International Journal of Bilingual Education and Bilingualism

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rbeb20

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INTERNATIONAL JOURNAL OF BILINGUAL EDUCATION AND BILINGUALISM
https://doi.org/10.1080/13670050.2024.2446987

The effects of ethnomathematics education on student outcomes: The JADENKÄ program in the Ngäbe-Buglé comarca, Panama

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ABSTRACT

To provide experimental evidence on the effectiveness of an ethnomathematics education program, in this article we evaluate the impact of JADENKÄ, an intercultural bilingual program designed to increase the mathematical and ethnomathematical skills of Ngäbe preschoolers, within the *comarca* Ngäbe-Buglé in Panama. Our results indicate positive effects of the program on the mathematical and ethnomathematical skills of students. The magnitude of the impact on mathematics (0.12–0.18 *SD*) is comparable to other intercultural bilingual education preschool programs in low- and middle-income countries. In ethnomathematics, the impact is around 0.23 *SD*. Additionally, and consistently with other studies, we find that JADENKÄ has a positive effect on the cultural identity of students. Second, results suggest that the effect of the program in ethnomathematics is higher for students who speak Ngäbere and for those whose teacher identifies as Ngäbe. Finally, the program increased teachers' ethnomathematical skills and knowledge of the Ngäbere language and culture. So, contrary to the position taken by some critics of ethnomathematics education, our findings indicate that a well-designed ethnomathematics program can reduce the indigenous achievement gap without putting students in a dilemma between their academic learning and their identity, culture, and language.

ARTICLE HISTORY
Received 2 December 2021
Accepted 19 December 2024

KEYWORDS
Ethnomathematics; intercultural bilingual education; randomized controlled trial; indigenous languages

Introduction

Within mathematics education research, ethnomathematics has developed from the idea that mathematics exists within cultural and social contexts. Most definitions of ethnomathematics share two basic assumptions (Cimen 2014). First, mathematics is not universal, because it is a human creation (Bishop 1988; D'Ambrosio 1985). Second, anthropological and historical studies (e.g. Ascher and D'Ambrosio 1994; Gerdes 1994; Rosa and Orey 2005) support that, throughout history, different cultural groups have created their mathematical language. One area of debate concerns the practical implementation of ethnomathematics education and its impact on learning.

Ethnomathematics education proponents offer four arguments. First, ethnomathematics builds on the knowledge that students bring to the classroom, allowing them to better understand the

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formal mathematics (Adam, Alangui, and Barton 2003; Clarkson 2007; Stillman and Balatti, 2000). Second, exposed to different mathematical cultures can boost their self-esteem and motivation to learn (Powell and Frankenstein 1997). Third, ethnomathematics attributes value to students' culture, which can improve their attitudes towards their cultural heritage (Meaney 2002; Rosa and Gavarrete 2017). Fourth, giving students the skills to be successful within their two (or more) cultures has been linked to improved learning (LaFromboise, Coleman, and Berton 1993).

Some researchers are skeptical about ethnomathematics in the school curriculum, worrying about potential negative effects on integration and equity as ethnomathematical skills would not help students compete in an increasingly mathematized world (Rowlands and Carson 2002; Skovsmose 1994). Others argue that school should be the place of universalized rather than local knowledge (Rowlands and Carson 2002). Contrary to the ethnomathematical stance, which argues that students have non-formalized mathematical skills before they start school, these scholars argue that all students are equally positioned to learn new knowledge (Rowlands and Carson 2004). Finally, some scholars worry that ethnomathematics education may generate ethnic conflicts by strengthening cultural identities (Vithal and Skovsmose 1997).

Despite the extensive theoretical debate, there is limited empirical evidence on the impact of an ethnomathematics approach within formal school systems. Additionally, most empirical studies are based on small samples (e.g. Adam 2004; Amit and Abi Quoder 2017). An exception is a randomized controlled trial (RCT) conducted in two regions in southwest Alaska, which examined the efficacy of a culturally based supplemental mathematics curriculum in 50 schools (Eliason Kisker et al. 2012). Their results show that the program significantly improved students' mathematics performance. Although it is also scarce, there is more evidence on the effect of bilingual education programs in the indigenous language on mathematics' learning. For example, Baker and Lewis (2015) summarize the literature on the evaluation of this type of program in the United States and Canada. According to the evidence reviewed by the authors, students in indigenous language programs tend to perform better than comparable monolingually educated children in several curriculum areas, including mathematics. They also conclude that when the home language is used in school, a child's sense of identity, self-esteem, and self-concept may be enhanced. In Latin America, Näslund-Hadley, Parker, and Hernández-Agramonte (2014), based on an experimental evaluation design, document a positive and significant improvement of 0.16 standard deviations in standardized test scores of students participating in a bilingual preschool mathematic program in Paraguay. Moreover, the program improved learning equally among both Guaraní- and Spanish-speaking students.

Based on this literature, the aim of this article is to provide rigorous at scale experimental evidence on the effectiveness of an ethnomathematics education program. This article describes and evaluates the impact of JADENKÄ (pronounced Ha-den-go), an intercultural bilingual education (IBE) mathematics program designed to increase the mathematical and ethnomathematical skills of the preschoolers in the *comarca* Ngäbe-Buglé[1] in Panama. To our knowledge, this is the first study to evaluate the effectiveness of an ethnomathematics intervention in preschool education through an RCT.[2] The program was designed by a team of experts in early mathematics pedagogy, Ngäbe mathematics and language, Interactive Radio Instruction (IRI) methodology,[3] as well as Ngäbe actors and singers.

