Estudia Khanmigo: An equity-focused pilot exploration of artificial intelligence tutoring in Puerto Rican classrooms

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Introduction

Puerto Rico has faced multiple consecutive natural disasters in the last decade. These events have exacerbated the island's already overworked public services infrastructure, including the education system. Continuous advances in educational technology show a promising potential to address the compounding achievement gap between PR's students and mainland US students; yet the equity is not always at the forefront of designers' minds when creating edtech products. A tool that is useful to the average middle-class American student, for example, may not be well suited for students such as Puerto Rico's public school enrollees. These students are Spanish-speakers, many live below the poverty line, and the majority of them are culturally very different from what is considered majority culture in the US (the culture for which most edtech is designed). Artificial intelligence, which has only recently entered the spaces of educational technology, is an unpredictable variable to begin with, let alone in the context of vulnerable populations living in Latin America. Thus, it is incumbent on the research community to explore the benefits and possible drawbacks of this technology in the classroom, particularly classrooms that educate vulnerable, linguistically diverse students of color.

The following is a report on the result of a pilot study examining student and teacher reception to Khanmigo, an AI-powered personalized tutoring training tool designed and created by Khan Academy. Using a mixed methods design, this study measured students' math motivation throughout the school year and observed their qualitative reactions to the Khanmigo tool. It also cross-referenced these reactions with teacher interviews. Focused on defending equity first and foremost, the research and implementation team became embedded members of the observed school communities to observe and directly respond to community needs. Findings show that Khanmigo shows a lot of promise when it comes to improving student math

motivation and self-efficacy, but that pervasive and deeply rooted infrastructural limitations hinder students and teachers from using the tool to its full potential.

Background

The Puerto Rico Department of Education (PRDE) operates as a unitary school system that serves approximately 850 schools across seven districts. As the executive department of the government of Puerto Rico (PR), it is responsible for public schools, the education system, and the curriculum on the island. In recent years, PRDE has observed an alarming gap in academic achievement, particularly pronounced in mathematics. In the 2022-23 academic year, only 23 percent of students in the system demonstrated performance levels classified as proficient or advanced. In comparison, the corresponding rates in English, Spanish, and science were 33, 36, and 38 percent, respectively. It is worth noting that there is a decline in achievement as students move through grades. The percentage of math proficient/advanced scores decreases from 61 to 42 percent between third and fourth grade, from 33 to 9 percent between fifth and sixth grade, and then remains around 8 percent for students in seventh, eighth, and eleventh grades (Departamento de Educación de Puerto Rico, 2024).

Perhaps more concerning is that standardized test results in mathematics have been worsening island-wide in recent years, with an average decrease of almost 10% since 2019. Data from the National Center for Education Statistics confirm both the low achievement in mathematics and the increasing lag between fourth and eighth grade. In 2022, only 10 percent of Puerto Rican fourth-grade students showed basic, proficient, or advanced performance levels, compared to 74 percent of students in the United States. The corresponding performance data for eighth grade showed figures of 6 percent basic, proficient, or advanced performance in Puerto

Rico, compared to 60 percent proficient performance in the US (National Center for Education Statistics, 2022).

These academic performance trends have at the backdrop a series of ongoing crises for the Puerto Rican people. Hurricane María devastated the island in September of 2017, with public service infrastructure becoming crippled following a total power grid collapse (Kwasinski etal., 2019). Earthquakes at the end of 2019 and beginning of 2020 further threatened PR's fragile infrastructure (Hain et al., 2023), which had no time to heal before the COVID-19 pandemic brought the flow of public life to a sudden halt (García et al., 2021). School reopenings and a general sense of stability for the school system were shaken once more by Hurricane Fiona in September of 2022, which brought massive amounts of rainfall and caused severe flooding in many of the island's communities (McSorley, 2022).

In short, describing Puerto Rico's K-12 students' schooling as discontinuous would be a gruesome understatement. Tackling the achievement gap between PR students and mainland US students will therefore require a strategic approach. The tools introduced into PR's school system must be adaptable to modality (virtual or in-person) and location changes, must be easily scalable to the hundreds of schools and hundreds of thousands of students in the system, must be of low cost, and must be tested for effectiveness before implementing island-wide, lest resources be distributed ineffectively in an already troubled education context.

The Research-Practice Partnership between the University of Toronto Department of Economics and PRDE has therefore taken it upon itself to explore the efficacy and viability of large-scale educational interventions on the island. Composed of faculty members from the University of Toronto and University of Puerto Rico, education professionals at PRDE, and implementation professionals employed through Universidad del Sagrado Corazón, the

partnership designs intervention programs and studies their effects on PRDE school communities.

Of particular interest to the group is the use of Khan Academy, a free online platform available in dozens of languages that provides videos, practice, and studying materials for all levels of K-12 mathematics and science classes. Synchronization between student and teacher accounts allows for students' individualized and personalized pacing and practice for math material, while saving teachers valuable time and energy in material creation. Thus, the partnership team has featured Khan Academy use and training in several of its intervention endeavors, including an island-wide three-year randomized control trial. With promising preliminary results, Khan Academy appears to be a feasible instrument that can help lessen the mathematics achievement gap that profoundly affects PR students' educational outcomes.

Khan Academy, Khanmigo and how they can help

PRDE has access to synchronization between its student information system and Khan Academy rosters through an application called Clever. This service eases the burden of set-up efforts for teachers considerably, as their classes and the corresponding students appear automatically rostered in teachers' Khan Academy accounts. Teachers can then easily assign videos and practice problem sets to all their classes and can monitor their students' performance and progress, both individually and as a group. Students must only activate their Khan Academy accounts using their PRDE email; once they do, they automatically see their classes and corresponding teachers on their Khan Academy dashboard.

