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# Attitudes toward Learning Mathematics with Technology: Psychometric Properties of the Mathematics and Technology Attitudes Scale

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**Abstract**

Technological mediation has gained relevance in teaching mathematics. Its usefulness and impact depend, to a great extent, on how students approach the learning of the discipline. Two independent instrumental studies were conducted to analyze the psychometric properties of the Spanish version of the Mathematics and Technology Attitudes Scale (MTAS-sv). The first was with 573 Colombian high school students (258 girls) and the second was with 400 (262 girls). Study 1 identified a three-dimensional factor structure formed by the subscales Attitude toward learning mathematics with technology, Self-concept in mathematics, and Confidence in technology, with good factorial properties and appropriate internal consistency scores ($\omega_{global}$ = .884). Study 2 collected evidence of convergent validity by demonstrating that the subscales correlate directly with similar constructs. This adapted and validated version offers a useful alternative for investigating the role of technology in mathematics education.

## Introduction

In the last thirty years, the role of affective components in the study of mathematics learning has gained momentum. Their connection with cognitive processes and instruction has been successful, as affective factors are crucial in students' learning outcomes in mathematics (McLeod, 1992). Affective factors, such as attitudes, impact students' learning efforts and persistence. Additionally, educational practices and interventions have evolved due to the penetration of technology, which has positively impacted the educational process (Chauhan, 2017). Research consistently recognizes that using technology in the classroom contributes to learning and motivation (Eyyam & Yaratan, 2014). Meta-analytical studies have reported its utility for mathematical problem-solving and the design of collaborative educational environments (Ruan et al., 2022). Other reviews have shown that both technology-based educational interventions and technology-assisted interventions have a positive impact on students' performance and attitudes in mathematics, although motivation may vary depending on the form of technological application (Higgins et al., 2019).This highlights the importance of examining students' attitudes toward mathematics learning, particularly in relation to how technology and its innovative didactic resources mediate this learning. Traditional teaching methods in this discipline rely on natural language, whereas integrating technology revitalizes and enhances the process (Taman & Dasari, 2021). Therefore, it is important to determine whether students' dispositions align with formative goals when technology is incorporated into mathematics classes

## Mathematics and Technology Attitudes Scale (MTAS)

Traditionally, attitudes toward mathematics and technology have been measured as independent constructs. However, in the last two decades, research on these variables has been favored by the emergence of measurement instruments that integrate them into a combined measure. Among these tools, Mathematics and Technology Attitudes Scale (MTAS) highlights, conceived within a comprehensive theoretical model that combines affective, motivational, and behavioral elements involved in the use of technology and school mathematics learning.

The MTAS was developed by Pierce et al. (2007) to examine the role of the affective domain in mathematics learning with technology in secondary school classrooms in Australia. According to the scale's creators (Pierce et al., 2007), the MTAS can be used in educational institutions aiming to monitor changes in attitudes and student engagement in their mathematics learning in response to modifications in the learning environment, thus analyzing the best way to implement this use of technology.The development of the instrument is based on the premise that it is possible to measure affective changes resulting from the use of technology and its impact on the mathematics learning process (Barkatsas, 2012). The MTAS model is operationalized into a measurement tool consisting of twenty (20) items compiled into five factors or dimensions that explain 65% of the total variance.

The dimensions of the model were identified through principal component analysis and are termed Behavioral Engagement (BE), Confidence with Technology (TC), Mathematics Confidence (MC), Affective Engagement (AE), and Mathematics with Technology (MT). The authors suggest that integrating technology into the general teaching-learning process fosters greater confidence in mathematics, improving students' behavioral engagement during school activities. Confidence in using technology encourages students to take an active role in mathematics learning, which, along with the use of appropriate devices and the presence of trained teachers, exerts a cognitive and metacognitive effect that contributes to learning (Pierce et al., 2007).

### Use of the MTAS in Research in Mathematics Education

Several international studies have tested the psychometric properties of the MTAS, or have applied it as a measurement instrument to assess student attitudes when learning mathematics with technology. Its use has been documented in samples of students from Europe, Asia, and Latin America. Barkatsas et al. (2009) tested its performance with a sample of 1068 students from Athens, corroborating the factorial structure described by Pierce et al. (2007), as well as satisfactory results in internal consistency scores ($\alpha MC = .92$; $\alpha MT = .89$; $\alpha TC = .87$; $\alpha BE = .77$, $\alpha AE = .68$). Meanwhile, Tabuk (2018) applied it to 1753 Turkish high school students to review its psychometric properties. After conducting exploratory factor analysis (EFA), they confirmed that the five-dimensional structure explains 62.63% of the construct's variance, in addition to showing good internal consistency scores for each subscale ($\alpha MC = .915$; $\alpha MT = .872$; $\alpha TC = .801$; $\alpha BE = .856$ and $\alpha AE = .838$) and for the overall test (α = .912). Confirmatory factor analysis (CFA) indicated a model with good fit (RMSEA = .048, GFI = .95, AGFI = .92, CFI = .99, NFI = .98, $x^2/df$ = 381.02/147 = 2.5), demonstrating that the MTAS correctly responds to evaluative purposes.