The background to the JADENKÄ program is twofold. First, Panamanian students score below the Latin American average in mathematics on the regional standardized learning assessment (TERCE).[4] 60.1% of Panamanian third graders scored at the lowest level of achievement in mathematics. Second, Panama has some of the region's largest learning gaps between indigenous and non-indigenous students. In third grade, indigenous students are 0.64 standard deviations below non-indigenous students in mathematics. In sixth grade, the gap increases to 0.7 standard deviations (OREALC/UNESCO 2017). The data from the national learning test (CRECER)[5] show that 83% of students in the *comarca* Ngäbe-Buglé achieve only the lowest levels of learning in mathematics (very low and low) (Sánchez-Restrepo 2019). The *comarca* Ngäbe-Buglé also has lower preschool attendance rates compared to other provinces, as well as higher rates of over-age students, repetition, and dropout (UNICEF 2019).

Materials and methods

Theoretical framework of JADENKÄ

JADENKÄ is an intercultural bilingual education (IBE) mathematics program designed to increase the mathematical and ethnomathematical skills of the preschoolers in the *comarca.* By mathematical skills, we understand the set of skills included in the mathematics preschool national curriculum in Panama and which at the same time are consistent with those assessed in standardized tests designed to measure student's skills in numeracy and mathematics in the early grades (RTI International 2009). By ethnomathematical skills and following the definition of Bishop (1988) who defines ethnomathematics as 'the knowledge of an identifiable sociocultural group, within the framework of its worldview, which is manifested through the following activities: counting, measuring, locating, designing, playing, and explaining', we define ethnomathematics skills as the specific arithmetic and geometry skills developed by the Ngäbe people. As explained in detail in the next subsection, the Ngäbe people have their counting system, which is not based on the decimal system taught in the national curriculum.

As was also pointed out in the introduction, literature suggest that an ethnomathematics program has the potential to improve students' cultural identity, so it is a dimension in which we evaluate the effect of the program. In this article, we define the cultural identity of the student as her knowledge, perception and attitude to elements of the Ngäbe culture (Sparks and Shepherd 1992). Elements of Ngäbe culture include handicrafts, clothing and dances. Following Birukou et al. (2013), we define culture as a set of traits (e.g. behavior, knowledge facts, ideas, beliefs, norms, etc.) that are shared and/or learned by a group of people, in this case by the Ngäbe people.

Design and implementation of the JADENKÄ program

JADENKÄ was designed by a team of experts in the Ngäbe culture and initial education. The Organization of Ibero-American States (OEI) led the design of the program, in collaboration with the Inter-American Development Bank (IDB) and the Ministry of Education of Panama (MEDUCA).

To define the mathematical skills that the program would seek to develop, the first step was to review the Panama national curriculum. Preschools in the *comarca* follow this curriculum, which encompasses a module on Mathematical Logical Thinking that covers concepts aligned with those taught internationally in preschool and kindergarten (MEDUCA 2014). The curriculum is intended to be taught through 60-minute daily lessons throughout the 200-day academic year. In developing JADENKÄ, all key content areas of the national curriculum had to be included, without expanding the actual time for mathematics instruction. Based on this, the curriculum of the program was structured on four major mathematical concepts: spatial and temporal thinking, geometry, numerical thinking, and mathematical operators. Within each of these concepts, a set of mathematical skills are developed (see Table A1 in the Appendix).

Following this set of mathematical skills, the curriculum was then structured to develop students' ethnomathematical skills, incorporating the elements of the Ngäbe culture. Elders from the *comarca* were consulted about the proposed learning objectives, concepts, skills, and activities of the program. These consultations were crucial to the acceptance of the program in the school communities. However, more valuable was a mapping of the everyday use of mathematics by the Ngäbe, including traditions, songs, children's games, the use of mathematics and geometry in spirituality, cosmology, farming, art, and clothing.

Based on this mapping, an expert on Ngäbe mathematics and language worked with pedagogues to structure the curriculum of the program into five units that integrated the concepts of the national curriculum with ethnomathematical concepts: *What are numbers? Let's work with numbers! The Shape of things! Let's measure! And Where is it?* For example, the *What are numbers?* unit covers both the mathematics numbering system in the national curriculum and the Ngäbe numbering system with roots for numerals that are combined with classifiers. The learning objectives of the unit include skills in using 11 different roots, depending on the characteristics of the object counted[6]. Students learn that an orange should be classified as round and rendered as 'Kwa-ti-naran' or 'rounded thing-one-orange'. They also learn that if that same orange is cut in half and is no longer round, its noun class changes, affecting the way it is counted. The shapes in the students' daily lives form the starting point of the unit *The Shape of things!,* including those used in *Ngäbe clothing, farming and art*. In the unit *Let's Measure!*, the linear concepts of time laid out in the national curriculum (e.g. before and after), are complemented with the Ngäbe notion of time as circular. Students learn to recognize seasonal patterns when different community activities should begin (e.g. harvesting specific crops and times for celebrations) and the linkages to the state of plants, animals, and insects.

