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EDITED BY

Ángel De-Juanas,
National University of Distance
Education (UNED), Spain

REVIEWED BY

Niroj Dahal,
Kathmandu University, Nepal
Dimakatjo Muthelo,
University of Limpopo, South Africa
Hlamulo Wiseman Mbhiza,
University of South Africa, South Africa

*CORRESPONDENCE

Miguel Ipanaque-Zapata
✉ ipanaquezapata@uss.edu.pe
Wendy Arhuis-Inca
✉ arhuisw@gmail.com

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Attitudes toward mathematics and virtual teaching of students in the context of COVID-19: validation and reliability of instruments

Isis Schmitt-Cerna¹, Maritza Ramírez-Olascuaga¹,
Wendy Arhuis-Inca^{2*}, Miguel Ipanaque-Zapata^{2*},
Sarai Raquel Arhuis-Inca³ and Janina Bazalar-Palacios⁴

¹Universidad Nacional del Santa, Nuevo Chimbote, Peru, ²Universidad Señor de Sipán, Chiclayo, Peru, ³Universidad Cesar Vallejo, Nuevo Chimbote, Peru, ⁴Universidad Tecnológica del Perú, Lima, Peru

Background: There are few instruments to assess attitudes toward mathematics and virtual teaching; Likewise, there are methodological limitations to study this phenomenon in high school students. The present study aims to evaluate the psychometric properties of the instruments of attitudes toward mathematics and the perception of virtual teaching during COVID-19 in high school students in Peru.

Methods: A total of 400 students participated. The research utilized exploratory and confirmatory factor analyses to evaluate the attitudes mathematics and the perception of virtual teaching instruments' structure, and assessed reliability through Cronbach's Alpha (α), Ordinal Alpha (ordinal α), and Omega (Ω) indicators.

Results: Exploratory factor analysis showed that Model 2, with factor loadings above 0.40, was the most suitable for both instruments. This model demonstrated acceptable fit indices (CFI and TLI > 0.90; RMSEA and SRMR < 0.08) and internal consistency (α , ordinal α , and Ω > 0.60). Furthermore, confirmatory factor analysis validated a five-dimensional structure for attitudes toward mathematics and a six-dimensional structure for perceptions of virtual teaching.

Conclusion: Both instruments are valid and reliable for assessing these attitudes and perceptions within the context of virtual education during the COVID-19 pandemic. Strengthening mathematical skills through targeted research and interventions is essential to addressing pandemic-induced gaps.

KEYWORDS

psychometric properties, attitudes, mathematics, virtual teaching, COVID-19

1 Introduction

Individual, cultural, family and educational experiences influence students' views toward mathematics (Ursini and Sánchez, 2019). Five attitudinal elements are proposed by Auzmendi (1992) to quantify the degree of motivation, usefulness, liking, confidence and concern. Priority in the education system should be given to effective teaching, with special attention to social contact, diversity of teaching techniques, constructive criticism, clear communication

and well-designed curricula (UNESCO, 2023; Garcia et al., 2022). Therefore, instead of expecting students to learn only academic information, it is crucial to move away from traditional teaching approaches and instead adopt programs that encourage the exchange of ideas and knowledge among students (UNESCO, 2023). According to Surdez-Pérez et al. (2018), student liking has an impact on the assessment of educational quality (teaching-learning, respectful treatment, infrastructure, and self-realization).

World Health Organization (2020) characterized COVID-19 as a pandemic, leading to drastic changes in organizations worldwide. Schools in the Netherlands and developing countries faced enormous challenges in implementing virtual learning, especially if teachers and students lacked technological tools and skills (Pulido-Montes and Ancheta-Arrabal, 2021). Another significant challenge was the poor performance in mathematics, as evidenced by the low scores of Latin American students in the PISA assessments (Organization for Economic Co-operation and Development, 2018).

Peru faced significant obstacles in the field of education during COVID-19. On the one hand, the closure of schools due to the declaration of emergency (Resolución Ministerial N°121–2021) and the low performance of students in the mathematics course (Ministerio de Educación, 2019). The efforts of the Ministry of Education resulted in the creation of the “Aprendo en Casa” (I Learn at Home) initiative, which offered classes by telephone, television, Internet and radio (Resolución Ministerial N°211–2021). Those most affected were people with disabilities and/or special educational needs (Ramos et al., 2021; Ortega et al., 2021). However, some members of the educational community presented difficulties, such as: lack of knowledge in the use of ICTs; inadequate environments; lack of resources (internet, mobile, computer or laptop); and income (Mateus et al., 2022; El Comercio, 2021; Ramos et al., 2021).