Khanmigo is a new, optional add-on feature available for both teacher and student Khan Academy accounts. It is a GPT-4 AI-powered personalized tutoring tool that helps students with academic understanding through guided problem solving. Khanmigo has two modalities through

which it can provide students with homework assistance. In a general dashboard setting, students can ask Khanmigo open questions about humanities, math and sciences; Khanmigo is also available during practice modules, as a chat window the student can access on the bottom right corner of the screen. In its module modality, Khanmigo refers to the specific problem and topic at hand, such that it redirects students when they get off-task. Meanwhile, it allows for a more open conversation flow in its dashboard modality. In both modalities, Khanmigo is programmed not to directly reveal answers to the student, but rather guide the student through the reasoning process and mathematical steps that can help them reach the answer on their own. For example, if asked for help with a problem that involves adding fractions with different denominators (e.g. ¾ + ½), Khanmigo will ask the student whether they know the first step to solve the problem (in this case, identifying the least common denominator). Khanmigo will then either a) help the student complete the first step if the student expresses confusion, or b) praise the student and then progress to a following step (finding the corresponding equivalent fraction to ½) if the student demonstrates familiarity with the first step. If the student at any point asks Khanmigo what the answer is outright, Khanmigo will clarify that it cannot give the answer and redirect the conversation towards figuring out the next step needed to solve the problem.

Khanmigo also offers essay writing help, games, simulated conversations with historical or literary characters, and other fun activities in its dashboard modality. In both modalities, Khanmigo has safety features, which include refusing to engage with inappropriate or concerning student comments and reporting them to the student's teachers through a notification and flagging system. For teacher accounts, Khanmigo provides helpful time-saving services, such as customizable lesson plan building, strategizing for fun and engaging teaching activities, composing class summaries and more.

Combined with its much lower cost relative to private one-on-one tutoring, these features give Khanmigo the potential to help improve student outcomes in the Puerto Rican context. Easily accessible, friendly, and individualized guidance available in Spanish could have a massive impact on PRDE's students, many of whom find themselves in overcrowded and understaffed schools.

Yet the Khanmigo tool, and AI in the classroom generally, are in their nascent stages. Before we roll out the red carpet for them, we must take care to investigate their compatibility with equity-focused educational endeavors. Thus, the research practice partnership decided to, with help from the Bill and Melinda Gates Foundation, conduct a small-scale pilot project wherein the specific, individual needs of two school communities in Puerto Rico could be documented, understood, assessed, and addressed. This project involved members of the research team becoming embedded within the school communities to introduce Khanmigo to students and teachers and to troubleshoot and address any limitations to the schools' effective use of technology in the classroom. Committed to equity work that is directly responsive to community needs, these research and implementation team members formed relationships with administration staff, teachers, faculty members, and students in both school communities, maintaining a person-first orientation towards Khanmigo introduction and implementation.

Pilot Project Context

Estudia Khanmigo's setting encompasses two schools based in San Juan, Puerto Rico's capital: School A and School B. School A, a middle school (6th through 8th grade) specialized in math and sciences, integrates multiple math and science courses into its school year curriculum. The school operates on a schedule of six class periods, each lasting 85 minutes, with a one-hour break between the fourth and fifth periods.

Its rigorous admission process is consistent with its ranking among the top public schools on the island. At School A, there are 28 teachers and approximately 310 students accommodated across four buildings: a main building consisting of two wings, each spanning three stories; two smaller annexes; and a single-story supplement comprising roughly seven classrooms. Given the library is not equipped with communal computers, PRDE devices were allocated to both teachers and students in 2020 during the COVID-19 pandemic. However, considering the equipments' life expectancy, most of them are reaching their retirement date.

School B is a middle and high school (grades 6th-12th) situated in an increasingly gentrified area of the municipality. Its teachers operate according to the Montessori philosophy by embracing different forms of learning and considering the socioemotional aspects of education. Their class schedule reflects these values with two project periods, each lasting 50 minutes, and three class periods, each lasting 95, with an hour for lunch. School B houses approximately 350 students across 3 buildings: a two-story building with two wings, a two-story annex, and a one-story annex. PRDE devices were distributed to the school when its enrollment was half of what it was during the 2023-2024 school year; this in combination with warranty expiration, device retirement and device loss has resulted in a considerable device shortage. Teachers have five PRDE laptops to be used in turns by each class group, comprising roughly 20 students. Additionally, they have occasional access to 28 communal desktops in the library, overseen by the librarian; irregular IT support is provided by the technology teacher.

Despite their institutional differences, School A and School B share a similar work infrastructure. Both schools have principals, teachers, educational professionals, non-teaching staff, and students, all organized by grade and homeroom; the only notable exception lies in School B's combined 7th and 8th grade class structure. Staff and student roles are clearly defined

and diligently fulfilled, fostering a cooperative and collaborative atmosphere among teachers and administrators. Their collective focus on ensuring smooth class execution is rooted in principles of human equality and learning-centeredness. It is this teaching model that aligns strongly with Khanmigo's personalized nature.

The tutoring platform's features and resources also coincide with School A and B's mission statements and goals. Supplied with fully funded year-long Khanmigo access, all teachers were able to undergo training for its usage. The streamlined information sharing processes established with teachers and parents by the school principals, as well as consistent space availability for Khanmigo use (e.g. school libraries), facilitated project implementation. Student encouragement was fostered by reward-based incentives, such as a cookie party for the homeroom class that collectively had the most conversations with Khanmigo during the month of December.

Implementation

Estudia Khanmigo's implementation period consisted of a full school year, from site selection to final retrieval of supplies. The participating schools were chosen based on their use of Khan Academy in previous school years, as observed in earlier research endeavors conducted by the University of Toronto/PRDE Research-Practice Partnership. While all teachers and students in the selected school communities received access to Khanmigo, only 6th- 8th grade students and their math teachers were involved in research participation. Following school selections and Khan Academy account activations, official implementation activities included:

A) ***Teacher training on Khanmigo use by Khan Academy staff***- All teachers in each school community were invited and encouraged to participate in Khanmigo training, as all faculty members received access to the tool. Khan Academy staff members

conducted the training sessions in person and on site, one at each school. Training last two and a half hours and included an in-depth explanation and simulation of the teacher tools available in Khanmigo, an introduction to the modalities in which students would be able to use Khanmigo, and an explanation of the tool's security features.

B) ***Fall semester survey*** – After collecting informed consent from parents and guardians, students with permission to take the math motivation survey did so if they so desired. The survey was administered in each participating classroom through an electronic form either sent to students' email address or pulled up on an implementation team member's laptop. The survey was administered before students were introduced to Khanmigo.