Similar to a vast number of Intercultural Bilingual Education (IBE) schools throughout Latin America (Näslund-Hadley and Santos 2021), many of the teachers in participating schools are not from the *comarca* and do not speak Ngäbere. An additional complication is that every classroom has a mix of monolingual students in Spanish or Ngäbere, as well as bilingual students. To implement JADENKÄ in this context, Ngäbe actors and singers were contracted to record 108 audio lessons that repeat all key concepts in Spanish and Ngäbere. Each audio has a duration of about 45 minutes, guiding the teacher in the delivery of the lesson. The audios are based on an inquiry and problem-based pedagogical approach where students learn by working in groups to solve mathematical challenges under teacher guidance, and sing and dance to songs that aim to reinforce different concepts. Teachers were instructed by the MEDUCA to use the last 15 minutes of each class for post-audio activities that were designed to reinforce key concepts. Teachers received a 2-day training in the use of audio lessons and post-audio activities. The training was complemented by coaching visits to support and monitor the implementation. In addition to USB drives with the audio lessons, each classroom was also equipped with a radio, a set of ethnomathematics story books in Ngäbere, a teacher guide, student worksheets, post-audio materials and simple materials such as counters. All these activities were implemented by the OEI in conjunction with the MEDUCA.

JADENKÄ was conducted during the 2018 and 2019 academic years. In practice, school closures due to floods, rains, and extreme weather, among other issues (e.g. logistical problems affecting the reception of materials, power outages), dramatically decreased the actual number of JADENKÄ lessons that were implemented. Since children do not have public transportation available, they generally must walk very long distances to school, so weather difficulties have a very strong impact on school attendance. The actual implementation period was 6 months in 2018 and 7 months in 2019. On average, 25.5 audio lessons were implemented in each classroom in 2018 and 36.0 in 2019. Although the MEDUCA instructed all schools and teachers in the treatment group to participate, the average of implemented lessons hide disparities among classrooms, ranging from 1 to a maximum of 61 in 2018 and 87 in 2019. In addition to the external factors, the different levels of implementation also reflect varying levels of interest in the program of individual teachers and school directors since the schools in practice had a certain autonomy to implement the program. Additionally, MEDUCA did not have sufficient capacity to supervise all participating schools.

Research questions

Our study seeks to answer three research questions. First, what was the impact of JADENKÄ on mathematics and ethnomathematics skills of students (RQ1)? These are the main expected outcomes of the program. Second, did the program have an impact on students' oral comprehension of Spanish and Ngäbere and cultural identity? (RQ2). Even though JADENKÄ is aimed at improving students' mathematical and ethnomathematical skills, the literature suggests that the program could have effects on other outcomes. For example, the fact that JADENKÄ combines content in Spanish and Ngäbere could have a positive impact on oral comprehension in both languages (Näslund-Hadley, Parker, and Hernández-Agramonte 2014). Also, the program's emphasis on the use of ethnomathematics and Ngäbere, as well as the inclusion of content related to the Ngäbe culture could have an effect on the student's cultural identity. Third, what impact did the program have on teachers (RQ3)? First, including JADENKÄ could have increased the amount of time allocated to mathematics, because even though the activities should have been carried out during the 60-minute daily lesson, it is possible that the teachers should have extended the class to implement the activities of the program. On the other hand, the program may have had positive effects on perceptions of the teaching of mathematics and ethnomathematics. Finally, the JADENKÄ program introduces the Ngäbe culture in the classroom. Therefore, it is plausible that the program may have had an impact on teachers' knowledge of the culture.

Evaluation instruments

The design and implementation of the evaluation instruments was carried out by Innovations for Policy Action (IPA), based on standardized instruments. Student assessment was applied by trained interviewers, using tablets. The evaluation is individual, which means that each interviewer administers one test to one student at a time. The enumerators belonged to the Ngäbe community and were fluently both Spanish and Ngäbere. The test was designed to measure five dimensions: (i) mathematical skills; (ii) ethnomathematical skills; (iii) oral comprehension in Spanish; (iv) oral comprehension in Ngäbere; and (v) cultural identity. Students' outcomes are measured as follows:

Mathematic skills: An adaptation of the Early Grade Mathematics Assessment (EGMA), developed by the United States Agency for International Development (USAID). This instrument has been extensively validated internationally (RTI International 2009). We used an adaptation that was validated in the context of Panama by Innovations for Poverty Action (IPA) with the support of MEDUCA. Table A1 shows the relationship between the skills developed by the program and those measured in EGMA.

Ethnomathematics skills: In the absence of a Ngäbe preschool mathematics instrument, a set of questions were designed and validated to measure the use of Ngäbe classifiers, roots, and mathematical operations; and grade-level components of ethnomathematics.[7] Measurement areas are parallel to some included in EGMA (Shape recognition of Ngäbe shapes, Counting objects, Number selection, and Addition and Subtraction), to ensure that we are measuring at least one comparable ability.

Oral comprehension in Spanish: We used an adaptation of the Early Grade Reading Assessment (EGRA), developed by USAID.

Oral comprehension in Ngäbere: A Ngäbere version of EGRA was also contextualized towards objects close to the Ngäbe culture.

Cultural identity: We included a module with items related to cultural identity: knowledge, perception, and attitude to Ngäbe objects (Sparks and Shepherd 1992). From these questions, we constructed and index measuring the knowledge of elements of the Ngäbe culture ('Nagua': traditional clothing and 'Kra': traditional bag), the preference of traditional Ngäbe clothing versus 'Latino' clothing and the attitudes to the traditional Ngäbe dance 'Jeki'.