The MTAS has also been used in applied studies within the educational context of diverse countries. Duru et al. (2010) evaluated 505 students from two cities in Turkey, reporting positive performance levels in all MTAS subscales, except for MT, where students' performance was neutral. The study revealed a statistical difference in the BE and AE subscales in favor of girls in the BE and AE subscales, while boys achieved higher values on the TC subscale. Additionally, the authors indicated that previous experience with technology use favored performance in the MT and CT dimensions. On the other hand, Bwalya (2019) employed the MTAS to assess the effects on attitudes towards mathematics learning with technology after an experimental intervention with 66 high school students from Zambia. The study analyzed the influence of using GeoGebra software on students' performance in geometric transformations and their attitudes, identifying significant effects that supported the initial hypothesis.

With a similar rationale, Canilao and Gurat (2023) applied the MTAS in an experimental study to evaluate the effect of mobile technology use on the five dimensions measured with the instrument in Filipino students. The study revealed neutral attitudes for the MT and TC dimensions, while the BE and AE dimensions showed positive attitudes. The only dimension with a negative attitudinal response was mathematics confidence (MC). These results were consistent between the control and experimental groups, which showed similar scores.

In Latin America, the instrument has been used with university-level students, showing similar results to those reported in secondary education. Navarro-Ibarra et al. (2017) evaluated 522 Mexican university students using the MTAS and applied AFE to corroborate the five-dimensional structure. Subsequently, they calculated principal components from these, grouping the BE, MC, and AE subscales, which explained a total variance of 42.42%. The second component included the TC and MT subscales, explaining a total variance of 21.29%. Thus, the total variance of the MTAS was 63.71%, close to the 65% variance described by Pierce et al. (2007), and to the 67% obtained in the subsequent review by Barkatsas et al. (2009). However, this study by Navarro-Ibarra et al. (2017) used the original version of the MTAS without cultural adjustment and without applying AFC.

These studies have used the five-factor version originally described by Pierce et al. (2007), although they have not conducted analyses of the psychometric properties. Recently, the MTAS has undergone adjustments in the wording of its items to be applied in the assessment of Filipino university students (Mendezabal & Tindowen, 2018); psychometric adaptations have been proposed for its use with mathematics teacher education students (Çalişkan Dedeoğlu et al., 2020), and it has even served as inspiration for the construction of other instruments with similar purposes (Aytekin & Isiksal-Bostan, 2019; Fabian et al., 2018).

**Current Study**

The present study was conducted in the Latin American educational context, which varies according to the characteristics of each country; however, there are common elements in terms of advancements and challenges. The research was carried out in Colombia, with students from three educational institutions located in the city of Barranquilla (Caribbean region), where the current educative context faces significant challenges such as access to education in rural areas, the need for investment in training processes and infrastructure, as well as a growing demand for the application of technology and a lack of training directed at educational stakeholders (Unicef, 2022).In this sense, it is worth mentioning that the results of official reports on educational evaluation in recent years have shown a significantly low performance of Colombian students in logical-mathematical skills (MEN, 2022; UNESCO, 2019). This scenario highlights the need to conduct research that addresses these issues in the context of mathematics education in the study.

This research aimed to determine the psychometric properties and assess the level of reliability of the Mathematics and Technology Attitudes Scale (MTAS) in Colombian high school students. The factorial analysis of the MTAS in Latin American countries such as Colombia will allow for its proper application to analyze and measure the impact of the growing use of technological learning strategies in mathematics on how students perceive such educational practices.

## Methods

The psychometric adaptation of the MTAS was carried out through two independent instrumental studies (Montero & León, 2007). The first study focused on obtaining evidence regarding the psychometric properties of validity and internal consistency, while the second aimed to gather evidence of convergent validity. The characteristics of each study are described below.

**Study 1**

*Participants*

Through consecutive sampling (Otzen & Manterola, 2017), 573 students were selected from different educational institutions in the city of Barranquilla (Colombia), aged between 14 and 18 years (M = 15.17, SD = 1.13). Of these participants, 55% (n = 315; $M_{age}$ = 15.21, SD = 1.15) were male and 45% were female (n = 258; $M_{age}$ = 15.11, SD = 1.09). Additionally, 20.9% (n = 120) were in ninth grade, 45.6% (n = 261) in tenth grade, and 33.5% (n = 192) in eleventh grade.

*Instrument*

*The Mathematics and Technology Attitudes Scale* (MTAS) (Pierce et al., 2007) consists of 20 five-point Likert-type items (items 1 to 4, "hardly ever" to "nearly always"; remaining items "strongly disagree" to "strongly agree"). The items correspond to five dimensions composed of four items each, according to a Principal Component Analysis conducted by the test creators. This five-factor structure explains 65% of the variance and demonstrates levels of internal consistency ranging from acceptable to good. The dimensions or subscales are named Mathematics confidence [MC] (α = .87), Confidence with technology [TC] (α = .79), Attitude to learning mathematics with technology [MT] (α = .89), Affective engagement [AE] (α = .65), and Behavioral engagement [BE] (α = .72). All subscales are positively correlated with each other except for Mathematics confidence, which only correlates directly with Confidence with technology.

*Procedure*

This validation process has permission from Dr. Robyn Pierce from the University of Melbourne (Australia), who authorized the validation and adaptation of the instrument in the Colombian context. The applied MTAS corresponds to the translated (MTAS-sv) and linguistically and culturally adjusted version in a previous independent study (Author, year).The administration of the instrument was conducted collectively in the educational institutions that provided authorization, in agreed-upon spaces with academic authorities, without interrupting educational activities. The process took 30 minutes per group in each institution, and professional support was provided to address any concerns during each session.