We plan to evaluate the constructs measuring attitudes toward mathematics and opinions about instruction in the COVID-19 context through exploratory and confirmatory factor analysis of the data collected. Thus, the objective was to investigate the psychometric qualities of the questionnaires used to measure high school students' attitudes toward mathematics and their impressions of virtual instruction in the COVID-19 environment in Peru. Our research will provide educators with reliable resources to assess and address children's learning difficulties. In the future, the inclusion of these methods in regular assessments may help to detect areas that need help, especially in the context of hybrid education. Improving overall student achievement requires teachers to have higher levels of self-efficacy and to cultivate positive attitudes toward mathematics.

Section 2 of our study provides an analysis of earlier research on attitudes toward mathematics and virtual instruction in the context of COVID-19, which serves as a foundation for the findings presented in this paper. The techniques utilized to examine the psychometric qualities of the research tools are explained in Section 3. Our conclusions and justification are given in Section 4. The results of the validation and dependability of the instruments employed in the COVID-19 setting, their applicability in other contexts, and a reference for further study are presented in Section 5's conclusion.

2 Previous work

The attitude toward mathematics encompasses several elements such as value, appreciation, satisfaction, curiosity, and interest in the

subject matter, with a stronger focus on the emotional rather than the cognitive components (Flores-López and Auzmendi, 2018). Many pupils are “traumatized” by mathematics, according to UNESCO, and while this is a problem with cultural and familial backdrop, instructors also bear some of the blame (UNESCO, 2023). During the COVID-19 pandemic, Pineda-Ramírez et al. (2021), found that Honduran students between 11 and 14 years report positive attitudes toward mathematics in areas such as mathematical competence, usefulness, and self-concept. However, they observed a negative attitude toward the factor of liking mathematics. In contrast, Segarra and Julià (2021) discovered that Spanish fifth-grade students have a good attitude toward mathematics. Those with a stronger positive attitude had mathematics teachers with a higher level of self-efficacy in teaching the subject. These findings indicate a difference in students' attitudes toward mathematics by country. Therefore, teachers must consider attitude as a vital component of their students' cognitive growth.

Regarding virtual learning, in a study conducted in Chile, 52% of university students identified themselves as emotionally overwhelmed or anxious about the change of learning strategy to virtual education (Romero et al., 2021). Just 5% of the sample of Colombian students claimed to have the necessary competences for the advanced use of virtual technologies, with the majority of respondents saying they were unprepared for virtual education. The sample revealed that autonomy and discipline were the most developed learning abilities; yet, the majority of people believe that virtuality has lessened the rigor of the educational process (Londoño-Velasco et al., 2021). Similarly, the study by De Gracia et al. (2022) notes that Filipino students experienced stress and difficulties in adapting to the abrupt change from traditional in-person classes to fully virtual classes. These concerns included those related to connectivity, workload, class preparation, lesson delivery and comprehension, classroom management, student engagement, and social interactions. However, after using the Home-Based Online Learning (HBOL) program, students obtained higher than passing grades in mathematics, science, and English. Teachers and school administration need to develop technological competencies and/or different teaching strategies to benefit student learning.

The most popular in Spanish-speaking contexts (Dörfer and Ulloa Duque, 2016; Yáñez-Marquina and Villardón-Gallego, 2016) is the Auzmendi questionnaire on attitudes toward mathematics. Other versions are also used for teaching perception and/or satisfaction (García et al., 2022; Segarra and Julià, 2021; Londoño-Velasco et al., 2021). Nonetheless, two papers using the Auzmendi Attitudes Toward Mathematics Scale were discovered during detention. Pineda-Ramírez et al. (2021) observed strong dependability (90%) after evaluating 597 elementary and high school pupils in Honduras. Similarly, 194 primary school pupils in Spain took part, and the instrument's 0.89 reliability score was recorded (Segarra and Julià, 2021). In the meantime, a study by García et al. (2022) regarding students' perceptions or levels of satisfaction with virtual teaching was discovered. They used the virtual teaching satisfaction questionnaire in high school students in Peru during the pandemic, and the results showed that the questionnaire was validly used. The dimensions of the questionnaire had ordinal alpha coefficients ranging from 0.88 to 0.926. Finally, the structured survey on students' perceptions of the teaching-learning processes was the instrument employed by Londoño-Velasco et al. (2021). The instrument's internal consistency

was ensured by the Cronbach's alpha coefficient, which produced an acceptable value of 0.82.