The average test application was 26 minutes, including sections in Spanish (EGMA and EGRA-Spanish), and Ngäbere (Ethnomathematics skills, EGRA-Ngäbere), and sections in either of the two languages. Other instruments included questionnaires for school principals, teachers, and parents. From teacher's questionnaire, we created an index of perception about mathematics and ethnomathematics, based on a Likert scale on statements related to both dimensions and a set of variables measuring their knowledge of Ngäbe culture, words, objects, and ethnomathematics.

Descriptive statistics of the sample and balance test

The final sample of the study includes 125 control and 248 treatment schools. The evaluation was carried out in the same sample of schools during both years. The details of the sample selection and randomization can be requested from the authors.

Experimental impact evaluations generate comparable groups before the intervention (Kopper and Sautmann 2021). Table 1 shows descriptive statistics of the sample and a *t*-test of the differences of the means (balance test) of a set of student, teacher, and school pre-treatment variables for both groups.

A majority of students (94.4%) are identified as Ngäbe by their teacher. However, most speak Spanish at home (72.7%). The rest speak Ngäbere or both languages. Only 29.3% of teachers self-identify as Ngäbe. Most (77.2%) declare to speak Spanish better, while 4.8% speak Ngäbere better and 17.5% both languages equally. As in many rural areas of Latin America, a high percentage of teachers do not have a degree in education (22.8%). Finally, 73% of schools are within the *comarca* Ngäbe-Buglé and 27.0% in the surrounding areas. 59.5% are unigrade (i.e. in the classroom with students of one grade-level) and the average size is 284 students. 37.5% declare that they use an IBE methodology and 40.0% have teachers with training in this educational model. In 43.7% of the schools, the predominant language is Ngäbere. Finally, a high percentage have connectivity problems: 22.6% do not have communication equipment (radio, telephone, or internet), 30.6% do not have electricity and only 38.0% have an internet connection. In terms of these characteristics, there are no significant differences between the treatment and control groups.

At baseline, there were no statistically significant differences in the main outcomes of JADENKÄ. Only in Oral Comprehension in Spanish, the treatment group scored 0.109 standard deviations over the control group. For teachers, no significant differences were observed in their pre-treatment knowledge of ethnomathematics. Finally, there are no significant differences in the degree of implementation of actions related to IBE education between treatment and control schools. These results are important to ensure that the post-treatment comparison between the two groups is an unbiased estimator of the effect of the program.

Econometric model

For the analysis of each student outcome (i.e. mathematical skills, ethnomathematical skills, oral comprehension in Spanish, oral comprehension in Ngäbere, and cultural identity), the score in each of them was calculated and standardized using the following formula:

$$Zij = \frac{Xij - \mu_c}{\sigma_c} \tag{1}$$

where Xij represents the score of each student i in school j, μ_c is the mean of the control group score, and σ_c is the standard deviation of the control group score. Zij expresses the standardized score, that is, expressed in standard deviations from a normal distribution where the mean is 0. The mean of the control group is used because it represents the mean of the population in the absence of intervention.

To estimate the effects of the program, we use a regression with the following specification:

$$Y_{is} = \mu_s + \beta T_{is} + \varepsilon_{is} \tag{2}$$

where Y_{is} is the post-treatment standardized score of the student i in the stratum s, μ_s is a stratum fixed effect and ε_{is} is the error. T_{is} equals 1 when the student receives the treatment and 0 when it is part of the control group. In this and in all the specifications presented later, standard errors are clustered at the school level to avoid ‘over-rejection’ (Bertrand, Duflo, and Mullainathan 2004). Following

Table 1. Descriptive statistics of the sample and balance test of pre-treatment variables.