*Data Analysis*

Two factor analyses were conducted using the RStudio program (R Core Team, 2020) and the lavaan package. The sample was divided into two subsets. The first contained 45% of the observations (141 males and 199 females) for Exploratory Factor Analysis (EFA), while the remaining observations (154 males and 139 females) were used for Confirmatory Factor Analysis (CFA). Both subsamples retained the same percentage distribution of males and females as the overall sample.

Initially, distributional assumptions were tested following Mardia's rule (1970), which led to identifying non-normality. The EFA was conducted using criteria different from those employed by Pierce et al. (2007). Firstly, due to the lack of normality in the data, and secondly, because the measurement corresponds to a five-point ordinal scale, it was more appropriate to use a polychoric matrix instead of a Pearson matrix. The adequacy of the matrix was tested using the Kaiser Meyer Olkin (KMO) index and Bartlett's sphericity test.

The number of dimensions to retain was identified using Parallel Analysis (Horn, 1965), and factor retention was determined using the Unweighted Least Squares (ULS) method (Jöreskog, 1977), which minimizes the sum of squares of the differences in the two analyzed correlation matrices (observed and reproduced correlations) (Lloret-Segura et al., 2014). ULS is appropriate when using a polychoric matrix (Chávez et al., 2016), even if the sample size is small, the number of variables is high, and few factors are retained (Jung, 2013). Additionally, this method avoids saturations greater than unity, and negative error variances (Heywood cases) are encountered (Chávez et al., 2016; Lloret-Segura et al., 2014).

The matrix rotation was performed using oblique criteria, considering that correlated factors were expected. For this purpose, the Promin method was employed, which is more powerful than other oblique methods, and includes the use of strategies from several of them (Promax, Promaj, and Simplimax) (Lorenzo-Seva, 1999). To retain items in each factor, a minimum factor loading of .40 was set (Velicer et al., 1998; Williams et al., 2010), along with a minimum of three items per factor (Lloret-Segura et al., 2014), and communalities ≥ .400.

After testing the factor structure, CFA was applied to the second subsample, and robust goodness-of-fit statistics were calculated. These included absolute fit measures such as Chi-square (non-significant values are expected); Chi-square degrees of freedom ($\chi 2/df$), with appropriate values ranging between 2 and 3, with a limit of 5 (Escobedo et al., 2016); Root Mean Square Error of Approximation (RMSEA), indicating good fit with values ≤ .05 (Escobedo et al., 2016; Lloret-Segura et al., 2014), and acceptable fit for values between .05 and .08 (Browne & Cudeck, 1993; Byrne, 1998; MacCallum et al., 1996); Root Mean Square of Residuals (RMSR), with values ≤ .05 indicating adequate fit, and values between .05 and .08 indicating acceptable fit (Yilmaz, 2018);

Goodness of Fit Index (GFI), determining the proportion of variance among items explained by the proposed model. It ranges from 0 to 1, with values above .90 considered adequate, indicating sufficient covariance among variables (Yilmaz, 2018).Incremental fit measures were also calculated, including the Non-Normed Fit Index (NNFI), for which values above .90 indicate adequate fit (Escobedo et al., 2016); the Comparative Fit Index (CFI), which analyzes the fit of the proposed model based on the difference between the data and the hypothesized model, while adjusting for sample size issues inherent in the model's chi-square fit. It ranges from 0 to 1, with values above .95 indicating an adequate fit, while values between .90 and .95 indicate an acceptable fit (Cinar et al., 2020; Yilmaz, 2018).

Internal consistency scores were calculated using Cronbach's Alpha (α), supplemented with ordinal α and McDonald's Omega coefficient (ω). Values greater than .70 were established as acceptable, and values greater than .80 were considered good (George & Mallery, 2003). Also, the Average Variance Extracted (AVE) was calculated to obtain evidence of factor convergence within the instrument. This statistic indicates the extent to which the analyzed factors share common variance and consistently represent a construct. To obtain evidence of convergent validity among the factors, the Heterotrait-Monotrait Ratio (HTMT) was calculated, whereby it is expected that different constructs or factors express low correlations (< 1) among them. The CFA was supported by creating a trajectory diagram to map the relationships among items and dimensions, as well as between the different retained dimensions.

**Study 2**

*Participants*

400 high school students were selected, divided into 262 girls (65.5%) and 138 boys (34.5%). The sample was balanced according to academic grade, with 100 students selected for each grade, from eighth to eleventh. The mean age for the entire sample was 15.21 years (SD = 1.30), while for boys it was 15.26 years (SD = 1.32), and for girls, it was 15.19 years (SD = 1.29).

*Instruments*

In addition to the validated and adapted version of the Mathematics and Technology Attitudes Scale (MTAS-sv) conducted in Study 1, the following questionnaires were administered:

*Questionnaire for the Study of Attitude, Knowledge, and Use of ICT (ACUTIC)* (Mirete et al., 2015). It consists of 31 Likert-type items (1 = completely disagree, 5 = completely agree) arranged into three factors (Attitude, Knowledge, Use). For this study, only the first subscale was used, which measures the attitude expressed by students towards ICT in teaching-learning processes. It consists of seven items (e.g., "ICT facilitates the development of classes") that explain 56.37% of the total variance and have good scores of internal consistency ($\alpha = .95$).