Little research has been conducted at the international and Latin American level on the validity and reliability of the study variables in the context of COVID-19. The main contribution of this work is statistical validity, since it aims to modify and validate instruments to measure attitudes toward mathematics and their perception of virtual learning environments in situations such as COVID-19 for high school students in Peru.

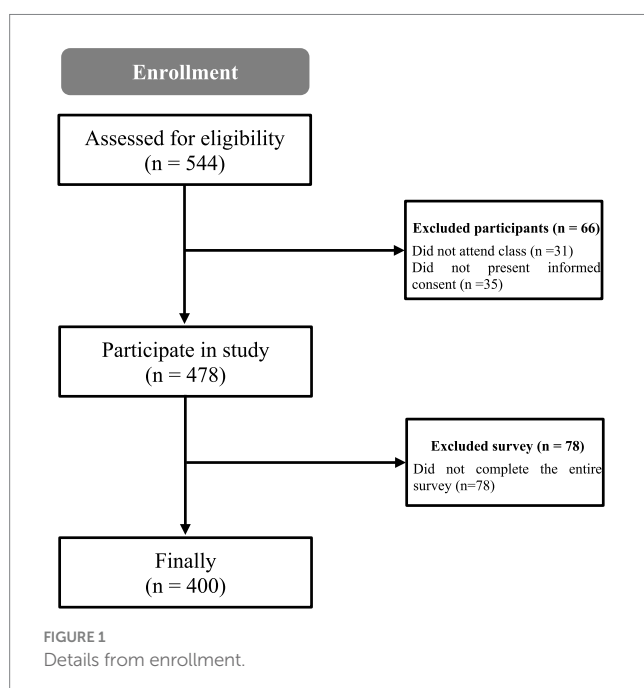
3 Materials and methods

3.1 Design and study area

The present psychometric research is a study conducted in students of a Peruvian state school in the second to fifth year of high school in virtual education. The instrument was applied during the period November–December 2021.

3.2 Sample size

The participants in this study were 544 students from the second, third, fourth, and fifth grades of secondary education at a public institution of regular basic education (EBR) located in a city in northern Peru. As the entire student population was included, no sampling method was employed. Additionally, the following inclusion criteria were applied for student participation: being enrolled in the 2021 academic year, attending class on the day the survey was conducted, having informed consent voluntarily provided by the parents, and completing 100% of the study questionnaires. However, 144 students were excluded for not meeting these criteria, resulting in a final sample of 400 students (see Figure 1).



3.3 Study variables and instruments

The variables used were attitudes toward mathematics and perceptions of virtual teaching.

3.3.1 Attitudes toward mathematics

The Scale of Attitudes toward Mathematics questionnaire was used, consisting of 25 items with a Likert scale of 5 categories (1 = Disagree; 5 = Agree) distributed in 5 dimensions. This instrument has a previous validation in Spanish in Mexico, obtaining acceptable reliability ($\alpha = 0.67$) and validity through exploratory factor analysis, reporting acceptable indicators such as the Kaiser-Meyer-Olkin Test (0.764) (Dörfer and Ulloa Duque, 2016); likewise, the total score of the instrument varies from 25 to 125 points.

3.3.2 Perception of virtual teaching

The perception instrument toward virtual teaching was used, consisting of 24 items with a 5-category Likert measurement scale (1 = Very little; 5 = Always) distributed in 10 dimensions. The instrument has a prior validation in Spanish, obtaining adequate reliability for each dimension (ordinal $\alpha = 0.82$ – 0.94) and the validity through confirmatory factor analysis showed acceptable indicators (CFI = 0.95, TLI = 0.93, RMSEA) (Garcia et al., 2022). The total score of the instrument ranged from 24 to 120 points.

3.4 Procedure

The research process began with the management of the required permission from the authorities of a public educational institution in northern Peru. Once the permission was obtained, the collaboration of the parents was requested through the tutors of the classrooms of the 3rd to 5th grades of secondary school. Only the students whose parents provided a duly signed consent were considered. These students were given a virtual survey that required approximately 30 min per student. At the end of this phase, the researchers proceeded to digitalize the collected surveys, generating a database for each questionnaire. Once this stage was completed, the data in both databases were randomly cross-checked and verified, being validated by the researchers, and then unified. In case of identifying discrepancies in the database in later stages, the entire research team was involved in their review and solution.