	Control (C)	Treatment (T)	Overall	(C) − (T)	*p*-value from orthogonality test (§)
Students					
Mathematics (*SD*)	0.000	0.035	0.023	−0.035	0.582
	(0.048)	(0.040)	(0.031)	(0.063)	
Ethnomathematics (*SD*)	0.000	0.028	0.019	−0.028	0.691
	(0.059)	(0.040)	(0.033)	(0.071)	
Oral comprehension in Spanish (*SD*)	0.000	0.109	0.073	−0.109	0.052*
	(0.043)	(0.036)	(0.028)	(0.056)	
Oral comprehension in Ngäbere (*SD*)	0.000	0.007	0.004	−0.007	0.907
	(0.042)	(0.038)	(0.029)	(0.057)	
Cultural identity (*SD*)	0.000	0.041	0.027	−0.041	0.529
	(0.053)	(0.037)	(0.030)	(0.064)	
Age	5.500	5.492	5.495	0.007	0.843
	(0.030)	(0.020)	(0.017)	(0.036)	
Female (%)	0.540	0.561	0.554	−0.021	0.708
	(0.045)	(0.031)	(0.026)	(0.055)	
Language spoken at home: Spanish (%)	0.719	0.731	0.727	−0.012	0.674
	(0.023)	(0.016)	(0.013)	(0.028)	
Language spoken at home: Ngäbere (%)	0.212	0.213	0.213	−0.002	0.944
	(0.019)	(0.013)	(0.011)	(0.023)	
Language spoken at home: Spanish and Ngäbere (%)	0.069	0.056	0.060	0.013	0.325
	(0.011)	(0.008)	(0.006)	(0.013)	
Ngäbe student (reported by teacher) (%)	0.939	0.946	0.944	−0.006	0.742
	(0.016)	(0.010)	(0.008)	(0.019)	
N	2275	4560	6835	6835	
Teachers					
Ethnomathematics knowledge (*SD*)	0.000	0.043	0.030	−0.043	0.588
	(0.066)	(0.045)	(0.037)	(0.079)	
Female (%)	0.915	0.912	0.913	0.003	0.918
	(0.026)	(0.017)	(0.014)	(0.031)	
Age	38.619	38.567	38.583	0.052	0.959
	(0.824)	(0.586)	(0.477)	(1.012)	
Best spoken language: Spanish (%)	0.756	0.778	0.772	−0.022	0.602
	(0.036)	(0.025)	(0.021)	(0.042)	
Best spoken language: Ngäbere (%)	0.050	0.047	0.048	0.003	0.894
	(0.017)	(0.013)	(0.010)	(0.022)	
Best spoken language: Spanish and Ngäbere (%)	0.188	0.169	0.175	0.019	0.628
	(0.032)	(0.021)	(0.018)	(0.038)	
Best spoken language: Other (%)	0.006	0.006	0.006	0.001	0.923
	(0.006)	(0.004)	(0.003)	(0.007)	
Ngäbe (self-declared) (%)	0.331	0.276	0.293	0.055	0.234
	(0.040)	(0.027)	(0.023)	(0.047)	
No teacher title (%)	0.246	0.220	0.228	0.026	0.603
	(0.042)	(0.026)	(0.022)	(0.050)	
N	178	387	565	565	
Schools					
School inside comarca Ngäbe-Buglé (%)	0.763	0.714	0.730	0.049	0.331
	(0.040)	(0.030)	(0.024)	(0.051)	
School has formal preschool (%)	0.680	0.720	0.706	−0.040	0.466
	(0.046)	(0.031)	(0.026)	(0.055)	
School has non-formal preschool (e.g. CEFACEI) (%)	0.476	0.459	0.465	0.017	0.781
	(0.049)	(0.035)	(0.028)	(0.060)	
School has pre-K education (%)	0.729	0.705	0.712	0.024	0.717
	(0.054)	(0.037)	(0.031)	(0.066)	
School has K education (%)	0.971	0.946	0.954	0.025	0.409
	(0.020)	(0.019)	(0.014)	(0.030)	
Monograde school (%)	0.610	0.587	0.595	0.023	0.682
	(0.045)	(0.032)	(0.026)	(0.055)	
Total enrollment	282.940	285.167	284.439	−2.228	0.947
	(23.524)	(20.251)	(15.632)	(33.376)	

(*Continued*)

Table 1. Continued.

	Control (C)	Treatment (T)	Overall	(C) − (T)	*p*-value from orthogonality test (§)
School uses Intercultural Bilingual methodology (%)	0.362	0.381	0.375	−0.019	0.734
	(0.045)	(0.031)	(0.026)	(0.055)	
School has teachers with IBE training (%)	0.459	0.373	0.402	0.086	0.131
	(0.048)	(0.032)	(0.027)	(0.057)	
Intercultural Bilingual Education (IBE) index	2.420	2.421	2.421	−0.001	0.993
	(0.045)	(0.037)	(0.029)	(0.061)	
Predominant language: Ngäbere (%)	0.466	0.424	0.437	0.042	0.458
	(0.047)	(0.032)	(0.026)	(0.056)	
Technological equipment quality index	2.337	2.389	2.371	−0.053	0.455
	(0.059)	(0.040)	(0.033)	(0.070)	
School does not have communication equipment (%)	0.228	0.226	0.226	0.003	0.958
	(0.039)	(0.027)	(0.022)	(0.048)	
School has no electricity supply (%)	0.299	0.309	0.306	−0.009	0.855
	(0.043)	(0.030)	(0.024)	(0.052)	
School has internet connection (%)	0.402	0.369	0.380	0.032	0.555
	(0.046)	(0.031)	(0.026)	(0.055)	
N	118	243	361	361	

Notes: (§) *p*-values from a *t*-test of the differences of the means of each variable. *, **, *** indicate that differences are statistically significant at a confidence level of 0.10, 0.05 and 0.01 respectively. *SD* indicates that the variables are standardized to the mean and standard deviation of the control group. School variables are reported by the principal. Type of education variables may not add up to one because a school may have more than one type. Technological equipment includes: computers, printers, projectors, photocopiers, televisions, video players, slide projectors, audio equipment, cameras, and video cameras. The index varies between 1 (lowest quality) and 3 (highest quality). Intercultural Bilingual Education (IBE) index is constructed from the actions implemented by the school in four dimensions: elaboration of educational plans with bilingual intercultural education, teacher training, enrichment of pedagogical materials and interaction between the school, the community, and the students. The minimum value of the index is 1 (absence of actions) and 4 (constant implementation of actions).

the impact evaluation literature, β is the Intention to Treat Effect (ITT). The ITT is an estimate of the effect of the program on those assigned to treatment. In many cases, researchers and policymakers care about identifying the impact of the offer of the program, even if some of them did not take it up, as this will resemble what will be likely to happen if the program is rolled out. For this reason, this estimator is also known as the 'policy impact' of the program.