*Attitudes towards Mathematics and Mathematics Taught with Computers (AMMEC)* (Ursini et al., 2004). It consists of 29 Likert-type items (eight of them reverse-scored) (1 = no, 5 = a lot), which form three dimensions: Liking for mathematics (e.g., "Mathematics is fun", [11 items, $\alpha = .81$]), Liking for Mathematics Taught With Computers (e.g., "I like using the computer", [11 items, $\alpha = .77$]), and Self-confidence When Working on Mathematics (e.g., "If a problem doesn't work out at first, I keep trying until I solve it", [7 items, $\alpha = .68$]).

*Procedure*

After obtaining approval from the educational authorities and informing the guardians of each student about the study's purposes, informed consent was obtained, and the instruments were administered collectively during academic sessions.

*Data Analysis*

Pearson correlations were calculated between the variables measured by the three applied instruments, and the effect size was determined using Fisher's z statistic. Subsequently, a multiple linear regression model was computed along with its respective effect size ($f^2$), using the overall score of the AMECC and the scores of the ACUTIC-Attitudes as predictor variables, while the overall result of the MTAS-sv was utilized as the criterion variable.

## Results

### Study 1

*Exploratory Factor Analysis*

The data matrix did not present any missing values. Descriptive statistics are presented in Table 1, which includes mean, variance, skewness, and kurtosis. The analysis of Mardia's test showed non-normality (skewness = 3685.46, kurtosis = 30.092, $p < .0001$). AFE was conducted after testing the adequacy of the polychoric matrix (KMO = .842, Bartlet's [df=190] = 2895.5, $p = .001 < .05$). However, the resulting model after obtaining the rotated loading matrix led to questioning the behavior of the test in terms of the number of dimensions originally proposed by the authors of the instrument. Firstly, because the data indicate the need to suppress item 16 ($\lambda < .40$), and secondly, because items 6, 7, 15, and 19 showed factorial loadings for more than one factor.

Table 1. Descriptive Statistics of the Items that Compose the MTAS

| Variable Code | Mean | CI (95%) | Variance | Skewness | Kurtosis |
|---|---|---|---|---|---|
| BE.item1 | 3.985 | (3.84 - 4.13) | .854 | -.763 | .222 |
| BE.item2 | 3.769 | (3.61 - 3.93) | 1.031 | -.542 | -.431 |
| BE.item3 | 4.169 | (4.02 - 4.31) | .825 | -1.083 | .760 |
| BE.item4 | 3.981 | (3.83 - 4.13) | .888 | -.764 | .122 |
| TC.item5 | 4.135 | (4.01 - 4.26) | .655 | -.862 | 1.142 |
| TC.item6 | 4.369 | (4.25 - 4.49) | .610 | -1.287 | 1.671 |
| TC.item7 | 3.227 | (3.07 - 3.39) | 1.014 | -.127 | -.306 |
| TC.item8 | 3.565 | (3.40 - 3.73) | 1.092 | -.418 | -.386 |
| MC.item9 | 3.188 | (3.02 - 3.36) | 1.184 | .016 | -.732 |
| MC.item10 | 3.823 | (3.67 - 3.97) | .876 | -.742 | .606 |
| MC.item11 | 3.873 | (3.73 - 4.02) | .857 | -.767 | .498 |
| MC.item12 | 3.585 | (3.41 - 3.76) | 1.235 | -.459 | -.554 |
| AE.item13 | 4.031 | (3.87 - 4.20) | 1.084 | -.986 | .366 |
| AE.item14 | 3.758 | (3.58 - 3.93) | 1.222 | -.624 | -.341 |
| AE.item15 | 3.750 | (3.56 - 3.94) | 1.464 | -.739 | -.303 |
| AE.item16 | 4.281 | (4.12 - 4.44) | 1.017 | -1.488 | 1.755 |
| MT.item17 | 3.808 | (3.63 - 3.98) | 1.194 | -.838 | .178 |
| MT.item18 | 4.027 | (3.87 - 4.19) | 1.026 | -.990 | .544 |
| MT.item19 | 3.708 | (3.53 - 3.89) | 1.245 | -.554 | -.479 |
| MT.item20 | 3.946 | (3.77 - 4.12) | 1.174 | -.913 | .350 |

BE = behavioural engagement, TC = confidence in using technology, MC = mathematics confidence, AE = affective engagement, MT = attitude to the use of technology to learn mathematics.

The model was adjusted by suppressing these items, retaining a structure of three factors. The subscale of Confidence with Technology (items 5 to 8) constituted the first factor, and Attitudes towards Learning Mathematics with Technology (items 17 to 20) constituted the third, while items 1 to 4 and 9 to 15 clustered in the second factor, thus combining three subscales into one. The communalities demonstrated values ranging from .541 to .762, except for items 2 to 4, with values below .400, indicating that the proportion of explained variance by the items was low relative to the retained factors, suggesting that the items were not well represented in the model. This led to reproducing a new model by suppressing items 2 to 4. The process achieved good performance in the adequacy tests of the matrix (KMO = .830, Bartlet [df=190] = 2610.0, $p = .001 < .05$). The results obtained are summarized in Table 2.