3.5 Statistical analysis

In the present study, a consolidated database was created by merging all the questionnaires administered to students using Microsoft Excel. Within the software, a data preparation process was conducted, where qualitative variables were transformed into numerical variables, and participants with incomplete data were excluded; ultimately, the database was exported to the statistical software RStudio (RStudio®, Boston, MA, EE. UU.). As the first stage of analysis, Exploratory Factor Analysis was performed using weighted least squares adjusted for means and variances (WLSMW), taking into account the polychoric matrix and oblique rotation, from which factor loadings were obtained, requiring values greater than 0.40 to be considered adequate (Van Zyl et al., 2021). The choice of a factor

loading threshold of 0.40 is significant as it allows for the identification of relevant factors that may be meaningful, even if their loadings are moderate, thereby seeking a broader understanding of the latent relationships in the context of ordinal data. Following this stage, the evaluation of item number models was generated based on the observed interactions, with the final model of the questionnaire achieved in our study being the last.

Subsequently, Confirmatory Factor Analysis (CFA) was conducted, reporting the goodness-of-fit indices (X^2 , CFI, TLI, RMSEA, SRMR, AIC). The primary indicators considered were the Comparative Fit Index (CFI) and the Tucker-Lewis Index (TLI), which are deemed adequate when they are greater than or equal to 0.90 (Brown, 2015). These indicators measure the improvement of the model fit compared to a null model, suggesting that a high value indicates a good fit. Additionally, the Standardized Root Mean Square Residual (SRMR) and the Root Mean Square Error of Approximation (RMSEA) are considered appropriate when they are less than or equal to 0.08 (Brown, 2015). The SRMR represents the average difference between the observed correlations and the model's predictions, while the RMSEA indicates the model fit in relation to its complexity, penalizing more complex models. Furthermore, the Akaike Information Criterion (AIC) is useful for comparing models, where lower values suggest a better fit of the model in relation to the number of estimated parameters (Brown, 2015). Finally, the reliability of the instruments was obtained using the Cronbach's Alpha (α), Ordinal Alpha (ordinal α) and Omega (Ω) indicators. It was reported that these indicators should be greater than 0.50 to be considered good reliability (Tuapanta et al., 2017). All analyses were performed within the Rstudio statistical program using the "lavaan," "semTools" and "semPlot" packages (Rstudio®, Boston, MA, USA).

3.6 Ethics statement

The study was conducted in accordance with the Declaration of Helsinki (Asociación Médica Mundial, 2017), and the protocol was approved by the Ethics Committee of the Universidad Nacional del Santa (N°102-UNS-CFEH). All subjects gave informed consent for their inclusion before participating in the study.

4 Results

In the first stage, an exploratory factor analysis of attitudes mathematics was conducted. The robust weighted least squares (WLSMV) method was employed, resulting in the presentation of three types of models. In the complete model and Model 1, deficiencies in the factor loadings of the items within their respective dimensions were observed ($\lambda < 0.40$). In contrast, Model 2 demonstrated stability and consistency in the items within each dimension, with factor loadings exceeding 0.40 (Table 1). The choice of a factor loading threshold of 0.40 is significant, as it allows for the identification of relevant factors, even when the loadings are moderate. This lower threshold can be especially beneficial in contexts where capturing the complexity of attitudes is essential. Higher loadings generally indicate a stronger relationship between the item and the underlying factor, but a threshold of 0.40 provides a more inclusive perspective on the structure of the data. Additionally, a parallel analysis was conducted

to identify the optimal number of dimensions that respond to the instrument, and the Kaiser-Meyer-Olkin (KMO) analysis indicated that the sample size was adequate for psychometric properties, with indicators exceeding 0.90. In our study, we demonstrated that the KMO value is acceptable, with an indicator equal to 0.93, supporting the optimal five-dimensional model (see Supplementary material 1).