C) ***Student presentations provided by implementation team-*** The implementation team briefly presented Khanmigo and its features to students in each home room, during a math class or free period. Students were given brief explanations of what AI is, were shown the different ways in which they could interact with Khanmigo and were encouraged to ask questions about the tool.

D) ***Weekly school visits-*** The implementation team visited each school at least once a week (and more often if requested by a teacher or principal). These visits included but were not limited to: IT assistance for student, teacher, and communal devices; observations of math class periods with Khanmigo use recommendations; assisting students in accessing Clever and Khan Academy; guiding students through Khan Academy practice problems following a lesson; distributing additional devices and routers for classrooms in need of them; addressing school network connectivity issues

with visiting internet service provider technicians and PRDE's centralized IT office staff; posting and distributing reminders and instructions of how to access and use Khanmigo; and introducing and conducting incentive programs for students' Khanmigo use.

E) ***Spring semester survey-*** The implementation team visited each classroom again to obtain follow-up responses from the students who had taken the Fall semester survey. All survey items, item order, and answer options were unchanged from the Fall semester version.

F) ***Student interviews-*** Participants were selected from the pool of students whose parent/guardian provided consent to be interviewed. To not interrupt class time, students were interviewed after school, either in person at the school library or virtually via Zoom (depending on schedules/availability). The interview asked about how often the student used Khanmigo, what they liked about Khanmigo, what they would improve about it, any previous experiences with AI tools, and more.

G) ***Teacher interviews***- The implementation team asked half of the participating math teachers to complete a semi-structured interview. The interview asked about the frequency with which they and their students used Khanmigo, examples of occasions in which Khanmigo hindered or helped student understanding, general feedback about Khanmigo's student and teacher functions, and Khanmigo's compatibility with students' particular needs.

While certain structural factors aided implementation efforts, numerous institutional elements within both schools presented obstacles. Reliable access to technology and internet connectivity emerged as significant barriers among various other critical incidents. Despite their desire to

improve student experiences with online educational platforms, they struggled to prioritize educational technology use amid challenging circumstances.

Critical Incidents

Several incidents severely complicated project implementation and regularly caused the research team to have to pivot their attention to critical events as they arose. These included but were not limited to: a large-scale change of the electronic student information system, PRDE wi-fi network blocking Khan Academy throughout the year, teacher resignation, and massive construction projects that put over half of School A's buildings out of service. These consistent issues complicated technology use (and therefore Khanmigo use) in the classroom considerably. Incidents are detailed fully in Appendix A.

Research Methods

Due to the small scale and short duration of this pilot project, the accompanying research study intended to investigate students' initial receptivity to Khanmigo. The research team chose to focus on students' attitudinal changes towards mathematics— feelings of increased motivation and self-efficacy, for example— rather than short-term changes in math scores. The challenge then became finding a suitable instrument written in Spanish and validated with children of similar ages in Latin America.

Arellano-García et al. (2022) performed a validation study with Berger and Karabenick's (2011) Spanish language math motivation scale. In Arellano-Garcías's work, the simple 14-item, 5-point Likert instrument reliably measured Mexican secondary school students' (ages 12 to 16) self-reported mathematics motivation. The questionnaire includes 5 subscales, interest (students' affinity toward math), importance (the degree to which students consider math skill to be an important part of their identity), utility (how useful math is), cost (how much students feel they

must sacrifice to achieve success in math) and self-efficacy (students' belief in their ability to solve math problems on their own). We found these observed qualities to be particularly compatible with both our research questions and the intended targets of Khanmigo's design and features.

Each subscale consists of two or three items scored from 1 (*Muy en Desacuerdo*- Strongly Disagree) to 5 (*Muy de Acuerdo*- Strongly Agree). Due to differences in the ranges of subscales' raw scores (2-10 for cost, 3-15 for all others), we opted to calculate the mean for each. To observe differences in math motivation throughout the school year we administered the survey once in the fall semester, before students were introduced to Khanmigo, and once in the spring semester, after the schools' Easter holiday week.

Additionally, the research team observed Khanmigo usage during 9 weeks in the Spring semester, noting the amount of Khanmigo conversations students had as well as the number of turns in each conversation. The number of turns was meant to (imperfectly) estimate the degree to which students persisted and engaged deeply with Khanmigo.

We also accompanied our quantitative inquiry with a qualitative exploration of students' and teachers' perceptions of and reactions to the Khanmigo tool. We conducted semi-structured interviews with a total of 13 students and 3 teachers at the end of the school year. Student interviews included questions about what they liked or did not like about Khanmigo and whether they found it helpful; it also involved delving into student interests and why some students may have chosen not to use the tool. Teacher interviews asked about their students' learning process and needs, specific examples where they felt students' learning was hindered or aided by Khanmigo use, and their use of Khanmigo's teacher tools. The interviewer asked probing

questions to further explore any salient topics, and communicated to participants that she was aware of ongoing events and challenges for the school community throughout the year.

Results and Findings

Survey Results

A total of 179 students filled out the Fall semester Survey, with demographic characteristics distributed as outlined in Table 1. Of these 179, we were able to obtain follow-up responses during Spring semester for 166 students. With a 92.7% continuity rate, the demographic makeup of the Spring semester participants was almost entirely the same.

Table 1

Fall Survey Participant Demographics

Demographic Characteristic		School A	School B
Age			
	10	6	0
	11	46	13
	12	42	5
	13	32	24
	14	2	7
	15	0	1
	16	0	1
		128	51
Gender			
	Male	79	21
	Female	49	30
		128	51
Grade			
	6th	55	18
	7th	33	10
	8th	40	23
		128	51

To clarify, these students do not represent every student who used Khanmigo, but rather, the students were present during the Fall survey administration dates and whose parents

consented to them filling out the survey. Conversely, not every one of these 179 students used Khanmigo during the 9-week period during which conversation use was observed. Of the 166 students who filled both the fall and spring survey, 95 used Khanmigo at least once during the observation period, while 71 did not.

The means for the subscale scores in both the Fall and Spring semesters are presented in Tables 2 and 3. Because School A is specialized in mathematics and because of the considerable differences in IT infrastructure and literacy between School A and School B, we additionally disaggregated the data by school. We hypothesized that School A would have higher mean scores than School B in the interest, importance, utility, and self-efficacy subscales, and lower mean scores than School B in the cost subscale. This is due to a presumed higher affinity for mathematics from School A's students, who voluntarily underwent an application process to enroll in their STEM specialized middle school. Subscale means that are significantly different between schools are marked with asterisks below; all significant differences varied in the expected direction.

