebra test. Ultimately, teachers were responsible for students' performance on the end of course assessment. Student performance on the algebra assessment was not tied to graduation requirements but it did factor into the accountability scores for high schools. The relative advantage (Rogers, 1995; Damschroder et al., 2009) for "exposure to" and "practice with" the algebra content on the end of course assessment was described as greater than remedial instruction. Algebra instruction was more aligned with school goals, which resulted in teachers allocating less time to ALEKS (Bryk & Schneider, 2003; Roehrig & Kruse, 2005; Honig & Hatch, 2004). Teachers identified an overall need for more instructional time, specifically a second mathematics class, in order to achieve the goals of filling in knowledge gaps and preparing students for the end of course assessment.

Teacher readiness to implement a new practice was also a key implementation factor. A few teachers had prior experience using online resources (e.g., PLATO, Khan Academy) to supplement instruction. No teachers had prior experience implementing personalized learning by integrating technology into instruction. In interviews, many teachers acknowledged education was moving in the direction of blended and personalized models; however, they were not early adopters of the innovative approach. Seven teachers participated in the study for the intended two years. Thus, the majority of teachers had no opportunity to apply lessons learned during their first year of implementation in a subsequent year. We did not analyze changes in implementation from the first to second year of implementation because of the small sample size. The National Implementation Research Network implementation model suggests changes in practice to integrate an innovation take up to 5 years, with initial implementation taking approximately 3 years (Fixsen et al., 2013). According to this model, all teachers were in early phases of skill development and changing their practices and it is unlikely teachers would exhibit strong implementation (Ensminger et al., 2004; Ebersole & Vordan, 2003; Rogers, 2000).

Further, the initial implementation stage is particularly challenging and requires considerable support from coaches (Joyce & Showers, 2002), as well as broader systems supports (Aladjem & Borman, 2006; Schofield, 2004). Throughout the study, teachers identified integrating ALEKS with the district algebra curriculum as an ongoing challenge. Nearly all teachers spoke positively about the support they received through regular in-person visits, emails, and text messages from ALEKS staff. However, they described this support as primarily technical (e.g., creating reports, navigating the teacher interface) and their mastery of ALEKS as basic. According to teachers, the resources ALEKS staff directed teachers to for implementation strategies provided very limited information on designing models or integrating ALEKS with the regular mathematics curriculum. Support from ALEKS staff did not extend to designing and implementing a blended model with the standard curriculum. Similarly, teachers reported almost no support from school or district staff on how to design and implement a blended, personalized model. Teachers also did not receive instruction in how to use the Chromebooks provided by the study to support implementation; some teachers reported struggling to master the technology. Overall, teachers' knowledge and skills with ALEKS, personalized learning, and, in some cases, technology were a barrier to implementation (Hew & Brush, 2007; Ensminger et al., 2004; Ebersole & Vordan, 2003; Damschroder et al., 2009; Ely, 1990, 1999).

Several other factors emerged as barriers to strong implementation in participating classes. Many teachers reported that less than half of their students attended class regularly. In addition, the vast majority of students were off task during observations of both ALEKS and standard instruction. This, along with poor attendance, hindered dosage, which the ALEKS software only counts when students actively engage with the software. Because of these factors, most students had reported usage lower than the amount of time teachers made available for ALEKS use.

Four participating schools had selective admissions criteria and five were open admission. The class achieving dosage and greater extent of personalized instruction was at the school with the most stringent admission criteria. The two other classes with promising implementation (dosage or extent of personalization) were also at schools with selective admissions. Although this did not guarantee better overall implementation, selective schools were more likely to have higher attendance rates and algebra proficiency results.

Suggestions for implementing and studying technology-enabled personalization

Measured by dosage and quality, implementation of robust technology-enabled personalized learning was very limited in this study, and there was no effect on student achievement. It is clear that further studies with stronger implementation and dosage, and careful documentation of implementation, may be needed to understand whether and how systems like this can support student learning. Our study also offers some more general recommendations that may improve implementation of any technology intended to enable blended, personalized instruction, and for researchers studying these efforts.

Consider teacher buy-in and school support. Implementing new instructional models is challenging and more likely to be successful with strong support and buy-in at multiple levels (Ebersole & Vordan, 2003; Ensminger et al., 2004). It is also important to give teachers time to pilot interventions and experiment with implementation of technology-enabled personalized learning (Brenner & Brill, 2016). Further, consider whether there is support for implementing personalized learning from school (e.g., principal, department chair) and district leaders, as well as the developers (Boddy & Macbeth, 2000; Scott, 2000). Coaching and support are important during initial implementation of innovations and changing long-standing professional practices (Hew & Brush, 2007).

Clarify key components of the intended implementation. We articulated key components of ALEKS, which can be refined through further research. In blended learning research more broadly, researchers can engage with software and curriculum developers to identify key components of software. In this study, if restricting students to use only ALEKS-provided tools is central to ALEKS's design, teachers need to understand this and formulate an enforcement plan, while still giving students adequate practice with the tools that will be available to them during standardized tests (Hew & Brush, 2007). Communicating these core components and developing plans to adhere to them may facilitate greater implementation fidelity (Damschroder et al., 2009; Scott, 2000; Surry & Ely, 2002).

Provide explicit, feasible models for personalization using the blended approach. Teachers need more ongoing support to truly integrate online and teacher-led instruction so that they complement each other. For example, it may be helpful to provide semi-prescribed models, schedules of integration, or a map linking software topics to standards to help teachers connect modalities. Strong models for personalized instruction, particularly in classes with a large gap in readiness for the course, could be particularly important (Surry & Ely, 2002; Boddy & Macbeth, 2000; Malbert et al., 2003). Professional development on how to deliver small group instruction in a secondary school setting or use online data to inform instruction may be useful. Considering different ways to structure or extend class time may also be helpful (Hew & Brush, 2007). Further, researchers, developers and district instructional leaders can develop rubrics for assessing the extent to which instructional modalities are integrated to provide personalization.

Consider student engagement more broadly. Student engagement was a challenge in classes where students used ALEKS, classes that used only the existing curricula, and classes using both. Personalized instruction and technology-based instruction may solve some student engagement challenges, but there are also risks that students will use technology as an opportunity to go off-task, or that they will not find the software engaging. Identifying and implementing strategies that improve engagement across modalities may enhance improvements in student achievement.

Conclusion

This paper proposes considerations for improving implementation of, and research on, adaptive learning software as a supplement to existing curriculum. Our findings identify multiple challenges to designing strong implementation models, as well as supports that may promote adherence to the core components of software and enable high quality blended instruction. Future research needs to explore the extent and shape of implementation with different adaptive and personalized systems and to assess whether and how such personalized instruction leads to better outcomes.

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