Table 2 presents the goodness-of-fit indicators from the confirmatory factor analysis (CFA). The complete model exhibited the worst fit, as the CFI and TLI indicators, although close to 0.90, did not reach the threshold, while the RMSEA and SRMR values exceeded 0.08. Model 1 demonstrated some improvement, with CFI values exceeding 0.90; however, the goodness-of-fit indicators TLI, RMSEA, and SRMR remained inadequate (TLI < 0.90, RMSEA and SRMR > 0.08). In contrast, Model 2 provided the best fit, reporting optimal goodness-of-fit indicators, with CFI and TLI values greater than 0.90, and RMSEA and SRMR values below 0.08. These results suggest that Model 2 accurately reflects the underlying structure of the data. Additionally, the Akaike Information Criterion (AIC) values indicate that Model 2 has lower values compared to the other models, reinforcing its suitability as the most appropriate model for the instrument. However, while these results are promising, it is essential to further discuss the implications of these fit indices. The CFI and TLI values indicate that Model 2 not only fits the data well but also supports the construct validity of the instrument by demonstrating strong relationships between the items and the underlying factors. The RMSEA and SRMR values suggest that the model is parsimonious, meaning it achieves a good fit without overly complicating the structure. A deeper analysis of these indices can enhance our understanding of how well the instrument measures the intended constructs, ultimately strengthening the interpretation of the CFA results.

Table 3 presents the reliability analysis for the dimensions of the mathematics attitudes instrument, identifying Model 2 as the best in terms of reliability, with acceptable indicators (α , α_{ordinal} and $\Omega > 0.50$). Although a threshold of 0.50 is lower than the standard of 0.70 for good reliability, it is justifiable in exploratory research that seeks to identify initial patterns. This approach allows for the inclusion of items that provide valuable information about the underlying constructs, which can guide future refinements of the instrument.

The second stage begins with the validation of the virtual teaching perception instrument. Table 4 presents the factor loadings of the 19 items of the instrument on the perception of virtual teaching, showing adequate indicators ($\alpha > 0.40$). Prior to this, the Kaiser-Meyer-Olkin (KMO) measure was obtained, which is equal to 0.90, indicating an adequate sample size. Additionally, the parallel analysis demonstrates that the number of factors is 6, which corroborates the findings reported by the original psychometric study (Appendix 2).

Table 5 showed that the goodness-of-fit indicators for the confirmatory factor analysis are adequate. The CFI and TLI presented values of 0.986 and 0.983 respectively, which shows that they are higher than the acceptance cut-off point (0.90). Likewise, the RMSEA and SRMR indicators presented indicators less than 0.08, which indicates that these values are adequate.

The results of Table 6 presented reliability indicators for the mathematics attitudes instrument, including Cronbach's alpha (α), ordinal alpha (α_{ordinal}), and Omega (Ω), which show good internal consistency, with α values ranging from 0.76 to 0.87, α_{ordinal} from

TABLE 1 Factor loadings of the exploratory factor analysis of the models created for the mathematics attitude instrument.

	Complete Model	Model 1*	Model 2**
Dimension 1: Anxiety			
A1. I find the subject of mathematics very difficult.	0.531	0.601	0.601
A2. Studying or working with mathematics does not frighten me.	-0.093	-	-
A3. Mathematics is one of the subjects that frightens me the most.	0.77	0.763	0.761
A4. I am confident in myself when I am faced with a mathematics problem.	-0.743	-0.489	-0.464
A5. When I am faced with a mathematics problem, I feel unable to think clearly.	0.702	0.748	0.751
A6. I am calm and collected when I am faced with a mathematics problem.	-0.550	-0.317	-
A7. Doing mathematics problems makes me feel nervous.	0.627	0.630	0.630
A8. Do not get me worked up when I have to do math problems.	-0.266	-	-
A9. Mathematics makes me feel uncomfortable and nervous.	0.800	0.820	0.833
Dimension 2: Liking			
AG1. I find mathematics fun and entertaining.	0.834	0.857	0.858
AG2. I feel good when talking to others about mathematics.	0.770	0.821	0.82
AG3. Mathematics is pleasant for me.	0.812	0.711	0.709
AG4. If I had the opportunity, I would enroll in more mathematics courses to improve my learning.	0.700	0.535	0.537
Dimension 3: Usefulness			
U1. I consider mathematics to be a very necessary subject in my studies.	0.757	0.726	0.726
U2. I would like to gain a deeper understanding of mathematics.	0.793	0.743	0.736
U3. I hope to use mathematics minimally in my professional life.	-0.352	-0.391	-
U4. I consider that there are other subjects that are more important than mathematics for my future profession.	-0.265	-0.182	-
U5. I would like to have a profession or occupation in which I will use mathematics.	0.748	0.607	0.602
U6. For my professional future, mathematics is one of the most important subjects that I have to study.	0.688	0.660	0.646
Dimension 4: Motivation			
M1. Mathematics is too theoretical to be of any use to me.	0.671	0.693	0.694
M2. Mathematics may be useful only for those who decide to pursue a career in "engineering," but not for other students.	0.670	0.585	0.589
M3. The topics covered in mathematics classes are minimally interesting.	-0.549	-0.518	-0.512
Dimension 5: Confidence			
C1. Having a good knowledge of mathematics will increase my chances of getting the best job offer.	0.655	0.621	0.621
C2. I get great satisfaction from being able to solve mathematics problems.	0.696	0.663	0.662
C3. If I put my mind to it, I think I could become very good at mathematics.	0.937	0.860	0.861