Table 2

Fall Survey Mean Subscale Scores

Subscale	School A	School B
Interest	3.4010	3.3137
Importance ***	3.8099	3.2876
Utility **	4.3047	3.9020
Cost	2.6328	2.5686
Self-efficacy ***	3.8333	3.3007

*Significance: *: $p < .05$, **: $p < .01$, ***: $p < .001$*

Table 3

Spring Survey Mean Subscale Scores

Subscale	School A	School B
Interest	3.2350	2.9773
Importance ***	3.1537	3.0682
Utility **	4.3388	3.7652

Cost***	2.3074	2.8864
Self-efficacy ***	3.7350	3.31970

*Significance: *: p < .05, **: p <.01, ***: p < .001*

To accurately capture math motivation changes pre- and post- Khanmigo use, we calculated difference scores for each subscale (Spring survey subscale score – Fall survey subscale score). When considering School A and School B together, students showed significant score decreases in three of the subscales: interest, importance and self-efficacy. However, disaggregating by school pointed to further patterns in math motivation changes. Subscale score differences in School A indicated decreases in interest, importance, and cost, while score differences in School B demonstrated a decrease in interest and an increase in cost.

Table 4

Cumulative Subscale Score differences

Subscale	Mean Score Change
Interest***	-0.249
Importance ***	-0.3253
Self-efficacy *	-0.1165

*Significance: *: p < .05, **: p <.01, ***: p < .001*

Table 5

Subscale Score differences by school

School A		School B	
Interest***	-.2213	Interest*	-.3258
Importance***	-.347	Cost*	.3523
Cost*	-.3156		

*Significance: *: p < .05, **: p <.01, ***: p < .001*

Since this pilot study had no counterfactual group with which to compare survey outcomes, it is not possible to pinpoint the exact reason for the subscale score differences. However, educated guesses can be made. For example, the differences in the two school's survey

participants' interest, importance and self-efficacy scores could be due to burnout from the school year, as students' enthusiasm for school life and academics typically wanes as the school year progresses (Cohen et al., 2023). The decrease in cost subscale scores for School A could be attributed to the student body's high level of exposure to and routine-building around mathematics, as School A is specialized and allocates an hour and a half of students' daily schedule to one of their two math classes. Conversely, roughly half of School B's participating students were left without a math teacher following their instructor's resignation halfway through Spring semester. Thus, it would be reasonable for students to feel they have less of a handle on their math class and school material when they lack a teacher's guidance, and an increase in their perception of the cost of doing well in math class would be understandable.

In the interest of further exploring possible reasons for variations in subscores between schools, we used linear regression models to determine whether students' total amount of Khanmigo conversations, average turns per conversation, or school attended had any explanatory power regarding the subscale score differences. We only found a significant effect by the independent variable of school attended on the dependent variable of Cost subscale score difference. This is consistent with an explanation of differing school cultures and events affecting students' perception of the cost of succeeding in their math class(es).

Table 6

Linear Regressions

	Standardized Coefficients		
Interest Difference	Beta	t	Sig.
(Constant)*		-2.185	.030
School	.056	.702	.484
Total Conversations	.001	.011	.991

Average Turns	-.042	-.491	.624
Importance Difference			
(Constant)		-1.970	.051
School	-.027	-.341	.733
Total Conversations	-.102	-1.178	.241
Average Turns	.063	.736	.463
Utility Difference			
(Constant)		-.841	.402
School	.015	.191	.849
Total Conversations	-.062	-.715	.476
Average Turns	.123	1.437	.153
Cost Difference			
(Constant)		1.854	.065
School***	-.286	-3.723	<.001
Total Conversations	.151	1.815	.071
Average Turns	-.023	-.279	.780
Self-Efficacy Difference			
(Constant)		-.193	.847
School	-.063	-.792	.430
Total Conversations	.075	.867	.387
Average Turns	-.064	-.744	.458

*Significance: *: p < .05, **: p <.01, ***: p < .001*

Despite the neutral results of our quantitative analysis, our qualitative exploration of students' and teachers' reactions to Khanmigo revealed that the tool has an impressive potential to aid student learning and improve the math class experience generally within the Puerto Rican public school context. Ahead, we report findings from our student interviews, followed by those from teacher interviews.

Selection for interview participants involved finding the first, second, and third terciles of Khanmigo usage (as measured by each student's total Khanmigo conversations) to make low usage, moderate usage, and high usage groups. A roughly equal number of students was chosen

randomly from each group, with re-draws occurring for a usage group if the resulting sample was disproportionately skewed in student grade or gender distribution. The research team also conducted re-draws if a chosen student's parents were unresponsive or if the student was otherwise unavailable.

Student Interview findings

Affinity and enjoyment

Students' reactions to Khanmigo were overall positive. None of the participating students gave any example of harm, displeasure, or significant confusion resulting from a Khanmigo interaction. Students had a variety of answers to the prompt "Name something you like about Khanmigo," indicating that they found the tool fun to interact with, and that they responded well to the icon's subtle personification (facial features, expressions, etc.).

Xiomara: *"Well, the Khanmigo icon is pretty… it inspires me because it looks really cute."*[1]

Ricardo: "*That it tells jokes or sometimes riddles."*

Eduardo: *"I'd like to have it as a friend."*

During informal observations periods, the research team witnessed students enthusiastically trying some of Khanmigo's general dashboard features, including having simulated conversations with some of history's notable scientists, asking Khanmigo about its personality and preferences, and demanding to speak to the "Avengers" Thor, not the "Norse god" Thor. In short, students found Khanmigo fun and easy to talk to.

Helping with math performance

1 The Spanish pronoun "él" can refer to both "he" and "it", such that students may or may not have ascribed personhood to Khanmigo in a way that cannot be unambiguously detected during a Spanish language interview.

When asked whether they found Khanmigo helpful, students who used the tool regularly indicated that it explained concepts well and helped them develop a step-by-step understanding of problem solving. Regular users displayed an understanding of mathematics as a process rather than simply a binary "right or wrong system". They also demonstrated having a *growth mindset* surrounding mathematics, challenging the characterization of math skills as being a fixed personality trait (being "good" or "bad" at math) and viewing them as malleable and improvable. Happily, Khanmigo helped these students feel more confident and less afraid when working on their math material.