To improve the precision of the estimators and test their robustness, the effects are also estimated with the following specification:

$$Y_{is} = \mu_s + \beta_1 Y_{is,\,t-1} + \beta_2 T_{is} + \varepsilon_{is} \tag{3}$$

This model includes the student's standardized score at the baseline as a control variable to reduce residual variance and improve statistical power (Imbens and Wooldridge 2009). However, in the case of the 2019 cohort, it will not be possible to carry out this analysis since no baseline data were collected.

Results

RQ1: impact of JADENKÄ on students' mathematics and ethnomathematics skills

Table 2 shows the average effect of JADENKÄ on the main outcomes of the program for the 2018 and 2019 cohorts and both cohorts together. We found in 2018 an ITT effect of 0.12 standard deviations (*SD*) in mathematics and 0.23 *SD* in ethnomathematics. In 2019, we observe a similar result in ethnomathematics (0.22 *SD*) and a larger magnitude of the impact on mathematics (0.18 *SD*). The 2019 results suggest that better implementation can increase the effect of JADENKÄ on learning. With 10 additional audios on average, JADENKÄ gets an effect 0.06 *SD* higher in mathematics in

Table 2. Impact of JADENKÄ on main outcomes, 2018, 2019 and both years.

	2018				2019		Both years	
	Mathematics	Ethnomathematics	Mathematics	Ethnomathematics	Mathematics	Ethnomathematics	Mathematics	Ethnomathematics
Intention to Treat Effect (ITT)	0.12*	0.23***	0.12**	0.23***	0.18***	0.22***	0.16***	0.23***
	(0.06)	(0.07)	(0.05)	(0.07)	(0.06)	(0.07)	(0.05)	(0.05)
N	2,518	2,518	2,518	2,518	3,246	3,246	5,764	5,764
Controls	No	No	Baseline	Baseline	No	No	No	No

Notes: The table reports the average difference. The scores have been normalized with respect to the distribution of the control group, therefore, the mean of the control group is 0. The standard errors (in brackets) are grouped at the school level. All models include strata fixed effects. *, **, *** indicate that the coefficients are statistically significant at a confidence level of 0.10, 0.05, and 0.01 respectively.

2019. The larger effect in 2019 could also be explained by an improvement in the quality of implementation, since in 2019 several teachers had already participated in the program and because some students may have been exposed to 2 years of lessons. Following Kraft (2020), JADENKÄ obtains an effect in mathematics of medium magnitude and an effect in ethnomathematics of large magnitude.[8]

When we analyze the heterogeneity of the impact, we found that the positive effect in ethnomathematics is higher for students who speak Ngäbere or Ngäbere and Spanish equally and for those whose teacher identifies as Ngäbe. Results of the estimation of the impact of the program depending on student, school, teacher, and students' tutor characteristics can be requested to authors.

Some qualitative evidence[9] suggests that the positive impact of JADENKÄ could be attributed to an improvement in the qualitative aspect of the classes. For example, class observations in a small group of schools showed an increase in the difficulty of the contents and in the time spent in critical thinking and mathematical talk, the incorporation of more topics, a more effective use of materials, and an improved classroom climate in the JADENKÄ classrooms.

RQ2: Impact of JADENKÄ on students' oral comprehension in Spanish and Ngäbere and Cultural Identity

We carried out the analysis presented in Table 2 but applied to three secondary outcomes of the program: (i) listening comprehension in Spanish (Spanish); (ii) listening comprehension in Ngäbere (Ngäbere), and (iii) an index of cultural identity (Identity). Results are presented in Table 3.

First, we did not find significant effects of JADENKÄ on listening comprehension in Spanish or Ngäbere. However, we observe that the treated students obtain a higher score in cultural identity, with a magnitude of 0.14–0.16 *SD* with respect to the control group in 2018. This impact is found again in 2019, with a similar magnitude (0.12 *SD*). These results are consistent with some qualitative data of the program, where we observed a higher use and valuation of Ngäbe cultural elements in the treated schools (e.g. the 'Nagua', a traditional dress, the 'Totuma', a traditional Ngäbe container and the traditional dance 'Jeki'). Additionally, a greater use of Ngäbere was observed as a learning dynamic and to give instructions during classes.

RQ3: impact of JADENKÄ on teachers

Table 4 presents estimations of the impact of the program in various teachers' dimensions, based on the specification in Equation (2) at the teacher level. First, the results indicate that there are no significant differences in the hours of mathematics per week reported by teachers in treatment and control schools. In this way, the effects of the program would be related to the change in the methodology and the contents of the lessons rather than to an increase in the instruction time. Second, we find no statistically significant effects on teacher perceptions of mathematics and ethnomathematics. Finally, results indicate that the teachers increased their knowledge of Ngäbere words (0.56 *SD* in 2018 and 0.69 *SD* in 2019) and culture (0.56 *SD* in 2018 and 0.72 *SD* in 2019), as well as their knowledge of ethnomathematics (0.56 *SD* in 2018 and 0.67 *SD* in 2019). On the other hand, we observe an increase in their knowledge of Ngäbe objects, but only when we add the data from both cohorts.

Discussion

In this article, we describe and evaluate the impact of JADENKÄ, an IBE mathematics curriculum program designed to increase the mathematical and ethnomathematical skills of the preschoolers within the *comarca* Ngäbe-Buglé in Panama. To our knowledge, this is the first study to evaluate the effectiveness of an ethnomathematics intervention in preschool education through a randomized controlled trial design. It is also the first to assess the effect of an intervention on the specific

Table 3. Impact of JADENKÄ on secondary outcomes, 2018, 2019 and both years.