*In model 1, items A2 and A8 were excluded due to low factor loading. **In model 2, items from model 1 and A6, U3 and U4 were excluded due to low factor loading.

TABLE 2 Goodness of fit of confirmatory factor analysis of the models generated for attitudes to mathematics.

	χ^2	df	CFI	TLI	RMSEA	SRMR	AIC
Complete model	2005.324	265	0.858	0.839	0.182 [0.174–0.189]	0.143	15345.4
Model 1	1133.688	220	0.902	0.857	0.117 [0.109–0.125]	0.128	12466.6
Model 2	812.84	160	0.927	0.941	0.075 [0.065–0.085]	0.077	10773.2

χ^2 , Chi square; df, Degree of freedom; CFI, Comparative fit index; TLI, Tucker-Lewis index; RMSEA, Root mean square error of approximation; SRMR, Standardized root mean square residual.

0.82 to 0.87, and Ω from 0.78 to 0.88. Although some values fall below the standard threshold of 0.70, a threshold of 0.60 may be justifiable in exploratory research contexts, where the aim is to identify initial patterns and a lower internal consistency is accepted to include items that provide valuable information about complex constructs. These

coefficients indicate that, despite criticisms regarding the reliability threshold, the instrument possesses acceptable reliability that can serve as a basis for future revisions and refinements, thereby enhancing the validity and utility of the instrument in the study of attitudes and perceptions.

TABLE 3 Reliability analysis of the models developed for the mathematics attitude instrument.

	Dimensions				
	Anxiety (ansiedad)	Liking (agrado)	Usefulness (Utilidad)	Motivation (Motivación)	Confidence (Confianza)
Full model					
α	0.750	0.805	0.714	0.617	0.768
α_{ordinal}	0.770	0.832	0.754	0.661	0.805
Ω	0.862	0.879	0.765	0.626	0.787
Model 1					
α	0.823	0.805	0.714	0.617	0.768
α_{ordinal}	0.844	0.831	0.754	0.667	0.805
Ω	0.832	0.839	0.719	0.623	0.760
Model 2					
α	0.832	0.805	0.770	0.617	0.768
α_{ordinal}	0.855	0.831	0.811	0.661	0.805
Ω	0.848	0.839	0.747	0.623	0.759

α , Alpha; Ω , Omega index; α_{ordinal} , ordinal Alpha.

TABLE 4 Factor loadings of the exploratory factor analysis of the models created for the instrument for the perception of virtual teaching.

	λ
Dimension 1: Teacher communication	
In the event of any connection problem, the teacher responds and provides support promptly.	0.781
The teacher quickly resolved any virtual communication problems that arose.	0.866
The teacher gave me guidance and technical support to receive my virtual classes.	0.883
Dimension 2: Availability of virtual means of communication	
I felt that I was integrating and developing bonds of friendship with my classmates through virtual teaching (sharing experiences and learning, etc.) through calls, video calls, zoom, etc.	0.867
I had easy access to the classes that were taught through TV, radio, learning at home, etc.	0.633
I had adequate technology (cell phone, computer or tablet) to easily connect with the teacher and my classmates.	0.879
Dimension 3: Evaluation	
I am satisfied with the evaluations that the teacher applied in virtual teaching.	0.789
I consider that the evaluation system that the teacher applied helped me to know my level of learning.	0.795
I am satisfied with the evaluations that were carried out through the virtual platforms.	0.876
Dimension 4: Feedback	
The teacher was kind and patient in explaining math assignments during virtual classes.	0.864
I feel that I learned the rules of coexistence through virtual teaching.	0.802
I could easily converse and exchange ideas with the teacher during virtual teaching.	0.750
Dimension 5: Teaching methodology	
The materials that the teacher used during virtual classes facilitated my learning.	0.841
The materials that the teacher sent to reinforce mathematical knowledge were adequate and very useful.	0.875
The teacher used teaching methods that facilitated the understanding of the topics.	0.764
The teacher provided appropriate guidance to clarify and deepen the topics covered during classes taught through virtual platforms, computers, cell phones, etc.	0.738
Dimension 6: Schoolwork	
I was able to easily access the assignments that the teacher left during virtual classes.	0.856
I am satisfied with the assignments that the teacher left during virtual classes.	0.739
The teacher left enough assignments to develop at the end of each virtual class.	0.741