In this model, the proportion of explained variance is .674, a result slightly higher than the one reported in the original version of MTAS (65%). The first factor has a proportion of explained variance of .373 composed of items 17 to 20, corresponding to the subscale of Attitudes toward Learning Mathematics with Technology proposed by Pierce et al. (2007). Factor 3 explains .128 of the variance and includes items 5 to 8 from the

Confidence with Technology subscale originally retained in the English version of MTAS. Compared to that version of MTAS, the novelty is the retention of a second factor with an explained variance of .172 and the grouping of nine items from three dimensions (item 1 and items 9 to 15).So, the second factor integrates the dimensions of Mathematics Confidence and Affective Engagement, along with an item from Behavioral Engagement. This grouping required revisiting the theoretical viability of the construct, as it now integrates items from three dimensions. The conceptual discussion resulted in naming this factor as Mathematics Self-Concept (MSC) (see discussion of Study 1).

Table 2. Descriptive Statistics of the Items and Rotated Factor Loadings Matrix of the MTAS for a Three-Factor Model Composed of 16 Items

| | **Mean** | **CI (95%)** | **Communalities** | **Factor 1** | **Factor 2** | **Factor 3** |
|---|---|---|---|---|---|---|
| TC.item5 | 4.135 | (4.01 - 4.26) | .740 | | | .801 |
| TC.item6 | 4.369 | (4.25 - 4.49) | .791 | | | .713 |
| TC.item7 | 3.227 | (3.07 - 3.39) | .728 | | | .774 |
| TC.item8 | 3.565 | (3.40 - 3.73) | .699 | | | .697 |
| BE.item1 | 3.985 | (3.84 - 4.13) | .640 | | .769 | |
| MC.item9 | 3.188 | (3.02 - 3.36) | 1.00 | | .760 | |
| MC.item10 | 3.823 | (3.67 - 3.97) | .771 | | .803 | |
| MC.item11 | 3.873 | (3.73 - 4.02) | .849 | | .736 | |
| MC.item12 | 3.585 | (3.41 - 3.76) | .921 | | .839 | |
| AE.item13 | 4.031 | (3.87 - 4.20) | .811 | | .765 | |
| AE.item14 | 3.758 | (3.58 - 3.93) | .680 | | .645 | |
| AE.item15 | 3.750 | (3.56 - 3.94) | .897 | | .871 | |
| MT.item17 | 3.808 | (3.63 - 3.98) | .832 | .665 | | |
| MT.item18 | 4.027 | (3.87 - 4.19) | .741 | .777 | | |
| MT.item19 | 3.708 | (3.53 - 3.89) | .883 | .906 | | |
| MT.item20 | 3.946 | (3.77 - 4.12) | .763 | .799 | | |

*Confirmatory Factor Analysis*

The confirmatory factor analysis was conducted to test the three-dimensional structure of the 16 retained items from the EFA (Table 3). This model demonstrated robust statistics of good performance; however, the $R^2$ values for items 6 and 14 were less than .50, indicating a low contribution to the total variance of the construct. As a result, a second confirmatory model was tested by removing these items. This model showed an improvement in the $R^2$ values of the items. Table 3 presents a summary of these values and the factor loadings of the model.

Finally, Table 4 includes robust statistics measuring the fit of the confirmatory factor analysis model integrating 14 items, showing good performance of the calculated statistics. Additionally, this model demonstrated convergent discriminant capabilities between factors, as reported by the HTMT statistic, with values of the diagonal being < 1 (HTMT = F1 MT↔ F2 MSC = .394, F1 MT ↔ F3 TC = .398, F2 MSC ↔ F3 TC = .496).

Furthermore, the table includes statistics for the internal consistency scores of each factor.

Table 3. Factor Loadings of the Items Included in the EFA of the Models with Three Factors Comprising 14 Items

| Factor | Item | $R^2$ | λ | Standard error | Z Score | p(>\|z\|) |
|---|---|---|---|---|---|---|
| Factor 1 (MT) | Item17 | .682 | .826 | | | |
| | Item18 | .925 | .962 | .067 | 17.441 | .001 |
| | Item19 | .539 | .734 | .056 | 15.881 | .001 |
| | Item20 | .693 | .833 | .064 | 15.695 | .001 |
| Factor 2 (MSC) | Item1 | .610 | .781 | | | |
| | Item9 | .608 | .780 | .047 | 21.235 | .001 |
| | Item10 | .783 | .885 | .043 | 26.249 | .001 |
| | Item11 | .668 | .817 | .043 | 24.257 | .001 |
| | Item12 | .713 | .844 | .043 | 24.874 | .001 |
| | Item13 | .590 | .768 | .042 | 23.398 | .001 |
| | Item14 | — | — | — | — | — |
| | Item15 | .632 | .795 | .044 | 22.944 | .001 |
| Factor 3 (TC) | Item5 | .625 | .790 | | | |
| | Item6 | — | — | — | — | — |
| | Item7 | .600 | .775 | .090 | 1.895 | .001 |
| | Item8 | .724 | .851 | .094 | 11.437 | .001 |

MT = Attitude to the use of technology to learn mathematics, MSC = Mathematics self-concept, TC = Confidence in using technology.