> **Xiomara:** *"Khanmigo has taught me a lot of things, I've learned more, so I feel more secure using it and doing math."*
>
> **Liam:** "*Khanmigo can help you understand step by step, it explains how to do it well. It can help you get to the answer."*
>
> **Sebastián:** *"Yes, because before sometimes I was afraid of math… Now I ask more when I have a question."*

One interview question asked whether students felt more comfortable, just as comfortable, or less comfortable with math after having used Khanmigo regularly. Most respondents answered that they felt more comfortable with math, and none of them answered that they felt less comfortable with math. Xiomara credited Khanmigo with helping her obtain more than 50 extra credit points in her Pre-Algebra class; meanwhile, Jessica reportedly finished fall semester with a C average in geometry that she was able to improve to an A by the end of spring semester. These anecdotes support our hypothesis that the Khanmigo tool significantly adds to (and does not subtract from) students' math learning and performance.

Khanmigo in a pinch

Khanmigo provided the extremely valuable contribution of being a resource for students' contingency planning. For example, one student cited Khanmigo's help as one of the reasons she was able to follow along with class material and keep her math grades up despite her prolonged school absence.

> **Marta:** *"I was hospitalized… basically for two weeks. I was so lost, I turned to Khanmigo for help when I came back from the hospital."*

Despite being an exceptionally strong math student, Marta demonstrates that even typically high-achieving students can benefit from Khanmigo's extra help when circumstances become difficult.

Other students shared that Khanmigo helped fill occasional gaps created by the limitation of a 1:20 teacher to student ratio. Students found that Khanmigo was able to provide them with focused help in scenarios where students would have otherwise remained stuck until they were able to get their teacher's attention.

> **Eduardo:** *"And if we have doubts and [the teacher] isn't there, we ask Khanmigo."*
>
> **Sebastián:** *"Well, since it's not a teacher, it has more time to dedicate to you…. It does it pretty quickly and you don't have to wait."*

Students also used Khanmigo to ask about other class subjects, demonstrating resourcefulness and willingness to explore with the tool.

> **Catalina:** *"One time I was doing some biology homework, then I didn't understand something, and I asked Khanmigo and it answered well, I was able to do my homework."*

Refraining from use

A considerable portion of the students surveyed did not use Khanmigo, however. Consequently, the research team used low-usage interviews to help determine why some students

chose not to take advantage of the learning opportunities Khanmigo presented to them. Perhaps unsurprisingly, participating students cited technological difficulties, such as a shaky internet connection that interrupted or prevented Khan Academy. School B students commented that the login process for Clever and Khan Academy was too complicated, as they did not know their student emails or passwords by heart and thus had to opt for a single sign-on login every time. Many low-usage students also cited a distaste for mathematics and/or a strong aversion to difficult math topics.

> **Luisa:** *"If I understand the topic, there comes a point in time where I start liking [math] but when I don't understand, well no, I don't like it."*
>
> **Miguel:** *"I liked math when there weren't any letters."*

These students' descriptions of their interaction with mathematics resembled shutting down or stonewalling, wherein they resisted or sometimes outright refused to engage with mathematics if they were uncomfortable with its difficulty. Logically, these students did not readily use resources provided if not explicitly instructed by a teacher to do so and did not display any significant curiosity for mathematics (or even schoolwork as a whole).

One student, Joel, expressed a particular affinity for learning through analog rather than digital media. Despite having a well-developed understanding of how AI works and how to use technology in everyday settings, this student commented that he was simply used to the "habit" of pencil and paper and thus preferred in-person learning rather than virtual learning. When asked if he felt more comfortable asking a question to a person or a digital resource, Joel decidedly favored human interaction.

> **Joel:** *"I think it's better to ask a person, especially the teacher, because he's the one who explained the topic to me and he knows exactly what I want to learn."*

The only student who gave a substantive answer when asked to name something they would improve about Khanmigo was Juliana. An outstanding mathematics student, Juliana was in the low Khanmigo usage category because she felt she simply did not need the instrument to understand material and succeed in her math classes.

Juliana: *"I'd like it to be more direct because there are times where you like, ask for help with the answer, and then it shows you what [the concept] is and it doesn't answer your question correctly."*

In her response, Juliana indicates that she has no trouble understanding the high-level concepts in her classes, and that she needs those assisting her (be they people or digital tools) to know that she does not need to review every concept or step in a problem-solving process; Juliana wants confirmation that her calculations are correct at step 5, not an explanation of why step 1 is necessary.

Ricardo, a moderate usage student, echoed this. Rather than utilizing Khanmigo for substantive help, he simply used it to confirm he had reached the correct answer before inputting it into a practice module, so as not to lose any points in the Khan Academy module because of a small calculation error:

Ricardo: *"I used it to see if my calculations were right."*

Thus, Joel, Juliana and Ricardo provide examples of how high-achieving students may not feel the need for extended assistance from Khanmigo and may therefore choose not to use it frequently. Combined with the low usage of students who dislike (and sometimes even fear) math, this suggests that Khanmigo is more appealing to students in a certain "middle ground". Namely, using Khanmigo is more natural to students in the middle of the achievement and interest curves. The student must have a need for Khanmigo—a topic or process they do not yet

fully understand—while still possessing the curiosity and interest in math needed to persevere and explore with assistance tools. This speaks to the importance of tailoring Khan Academy and Khanmigo usage to different groups of students, such that all can access its useful assistance. For students with lower math achievement, teachers can select simpler and more foundational practice exercises to scaffold their learning. Teachers can focus on developing a growth mindset in their students to teach all of them, lower-achieving students included, that with enough effort they can get better at math and develop a greater understanding of it. Likewise, teachers can take special care to assign more challenging and advanced material to students with high math achievement, so that they remain interested and willing to explore using Khan Academy and the Khanmigo tool in particular.