λ , Factor loadings of the items within each of the dimensions of the instrument.

5 Discussion

The study uncovered a concerning trend of low attitudes toward mathematics and perceptions of virtual teaching, revealing a positive correlation between these two variables.

This is the first study in Peru to evaluate the psychometric properties of instruments on attitudes toward mathematics and virtual teaching in the context of COVID-19, and thus contributes to the clarification of the internal structure of the construct “attitudes toward mathematics and virtual teaching” in low-and middle-income countries by validating a measurement scale with solid psychometric properties. According to the results, the Model 2 instrument of attitudes toward mathematics and the instrument of perception of virtual teaching provided satisfactory indications of reliability, goodness of fit and RMSEA, that is, psychometric indicators acceptable for use.

5.1 Attitudes toward mathematics

The study focuses on attitudes toward mathematics, particularly self-perception of competence and enjoyment, relevant to educational transitions. The attitude scale, which demonstrated validity and reliability, revealed stability (model 2) with factor loadings higher than 0.40, a value that exceeds the conventionally considered 0.30 of the traditional test validation proposal. Which guarantees that the items included respond to important factor values and rules out three items with low factor loadings that may affect the overall functioning of the test (A6, I am calm when I face a math problem; U3, I consider that there are other subjects more important than mathematics for my future profession; and U4, I would like to have a profession or occupation in which mathematics will be used). Analyzing the factors, students generally show a positive liking for mathematics, although the scores for the liking factor are comparatively lower. In particular, the question about enrolling in more math courses to improve (AG4, If I had the opportunity to enroll in more math courses to improve my learning) received the lowest score. Emphasizing a high liking factor

is crucial, as liking increases intrinsic motivation and learning (Ma and Kishor, 1997). Participants showed low anxiety levels, a variable that facilitates academic performance (García-Fernández et al., 2013). Positive motivation toward math aligns with previous research, reflecting high scores on motivation (Flores-López and Auzmendi, 2018). The utility factor received positive responses, and scores on the confidence factor were also positive, emphasizing the importance of confidence in using mathematical concepts (Cardoso et al., 2012). It is recommended to assess students' attitudes at the beginning of the academic year. Addressing the factors with lower scores through specific activities is crucial to improving the overall attitude. Teacher self-efficacy is critical as it influences students' attitudes and, consequently, their academic performance. It is essential to recognize that low teacher self-efficacy can affect students' attitudes and, consequently, their academic performance.

Regarding the reliability of the instrument scores, this study uses traditional measures based on internal consistency, such as Cronbach's alpha. However, recognizing the limitations and considering the scale's grading, McDonald's omega has also been calculated, a measure based on factor loadings well supported in the literature. Reapplicability measures have been incorporated to reinforce this analysis (Ventura-León and Caycho-Rodríguez, 2017). The results indicate that the two-dimensional model presents satisfactory reliability in the scores obtained. In addition, the replicability analysis shows that the retained items are adequately aligned with their respective dimensions.

Finally, the goodness-of-fit statistics of the factor model meet the minimum requirements, with an RMSEA value close to 0.90 and a GFI goodness-of-fit index close to 1. Although the RMSR value is slightly higher than the critical limit, a thorough analysis of the indicators allows us to assume an acceptable performance of the model.