Table 4. Robust Fit Statistics of the Confirmatory Factor Analysis Model of the MTAS-Sv and Calculation of Internal Consistency Scores

| | | Acceptable threshold | MTAS-sv |
|---|---|---|---|
| AFC (n = 313) | $x^2/df$ | ≤ 2 ≤ 3 | 1.01 |
| | *CFI* | ≥.95 | .999 |
| | *TLI* | ≥ .95 | .999 |
| | *GFI* | ≥ .95 | .998 |
| | *NNFI* | ≥ .90 | .973 |
| | *RMSEA [90%]* | ≤ .08 | .014 [.000, .036] |
| | *SRMR* | ≤ 1.0 | .049 |
| | **F1** | **F2** | **F3** |
| *α* | .873 | .907 | .797 |
| *α ordinal* | .905 | .930 | .847 |
| *ω* | .874 | .908 | .807 |
| *AVE* | .710 | .657 | .649 |

The path diagram visualizes the final version of the three-factor model (Figure 1). It shows that the dimensions have positive relationships. Unlike the original scale, where Attitude to the Use of Technology to Learn Mathematics (MT) was only related to Confidence in Using Technology (TC), it now also relates to Mathematics self-concept (MSC).

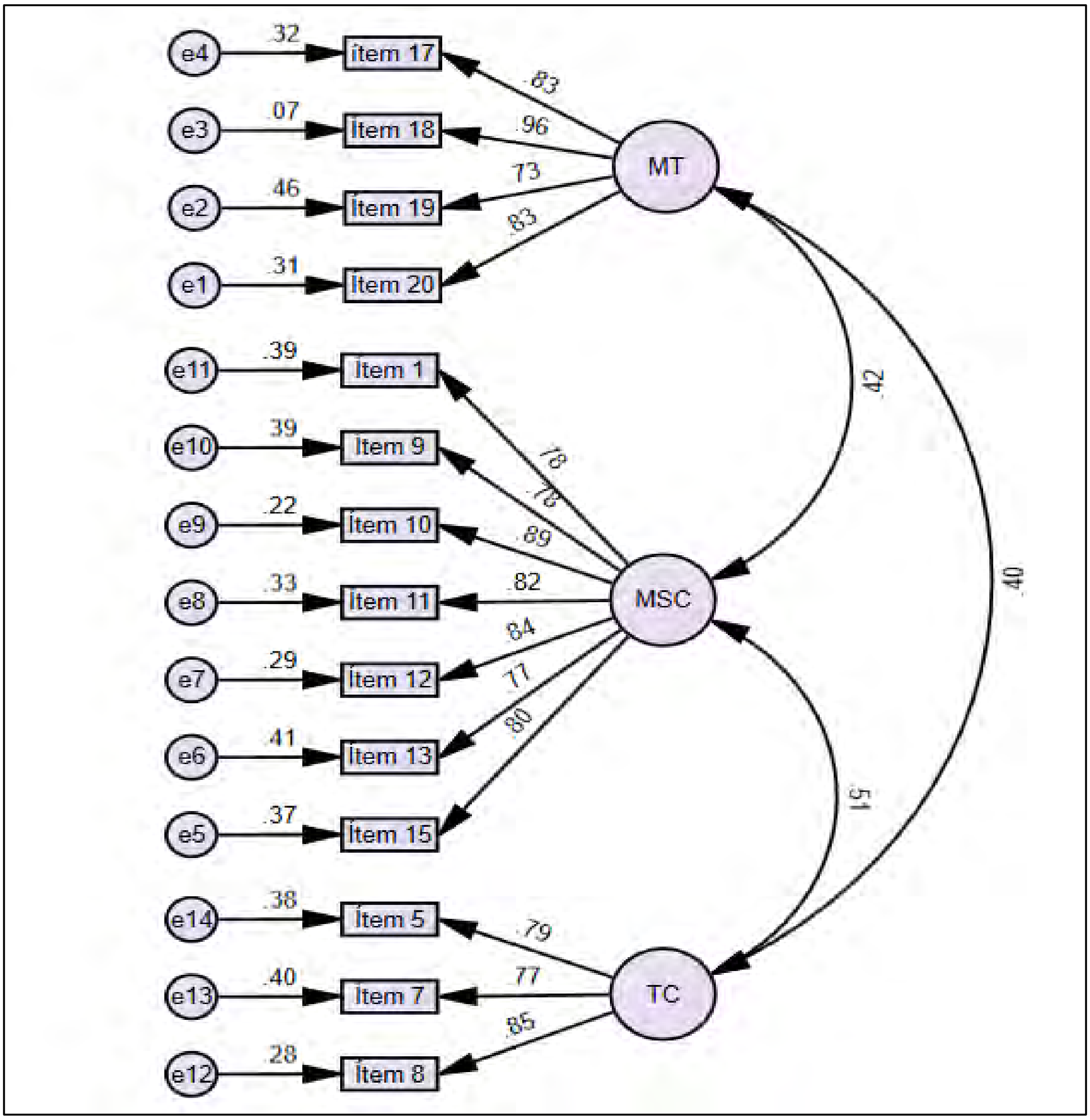


Figure 1. Path Diagram of the Definitive Three-Factor Model of the MTAS-Sv

*Summary*

The trifactorial model with 14 items demonstrates psychometric properties robust enough to ensure a reliable and valid measure of the construct. This model proposes the integration of items that were part of three factors in the original version of the instrument. These dimensions correspond to Behavioral Engagement (item 1), Affective Engagement (items 13 to 15), and Mathematics Confidence (items 9 to 12).