A self-efficacy success story

Jessica, an 8th grader in School A, was named in a teacher interview as a notable Khanmigo success story. As mentioned above, Jessica was able to raise her math grade by two full letter grades between fall semester and spring semester, a remarkable feat that both she and her teacher believed Khanmigo helped considerably with. Even so, the improvement in her grade was not Jessica's biggest achievement during the school year. During Jessica's interview, the research team remarked at the enthusiasm and confidence Jessica now viewed math with. She gushed about Khanmigo's ability to explain and recounted that she recommended the tool to all of her friends, describing how her interactions with Khanmigo blossomed and eventually developed.

> **Jessica:** *"With just explaining the process of how to do it, and not giving me the answer, for me that's what I want… I like that it's like… 'Okay, let me figure it out, I can do it, I*

can do it.' Khanmigo would explain and I'd go "oh, okay". And little by little, well—I keep using it, but I start letting go."

With this quote, Jessica demonstrated how Khanmigo has the potential to achieve exactly what it was intended to. Giving Jessica the small nudge she needed to be able to thrive in her math class, Khanmigo provided the scaffold that helped Jessica realize that she is an extremely capable math student. Jessica not only understands her math material better; she now believes she can tackle future topics and problems more effectively, and she has developed the confidence to attempt to do so on her own. Admittedly, Jessica's use of Khanmigo diminished over time, not because it was unhelpful, but precisely because it was effective. In Jessica's case, Khanmigo began working itself out of a job—the goal for any educator who has undertaken individual tutoring duties.

Overall, students responded well to Khanmigo and were receptive to it. While their ability to use Khanmigo in class consistently was limited by internet and technology issues, many students felt comfortable exploring with Khanmigo on their own, be it at home or during their after-school program. More than 120 students who did not have parental consent to fill out surveys or be interviewed were surveyed, such that these observations are but a small sampling of student reactions to Khanmigo. As expected, variations in interest and personalities played a role in Khanmigo interest and use; however, Khanmigo shows promise as a useful, helpful, and safe tool for students of all math abilities to use.

Teacher interview findings

Systemic barriers

All teachers interviewed mentioned that they were not able to use Khan Academy and Khanmigo as much as they would have liked given the systemic issues surrounding network

connectivity issues, inconsistent electrical service, resulting class schedule changes and device availability. One teacher, Jímenez, who had achieved outstanding momentum with Khan Academy in classwork in the previous school year, expressed frustration and continued bewilderment with how the PRDE network blocked access to Khan Academy when it had not done so pbefore. Vélez echoed the sentiment of not being able to establish a technology-assisted routine in his classroom.

> **Vélez:** *"The situation sadden—well, it's not that it saddened me, but… I had every intention of using it, I wanted to get started with the [tech] stations, but I felt very limited."*

Furthermore, School A's teachers were particularly overwhelmed by how ongoing construction interrupted their school schedules and academic life, describing weekly schedules as extremely touch-and-go.

> **Meléndez**: *"Literally, day by day with whatever we faced. We couldn't plan in the long-term, not even within the same week."*
>
> **Gómez**: *"A lot of days off, a lot of mess with the construction, a lot of activities that took place, I mean, it was a very impetuous year, where I would have liked to do more things than I saw able to do."*

Lesson planning was also profoundly impacted by school construction. With nearly half of the school's classrooms out of service at a time and with several available classrooms affected by low voltage, teachers had no reliable designated space in which to spend their planning period. Provided additional spaces also lacked support for technology use during lesson planning.

> **Meléndez:** *"And then during that professional development period, where you're supposed to prepare your classes and such, well you don't have internet access, you're*

not able to connect your computer. So, there wasn't… there was part of the time where we almost didn't work on the computer at all when it came to lesson planning."

As such, teachers found that accessing Khan Academy outside of school hours to assign students homework and test reviews through Khan Academy was the most effective way in which they could encourage the platform's use. In-class use was not null, however, as several teachers were able to provide students with demonstrations about the specificity of questions that helped Khanmigo answer most effectively, and some designed guiding Khanmigo questions to introduce students to new topics.

Value Khanmigo adds

Despite the repeated tech challenges, teachers found that Khanmigo provided new value that previous educational platforms and/or apps have not been able to. One of the teachers' primary concerns was that technology that provides students with answers is detrimental to their development of problem-solving strategies and their understanding of mathematics as a structured process rather than a set of answers. Teachers were encouraged by Khanmigo's step-by-step format and saw it as a positive step towards improving technology use and practice in the classroom, even for students who already appear to understand certain topics or problem types.

Vélez- *"And one of the things I do like about Khanmigo is it doesn't give you the answer, rather it guides you through—which is an artificial intelligence that is effective for the classroom."*

Meléndez- *"And then, the part—right, the disadvantage in that sense is that if they don't use Khanmigo, which Khanmigo does guide them through the structure of the process, and they only use the regular practice exercise because they understood, they're going to have it right, but they're not necessarily going to develop that structure."*

Gómez, a 6th grade teacher, spoke about the specific challenges of introducing students to levels of mathematics that are no longer as simple as just the arithmetic they have previously encountered. She highlighted the importance of gently introducing students to multi-step problems as the norm and found that Khanmigo helped facilitate that introduction.

> **Gómez-** *"And there the student says 'Wait, it's not as easy as a, b, c, and this one's it.' So, yes, Khanmigo in that part helps them understand how to do the processes."*

Overall, the teachers thought about Khanmigo from the perspective of their teaching goals and their students' level of problem-solving skills. While they did not view Khanmigo as a cure-all, they felt that Khanmigo addressed some of the issues that previous edtech has, namely, by emphasizing the steps and process of mathematics rather than holding a binary view of "right answer/wrong answer".

Khanmigo's teacher tools

Teachers also found Khanmigo's teacher tools, particularly the creation of lesson plans, to be particularly valuable. Vélez remarked at how collaborative the lesson planning process with Khanmigo was, stating that Khanmigo's suggestions encouraged him to think deeply about the compatibility between his students and the lesson plan and to identify important missing explanations.

> **Vélez-** "*And in that discussion, I realized and I said 'Wow, I'm missing this." And in the conversation, it tells me something, but I also told it something and it was like "Of course! You have to include that." So, it was a very interesting conversation."*

Vélez remarked that this was useful to make sure he didn't skip any steps in explaining material to his students, who might need explanations of intermediary steps to scaffold their current knowledge. He also mentioned that his substitution classes are often given by teachers who are

not math teachers- who may, for example, teach history or Spanish and who haven't taken a math class in a long time- and that Khanmigo's thorough lesson plans can help them better guide students through substitution work.