5.2 Perception of virtual teaching

The instrument assessing students' perceptions of virtual teaching demonstrates robust psychometric reliability, which is crucial given the increasing shift toward digital learning environments. The validation of this instrument with secondary school students significantly adds to the literature, which has historically focused on more self-regulated populations, such as undergraduate and graduate students (Prior et al., 2016). This distinction is important because secondary students often exhibit lower levels of attention and engagement during online learning and depend more heavily on external academic and behavioral support from teachers and parents (Lau and Lee, 2021). Recent studies have supported similar findings, emphasizing that younger kids suffer greater difficulty in self-regulation and attention retention in virtual classrooms than older

TABLE 5 Goodness of fit of the confirmatory factor analysis of the models generated for the perception of virtual teaching.

	χ^2	df	CFI	TLI	RMSEA	SRMR
Perception of virtual teaching	562.96	137	0.986	0.983	0.076 [0.069–0.084]	0.068

χ^2 , Chi square; df, Degree of freedom; CFI, Comparative fit index; TLI, Tucker-Lewis index; RMSEA, Root mean square error of approximation; SRMR, Standardized root mean square residual.

TABLE 6 Reliability analysis of the models created for the instrument for the perception of virtual teaching.

	Dimension 1: Teacher communication	Dimension 2: Availability of virtual means of communication	Dimension 3: Evaluation	Dimension 4: Feedback	Dimension 5: Teaching methodology	Dimension 6: Schoolwork
α	0.81	0.78	0.81	0.80	0.83	0.76
α ordinal	0.87	0.83	0.86	0.85	0.86	0.82
Ω	0.84	0.80	0.78	0.83	0.88	0.78

α , Alpha; Ω , Omega; α ordinal.

students, affecting their learning outcomes (Carter et al., 2021). Furthermore, studies have indicated that virtual teaching approaches with interactive components and continuous feedback are more beneficial for high students, improving both engagement and academic performance (Schmid et al., 2021).

The importance of tailoring virtual teaching approaches to meet the developmental needs of high school students cannot be overstated. Adolescents are at a critical phase of cognitive and emotional development, so their learning environments require structure and flexibility (Yates et al., 2021). Studies have found that when these students are provided with adequate guidance and support, such as through more interactive teaching methods or personalized feedback, their performance and attitudes toward online learning improve significantly (Hodges et al., 2020). Given these factors, the strong psychometric properties of the perception of virtual teaching instrument provide a valuable tool for evaluating and improving virtual education strategies specifically for secondary students, making it an important contribution to the field.

5.3 Strengths and limitations

A notable strength of this research lies in being the first study conducted in a public secondary school in the Peruvian context during the COVID-19 lockdown. However, certain limitations were identified, including sample size and lack of test–retest reliability. Specifically, the validation of the instruments was conducted only with a subgroup of secondary school students. Given the increasing prevalence of online learning, extending the validation to secondary school students in diverse settings would improve the applicability of the learning.

6 Conclusion

The instruments showed strong reliability and validity for measuring attitudes toward mathematics and perceptions of virtual teaching, making them suitable for future research in Peru. Further studies are crucial, especially given the significant impact of COVID-19 on students' academic performance. This unexpected disruption highlights the need for preparedness in future scenarios. Strengthening mathematical skills through targeted research and interventions is essential to addressing pandemic-induced gaps.

6.1 Implications

The findings of this study have important implications for Peru's educational system. The positive correlation between low attitudes toward mathematics and negative perceptions of virtual teaching underscores the need for targeted interventions to improve student engagement in both areas. The study validates psychometric tools for measuring these attitudes, giving educators credible tools to assess and address kids' learning issues. Moving forward, including these techniques in frequent assessments might help identify areas that require assistance, particularly in hybrid education. Strengthening teacher self-efficacy and encouraging positive attitudes toward mathematics are critical for improving overall student performance in Peru (Bazo-Alvarez et al., 2024). Country with wide gaps in reading, writing, and mathematics success, indicate considerable differences

based on socioeconomic status, geographical location of children, and kind of schooling (public or private) (Ministerio de Educación, 2024).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The protocol was approved by the Ethics Committee of the Universidad Nacional del Santa (N°102-UNS-CFEH). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

IS-C: Conceptualization, Writing – original draft, Writing – review & editing, Supervision, Validation. MR-O: Conceptualization, Project administration, Writing – original draft, Writing – review & editing, Validation. WA-I: Conceptualization, Project administration, Validation, Writing – original draft, Writing – review & editing. MI-Z: Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. SA-I: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. JB-P: Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/educ.2024.1466021/full#supplementary-material>

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