From the theoretical model of Pierce et al. (2007), these dimensions are assumed to be separate but related. Their model is based on the hypothesis that solving real-world problems makes mathematics more relevant to students' lives, generating affective engagement. Likewise, using mathematics produces student confidence, and the two effects increase behavioral engagement. The authors separate confidence in mathematics from affective engagement, meaning how students feel about the subject, while behavioral engagement examines what students do to learn in class. However, the operationalization of these dimensions through the selected items shows similarities: confidence notion implies students' perception of their ability to achieve good results in the discipline, while engagement defines their positive or negative approach to it based on interests or achievements associated with performance. From this perspective, integrating the eight items into the same construct that encompasses self-referential elements seems acceptable, hence the second factor in this study is named Self-Concept in Mathematics.

**Study 2**

,

Figure 2 Presents the Heatmap of the Calculated Correlations.The Mathematics Attitude towards Learning with Technology subscale (MTASF1-MT) directly correlates with the liking for mathematics with computer (AMECCF2-GMC) ($r = .314$, $p < .0001$, Fisher's $z = .32$) and with attitudes towards ICT (ACUTIC-Act) ($r = .311$, $p < .0001$, Fisher's $z = .32$). The Mathematics Self-concept subscale (MTASF2-MSC) shows a moderate correlation with self-confidence in working with mathematics (AMECCF3-AM) ($r = .593$, $p < .0001$, Fisher's $z = .68$) and a strong correlation with the liking for mathematics (AMECCF1-GM) ($r = .785$, $p < .0001$, Fisher's $z = 1.0$). Meanwhile, Confidence in Technology Use (MTASF3-TC) directly correlates with all analyzed variables, a result also observed when testing the relationship of the overall scores of the MTAS with the other variables.

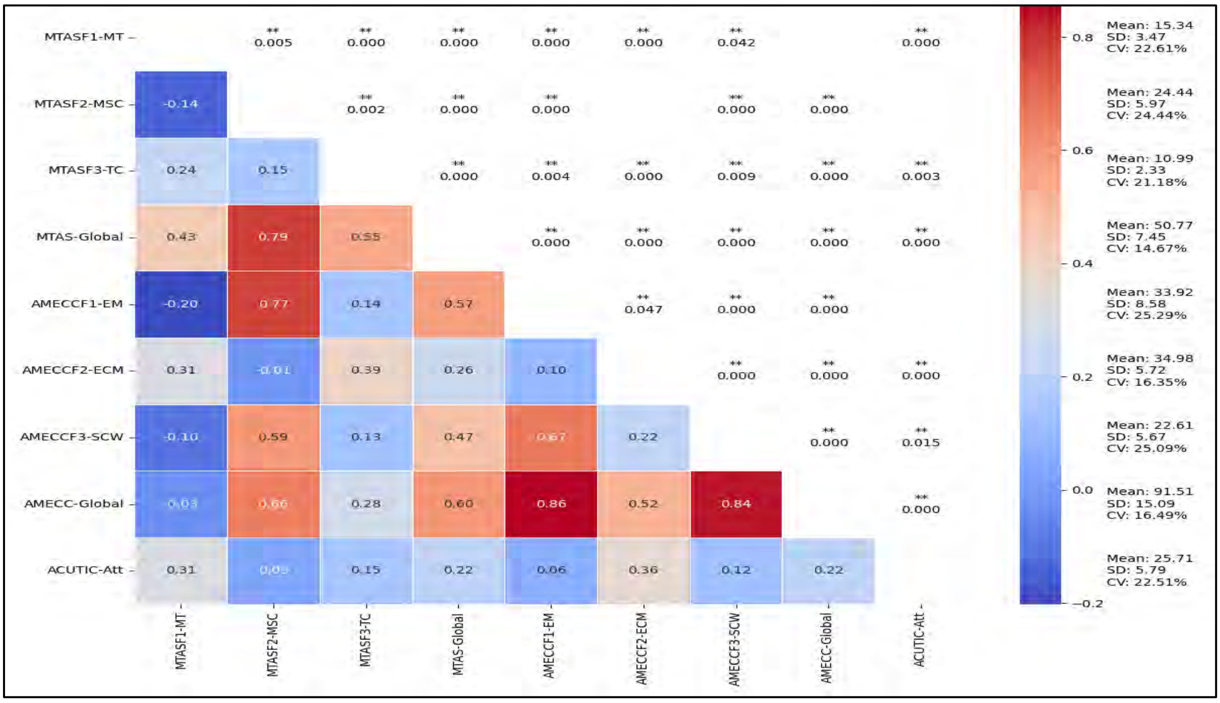


Figure 2. Heatmap of Correlations between Variables

A multiple linear regression model was performed using the overall score of the MTAS-sv as the criterion variable, with the prediction based on the values obtained in ACUTIC-Attitudes and AMECC-Global. The model fit was appropriate ($F[2, 399] = 115.056$, $p = .0003 < .001$), and it obtained an adjusted R-squared statistic of .364 and a Change in R-squared of .367. The Durbin-Watson test yielded a value of 1.8 (> 1.5 < 2.5; $p = .052$), indicating that the residuals are not autocorrelated.