A veteran teacher enthusiastic about incorporating technology in the classroom, Gómez marveled at the time-saving aspect of the lesson plan tool. She commented that Khanmigo not only created a plan to be used in class, but also identified the Khan Academy videos and practice sets that corresponded to the material in question, helping simplify the process of assigning material to students.

> **Gómez-** "*Because when you ask for the lesson plan, which it gives it to you whole, with the exit ticket and everything, it also gives you the lessons it recommends you assign in Khan Academy itself. So, you don't have to be searching "ok now let me go into Khan Academy to see what to [assign] since I'm giving this material."*

In short, Khanmigo also appeared to add value to teachers' practice, giving them more time and bandwidth to think about the material they are teaching more deeply and to select appropriate practice material for their students.

Student motivation

Teachers' feedback regarding Khanmigo's effect on student motivation was mixed. A common observation was that students are, to a certain extent, used to instant gratification when it comes to technology use and obtaining information. While some students were naturally curious and chose to explore with Khanmigo, even venturing to topics beyond math class, many were mildly frustrated by Khanmigo's refusal to outright provide an answer to the problem in question.

Gómez- *"What happens is that they're impatient and they want the answer. And they don't want to go through the process, and that's a struggle we've had with kids since the beginning of time."*

Meléndez- *"Technology in some way has gotten us used to everything being fast… Like, the teacher is telling you step by step what goes next, but some students would lose their patience with that and say "Look, I'm not gonna do this because I'm not trying to waste my time.""*

That all interviewed teachers mentioned this speaks to a more deeply rooted problem of students not having developed the patience for problem-solving throughout their schooling. This suggests, however, that a focus on problem-solving that is not technology-assisted could significantly help students develop the patience and perseverance necessary for tackling the more complex math problems they encounter in later grades. Ideally, such teaching strategies would be present in students' elementary and early childhood education; however, maintaining a growth mindset that frames middle schoolers as capable of developing this patience is important, and Khanmigo is arguably a tool that can help them do so with repeated use and habit-building.

Student self-efficacy

Finally, Vélez found Khanmigo to be particularly valuable to student self-efficacy in the Montessori context. He explained that Montessori teachers encourage students to practice the "Three before me" strategy, where they seek help from three different resources (reference material, classmates, etc.) before asking their teacher for assistance. He envisioned Khanmigo having a well-defined place in Montessori teaching within this framework, as one of the "three before me" resources. Importantly, he believes that Khanmigo's step-by-step guidance can help promote a feeling of accomplishment and self-sufficiency for students.

> **Vélez:** *"I think that's one of the things that one most has to help build as a teacher. For them to feel that they're capable of doing things, and that through that capacity they can continue to be efficient in their classes and in life, which is the goal… "Three before me" is one of the parts where I most see Khanmigo being efficient. Meaning, it can be part of the "three before me" first step. That "I don't know how to do this," then go and ask Khanmigo. It seems like a very good first step to me."*

Jiménez echoed this sentiment during one of the classes his research team observed. When a student commented that they did not know what to do, he encouraged them to ask Khanmigo for help with the problem first. He joked how it was a relief to be able to unload work to Khanmigo— and yet he immediately responded when a student who appeared to be struggling asked for his help. Jiménez masterfully identified which students would be able to get unstuck and continue the practice set on their own just using Khanmigo's help– and he knew exactly which students needed more assistance and personalized attention from him.

This event perfectly highlighted one of the foundational tenets of participating teachers' practice—that teachers carry out vital roles that neither AI nor any other educational technology will be able to reproduce. Throughout their interviews, the teachers displayed an intimate familiarity with the ways in which they, as people who care for their students, can help students learn and develop independent of technology's presence in the classroom. In the face of almost constant challenges throughout the school year, these teachers displayed an unwavering dedication to their students' education and wellbeing. Thus, Khanmigo can best be viewed as a tool, a supplement to teachers' already good work, which can free up some of these educators' time so they can focus on what they do best; connect with and teach students.

Discussion

Our findings indicate that with consistent usage, Khanmigo has incredible potential to fit well into teachers' existing teaching practices and to help students develop their math knowledge and problem-solving skills. Students responded either positively or neutrally to the tool, and it appeared to have no detrimental effects on students' math motivation. Teachers found that, when accessible, Khanmigo saved them time, aided them in lesson planning, and helped students work through questions and progress through math material in more self-sufficient ways. The research team also observed instances where Khanmigo was able to help students thrive and keep up with material despite exigent personal circumstances, and where it piqued the interest of students whose curiosity and academic vitality is sometimes overflowing. Thus, it is the research team's firm belief that under the right circumstances, Khanmigo can be an excellent tool that can help promote educational equity in underserved communities such as PR's public school system.

Yet, a more thorough review of Khanmigo and its benefits and/or drawbacks for the student populace would require a) a larger sample size, b) the opportunity to compare to a counterfactual, and c) the ability to implement Khanmigo use in the classroom with fidelity. The third of these was the biggest barrier in this pilot project. Our school communities' motivated teachers and students could only do so much in the context of unreliable access to the internet, to technology, and at times, to electrical power itself. Children cannot be made responsible for securing the resources they need to learn, and as more than one teacher commented during informal observation visits, planning a lesson that depends on a resource that cannot be reliably counted on would be, frankly, irresponsible on their part. The participating teachers prioritized students' learning above all, which at times meant setting aside technology and continuing a class with limited resources or with concrete manipulable tools that students find familiar and learn well with. Therefore, the foundational issue that prevents us from observing more marked

improvements in students' math motivation and educational outcomes has nothing to do with student or faculty shortcomings in interest, curiosity, or dedication.

The systemic barriers that impeded more consistent Khanmigo use are, ultimately, the results of large-scale emergencies that have severely compromised school infrastructure and education system organization. Puerto Rico's unstable electrical grid, the sudden need for and haphazard distribution of student devices brought on by the pandemic, and the almost constant presence of natural disasters have left teachers, administration, and education professionals struggling to put out metaphorical fire after fire. Significant improvement in education quality therefore depends on aggressive action towards both repairing educational infrastructure damaged by years of continued emergencies and preparing it for future emergencies. Only then, when teachers, students and administrations can feel secure in their education system and resources, will we see more Jessicas making the most of edtech tools. Only then will we see teachers like Vélez and Jiménez able to bring effective tools such as Khan Academy and Khanmigo consistently in their classrooms. Only then can we expect to see a reduction of the academic achievement gap between PR's students and mainland US students.