	2018						2019			Both years		
	Spanish	Ngäbere	Identity	Spanish	Ngäbere	Identity	Spanish	Ngäbere	Identity	Spanish	Ngäbere	Identity
Intention to Treat Effect (ITT)	0.00	−0.01	0.16***	−0.02	−0.01	0.14**	0.07	−0.03	0.12**	0.04	−0.02	0.14***
	(0.05)	(0.06)	(0.06)	(0.05)	(0.06)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.05)	(0.04)
Observations	2,518	2,518	2,518	2,518	2,518	2,518	3,246	3,246	3,246	5,764	5,764	5,764
Controls	No	No	No	Baseline	Baseline	Baseline	No	No	No	No	No	No

Notes: The table reports the average difference. The scores have been normalized with respect to the distribution of the control group, therefore, the mean of the control group is 0. The standard errors (in brackets) are grouped at the school level. All models include strata fixed effects. *, **, *** indicate that the coefficients are statistically significant at a confidence level of 0.10, 0.05 and 0.01 respectively.

Table 4. Impact of JADENKÄ on teachers.

	2018	2019	Both years
Number of hours of mathematics per week	−0.33	−0.14	−0.22
	(0.26)	(0.25)	(0.19)
N	423	496	919
Perception about mathematics (*SD*)	−0.06	0.01	−0.02
	(0.10)	(0.10)	(0.08)
N	479	534	1,013
Perception about ethnomathematics (*SD*)	0.05	–	–
	(0.05)	–	–
N	418	–	–
Knowledge about Ngäbe culture (*SD*)	0.56***	0.72***	0.64***
	(0.10)	(0.11)	(0.08)
N	547	523	1,070
Knowledge about Ngäbere words (*SD*)	0.56***	0.69***	0.62***
	(0.10)	(0.11)	(0.09)
N	547	524	1,071
Ethnomathematics (*SD*)	0.56***	0.67***	0.61***
	(0.10)	(0.10)	(0.08)
N	547	524	1,071
Knowledge about Ngäbe objects (*SD*)	0.14	0.11	0.13*
	(0.10)	(0.09)	(0.07)
N	547	535	1,082

Notes: The table reports the average difference. *, **, *** indicate that the coefficients are statistically significant different from zero at a confidence level of 0.10, 0.05 and 0.01 respectively. All models include strata fixed effects. All the variables, except number of hours of mathematics have been normalized with respect to the distribution of the control group, therefore, the mean of the control group is 0. The standard errors (in brackets) are grouped at the school level.

mathematics skills of indigenous preschoolers in addition to that on the mathematics included in the national curriculum.

Our results indicate positive effects of the program on the mathematical and ethnomathematical skills of students. The magnitude of the impact on mathematics (0.12–0.18 *SD*) is comparable to other preschool mathematics programs implemented in low- and middle-income countries (e.g. Bando, Näslund-Hadley, and Gertler 2019; Bando, Näslund-Hadley, and Gertler 2019; Gallego, Näslund-Hadley, and Alfonso 2019; Näslund-Hadley, Parker, and Hernández-Agramonte 2014). In ethnomathematics, the impact is around 0.23 *SD*. So, our findings indicate that a bilingual preschool program based on audio-instruction which at the same time introduces elements from the local culture can have positive effects on mathematics' learning compared with a monolingual education model. From the point of view of the educational policy, this result is relevant considering the evidence showing that the development of pre-math skills at an early age is fundamental to foster later mathematical skills, especially for students from disadvantaged backgrounds (Starkey, Klein, and Wakeley 2004) and that high-quality early childhood interventions are more cost-effective than those in older ages (Kautz et al. 2014). Given this, the JADENKÄ program could potentially be replicated in similar contexts in Panama, and in other educational systems where there are educational gaps between indigenous and non-indigenous students.

Additionally, and consistent with other studies evaluating IBE curriculums (e.g. Amit and Abi Quoder 2017; Falbo and de Baessa 2006), we find a positive effect on the cultural identity of students. In this way, the program has the potential to close the achievement gap without putting students in a dilemma between their academic learning and their identity, culture, and language.

When we analyze the heterogeneity of the impact, the effect in ethnomathematics is higher for Ngäbere speakers or Ngäbere-Spanish speakers. This suggests that a linguistic base increases ethnomathematics learning. Additionally, the program produced effects on teacher abilities, including ethnomathematical skills and knowledge of Ngäbere and Ngäbe culture. The latter is fundamental since a weakness of many IBE policies in Latin America is precisely teachers' lack of cultural and language skills (López 2020).

The evaluation brings understanding of the limitations and challenges of IBE in a developing country context. While JADENKÄ was successful in the period of implementation, medium- and long-term effects will have to be evaluated to understand if effects persist beyond preschool. Additional research is needed to understand the mechanisms behind the impact of the program and its potential effects in urban settings and in other educational systems.