Conclusion

The continued trailblazing of education technologies brings forth several urgent questions. There is, of course, the fundamental question of what education work can be left to machines and computers—and transitively, what work can only be achieved by the human connection in the teacher-student relationship. There is also the ever-growing fear of technology being used for cheating and plagiarism, and what academic integrity will look like in the age of ChatGPT and instant math-solving mobile applications. But those of us whose education work focuses particularly on equity have even further concerns. Those of us living and working in

under-resourced and underserved communities are used to seeing new education tech discourse take off in the education zeitgeist. We are used to being asked to comment on the latest technologies being brought into classrooms—classrooms that are assumed to be equipped with technology literacy and resources. And we are, of course, used to seeing our schools and students be left behind yet again. We are used to wondering what these new technologies could do for our students; if only a 1-to-1 student to device ratio were possible in the first place, if only our students didn't have far bigger fish to fry in their home lives than homework, if only all our students had a home to go to– if only, if only, if only. Our concerns go deeper than the effectiveness of educational technology. Our concerns consider whether each new education technology tool will, rather, exacerbate the already severe educational inequalities we encounter in our school systems to begin with.

The public education system in Puerto Rico falls squarely into the under-resourced category. Repeated natural disasters have crippled public service infrastructure and systems of all kinds. Yet, this pilot study has demonstrated that despite these overwhelming odds, Puerto Rico has no shortage of the human capital necessary to overcome adversity in the education system. Teachers are willing to use new technologies, students are willing to explore them, school administrators are willing to adapt to new situations and new barriers in the name of their students' education, again and again and again. It is therefore the responsibility of those of us who can see the bigger picture– researchers, policymakers, and education department officials at the central levels– to ensure that our school communities have the resources they need to thrive. Puerto Rico's students, teachers and school staff can make a lot out of very little; but they need to be given something to begin with, a fighting chance to make the best out of their educational resources. It is our sincere hope that this pilot study can illuminate the ways in which higher

level education professionals can better equip school communities for success, and it is our humble goal to point out our community's strengths and capacities along the way.

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Appendix A

Description of Critical Incidents throughout *Estudia Khanmigo* Implementation

Critical Incidents

1) ***Change from SIE to PowerDE-*** At the beginning of the 2023-24 school year, PRDE changed its student information system from the Sistema de Información Estudiantil (SIE) to PowerDE (provided by Powerschool). This required school principals and their administrative team to perform a complete migration of all school organization data into PowerDE. Schools' administrative staff had limited access to training and guidance on managing the data migration. While one participating school was able to complete data migration in late August, the other had to schedule a PRDE IT assistance session and was therefore not able to finalize the migration until late September. Additionally, because the after-school program RAE was not approved until late August, RAE rosters took longer to update.

2) ***Clever synchronization issues-*** Due to contracting delays and issues, Clever was not able to accurately sync with PowerDE until late October. Thus, teachers did not have student rosters synched to Khan Academy classes and were not able to assign work and monitor student progress. Additionally, on November 30th, a synchronization of RAE roster updates went wrong and upended all PRDE school rosters. This caused around half of the teachers and students to suddenly be assigned to different schools on Clever, preventing many from being able to view the Khan Academy logo in their dashboard. Khan Academy classes (i.e. teacher courses with linked student rosters) also disappeared altogether. Consistent contact was kept with the Clever/PRDE contractor, who was able to remedy the situation early the next week.

3) ***Device Availability-*** School B experienced individual challenges in the form of limited device availability. Because student devices had been secured in 2020 when the

school had around 50% of its current student enrollment, a 1-to-1 device to student assignment was not possible. After accounting for device loss, disrepair, and warranty expiration each teacher only had 5 laptops for every home room (approximately 20 students each). These devices were undergoing maintenance and inventory registry and became available to teachers and students in early November (~Nov. 9th). To address this shortage of device availability, researchers purchased 30 Amazon Fire tablets to distribute to the School B teachers (15 per teacher).

4) ***Consistent connectivity issues with Khan Academy-*** PRDE Wifi network connectivity issues with Khan Academy became evident in October. These issues involved student and teacher devices being able to access Clever but receiving an error message upon trying to enter Khan Academy. This occurred independent of browser used, and continued occurring even after browser cache was cleared and third-party cookies were allowed. Internet technicians were called several times, to no avail. HotSpots and personal wifi networks were a workaround, so the problem seemed specific to the school network. Despite several attempted fixes, these problems persisted until March, when participating teachers were given small routers to use as hotspots.

5) Email issues for new teacher- One of the School B teachers was new to the public school system. This meant his PRDE email address was new. Due to technical issues with the novelty of the email account (outside of the teacher's control), he was unable to reliably receive messages at that email address until November. This caused significant issues being able to access his Clever and Khan Academy accounts, preventing him from being able to reliably assign KA material to his students.

6) Teacher resigned- The new School B teacher ended up resigning in mid-March. Because of the proximity to the end of the semester, unavailability of district substitutes, and the bureaucracy-laden process of hiring a replacement teacher, his position was not filled by another teacher. Students were instead taken to the library and shown videos to cover content. The librarian was instructed to tell students that any content questions should be directed to their science and history teachers.

7) *School construction-* School A had earthquake safety construction begin in January. This construction made one of the two wings of the school's main building completely unusable. Thus, a system was devised where instead of students travelling to each teacher's classroom, students remained in their homeroom and teachers travelled to them. Construction also regularly interfered with electrical service, as cable work and breakers were located in the affected wing. In February and March, serious interference occurred with electrical work, causing the other wing of the school's main building to suffer from low voltage. This affected A/C unit usage, internet connectivity, lighting, and more.

8) *School principal unavailable-* School A also faced the principal's absence between January and mid-March. During this time, one of the math teachers involved in the Khanmigo project took over the role of assistant principal to the new part-time interim principal. This limited her ability to focus on Khanmigo implementation and usage in her class.