Notes

1. Panama has three indigenous areas (*comarcas*). A *comarca* is an indigenous territory with a semi-autonomous political organization under the jurisdiction of the national government. The *comarca* Ngäbe Buglé is inhabited by the Ngäbe and Buglé indigenous peoples, as well as non-indigenous rural people. 154,355 people live in the *comarca* (according to the 2010 census). The largest group, the Ngäbe, speak Ngäbere, while the smallest group, the Buglé, speak Buglere. The Ngäbe constitutes the largest indigenous population in Panama.
2. The development of pre-mathematical concepts at an early age is decisive for future mathematical understanding and problem-solving skills (e.g., Geary et al. 2013; Resnick 1989).
3. IRI is a low-cost evidence-based methodology, which can be defined as a 'distance education system that combines audio programs with active learning to improve the quality of education and teaching practices' (World Bank 2005).
4. TERCE (*Tercer Estudio Regional Comparativo y Explicativo*) was a learning assessment applied by UNESCO in 2013 in 15 Latin American countries. The assessment evaluated school performance in third and sixth grades in Mathematics, Language and Natural Sciences. The contents of the tests are defined based on the review of the official curricula of the participating countries, to establish the common conceptual domains comparable across countries. Therefore, the test only assessed a part of the national curriculum that is common to all schools and students (both indigenous and non-indigenous).
5. CRECER is a standardized assessment of reading, mathematics, and science competencies in third and sixth grades.
6. The Ngäbe numerical system combines linguistic markers for numbers with quantifiers classifying the elements that are counted [e.g., shape (round, long, and flat), arithmetical (multiplication, division, and addition), human being, days of the month, money, and vegetables]. Combining them implies that numerical symbols are not independent (they do not have a meaning without combining them with the quantifier). With 11 numbers ranging from 1 to 10 and 20 as the foundation link between the decimal and vigesimal bases, quantifiers are required for counting but do not impact arithmetic operations (Le Carrer 2013).
7. To develop the instrument, we had interviews with experts in ethnomathematics: Ismael Jaen, Latin American Network of Ethnomathematics Panama (specialist in ethnomathematics of the Ngäbe people); Blas Quintero and Jorge Sarsaneda, Ngäbe Cultural Association; Hilbert Blanco, Latin American Network of Ethnomathematics; and Griselda Atencio, National Direction of Bilingual Intercultural Education in the MEDUCA.
8. Kraft (2020) reviews 750 experimental evaluations in education. Based on the distribution of effect sizes, he proposes the following categorization: small: <0.05 standard deviations; medium: 0.05–0.19 standard deviations; and large: ≥ 0.20 standard deviations.
9. We conducted class observations and semi-structured interviews with several educational actors (teachers, directors, families, and tutors of the program) in 22 schools chosen randomly. To analyze how control would carry out a math class, teachers were asked to prepare a class for the day of the visit. Detailed results of the qualitative evaluation can be requested from the authors.

Acknowledgments

The authors are thankful to the Inter-American Development Bank and the Government of Japan for funding the research presented in this paper. The authors also thank the outstanding research assistance of Gabriella Wong, Pilar Ouro Paz, María Luisa Zeta, Carolina Magnet, Marcia Ruiz, Jennifer Lucas, Santiago Deambrosi, Irene de la Torre, and Emma King. Innovations for Poverty Action (IPA) assisted with the project management, field work, and IRB review.

Disclosure statement

The JADENKÄ Program RCT is registered as IPA IRB Protocol #14535 and AEA RCT # [AEARCTR-0008442] https://www.socialscienceregistry.org/trials/8442. The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the Inter-American Development Bank, its Board of Directors, or the countries they represent. The authors have no conflicts of interests or financial or material interests in the results.

Funding

This work was supported by the Japan Poverty Reeducation Trust Fund (JPO) of the Inter-American Development Bank (IDB) under Grant PN-T1224.

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Appendix

Table A1. Mathematical concepts and skills developed by Jadenkä.

Mathematical concepts	Mathematical skills	Mathematics test skills (EGMA)
Spatial and temporal thinking	Discrimination of measures: distinction between large–small and high–low Discrimination of measures: distinction between more and less heavy	Section 1: Spatial reasoning and measures (size)
	Understanding of spatiality: distinction between up–down and inside–out. Relative positions of objects/beings Spatial relations: distinction and management of the left, right, above, below, in front and behind	Section 2. Spatial reasoning and measures: up–down, inside–out
	Discrimination of quantities: distinction between more-less-equal	Section 3. Quantity discrimination (more-less-equal) Section 4. Quantity discrimination (more-less-equal)
Capacity discrimination: greater and lesser capacity distinction. Non-standard units of measure to compare capacities (e.g. one cup, half cup) Understanding of time: distinction between before and after. Hours and dates		
Geometry	Recognition of two-dimensional geometric figures: circles, squares, triangles, and rectangles Recognition of the attributes of two-dimensional geometric figures: number of straight sides, corners, and angles Recognition of three-dimensional geometric figures: spheres, cylinders, cubes, cones, and rectangular prisms Recognition of the attributes of three-dimensional geometric figures: number of faces and shape of cubes and rectangular prisms	Section 5: Shape recognition
Numerical thinking	Ability to count by 1 to 50 or by 10 to 100 Ability to count objects/beings. Understanding that the last number counted corresponds to the total amount	Section 6: Oral counting Section 7: Counting objects Section 8: Counting objects
	Determination of quantities of objects/beings. Comparison and distinction between groups with more and less quantity Recognition of written numbers Recognition of written numbers Recognition of different ways of representing numbers. Ability to write numbers from 1 to 10	Section 9: Number selection Section 10: Number selection (basic, intermediate, and advanced) Section 11: Number naming
Mathematical operators	Ability to solve simple mathematical operations with small quantities Identify the symbols +, − and = and use the vocabulary of subtraction and addition correctly	Section 12: Addition and Subtraction