No influential points were identified using Cook's Distance. The multicollinearity diagnosis included calculating the Tolerance and Variance Inflation Factor (VIF), with values close to 1 indicating that predictors are not collinear (Table 5). The computed model provides evidence to suggest that its performance is better than assumed by the null hypothesis (H0), indicating that both AMECC-Global and ACUTIC-Attitudes predict 37% of the MTAS-sv global scores with a large effect size ($f^2 = .57$).

Table 5. Multiple Linear Regression Model to Predict the Global Score of the MTAS-Sv

| | | Coefficient | | | | | Diagnosis of multicollinearity | |
|---|---|---|---|---|---|---|---|---|
| | | Unstandardized | | Standardized | | | | |
| | | β | ET | β | t | p | Tolerance | FIV |
| $H_0$ | (Intercept) | 50.770 | .372 | | 136.347 | < .001 | | |
| $H_1$ | (Intercept) | 21.627 | 2.060 | | 10.500 | < .001 | | |
| | AMECC-Global | .286 | .020 | .580 | 14.172 | < .001 | .952 | 1.050 |
| | ACUTIC-Attitudes | .115 | .053 | .089 | 2.185 | .029* | .952 | 1.050 |

* $p < .05$, ET = Standard error, FIV = Variance Inflation Factor.

*Summary*

The MTAS-sv subscales show direct correlations with similar constructs measured by other instruments. Attitudes towards learning mathematics with technology, measured by the MTAS, correlate with two similar scales: liking for learning mathematics via computer and attitudes towards ICT. The results highlight that factor 2 (Mathematics self-concept), proposed in the adaptation conducted in Study 1, shows correlations ranging from moderate to strong with constructs such as Self-confidence in mathematics and liking for mathematics measured by the AMECC, providing evidence of the convergence of scores provided by the new dimension of the MTAS-sv.

Additionally, the analysis of the regression model demonstrates that the overall scores of the MTAS-sv can be predicted from the values of the variables analyzed. The data supports the idea that the adapted version of the MTAS efficiently captures the measurement of the construct, yielding results consistent with those of tests already available in the literature.

## Discussion

Measuring cognitive, affective, and emotional variables involved in mathematics learning in schoolchildren is a topic of general interest. In addition to being relevant to the educational context and specifically to mathematics educators, it also demands society's attention. This is because the deficit in mathematical knowledge has been a widely documented concern for international organizations interested in education, such as UNESCO (2019).

The literature reviews that technology provides numerous benefits for mathematics learning (Paredes et al., 2023), therefore, its use in educational mediation can translate into success. Moreover, technology itself is relevant if attributive variables are set aside. Therefore, it is important to have measurement tools that help understand how students perceive mathematics learning with the mediation of technology.The MTAS had already been used in a Latin American context such as Mexico (Navarro-Ibarra et al., 2021), where it evaluated the role of attitudes towards the use of technology in mathematics anxiety. However, the study did not have a validation of the instrument. Therefore, following the literature review results, this study offers the first validated adaptation of the MTAS, providing a product available to the academic and scientific community for future adaptations in other countries and for applied research.

Regarding the analysis of factorial structure and internal consistency, it is noteworthy that the procedure used in this study was rigorous and demanding to ensure the validity and reliability of the results. The results obtained in Study 1 showed that the original model consisting of five factors (Pierce, 2007) presented factorial order problems by retaining items with loads for more than one factor. Therefore, a second model of the MTAS-sv with three factors was tested as the ideal solution according to what was suggested by the Parallel Analysis

The result was two new three-dimensional models consisting of 16 and 14 items. Opting for greater parsimony, the final decision leaned towards the model that, with fewer items, offered good fit and internal consistency results. The final version of the MTAS-sv consisted of three factors with a total of 14 items. Two of these factors were retained from the original version of the instrument: *Factor 1, Confidence in technology (items 5 to 8), and Factor 3, Attitudes towards learning mathematics with technology (items 17 to 20).* Meanwhile, Factor 2 grouped items (1, 9, 10, 11, 12, 13, 15), integrating the dimensions of Confidence in mathematics and Affective commitment, in addition to one item from Behavioral commitment.

The retention of Factor 2 is theoretically justified based on the analysis of the psychological, cognitive, and affective variables measured by the retained items, such as concentration, confidence, interest, pleasure, and satisfaction. The operationalization of each item allows for the identification of what is described. (p. e.: *Item 1. Me concentro mucho en las matemáticas* [*I concentrate hard in mathematics*] (attention)*, Item 9. Tengo una mente matemática* [*I have a mathematical mind*] (belief of possessing an ability). *Item 10. Puedo obtener buenos resultados en matemáticas* [*I can get good results in mathematics*] (personal competence and sense of achievement). *Item 11. Sé que puedo manejar las dificultades en matemáticas* [*I know I can handle difficulties in mathematics*] (attitude of perseverance). *Item 12. Tengo confianza en las matemáticas* [*I am confident with mathematics*] (confidence in the usefulness of mathematics). *Item 13. Me interesa aprender cosas nuevas en matemática* [*I am interested to learn new things in mathematics*] (interest in and openness to learning). *Item 15. Aprender matemáticas es agradable* [*Learning mathematics is enjoyable*] (enjoyment and pleasure in learning).

Accordingly, the decision to name Factor 2 "Mathematics self-concept" is justified, as this factor is understood as the perception and evaluation that a person has of their abilities, competencies, and worth, which they attribute to their capabilities to understand and use mathematics. The attributions that students make of themselves will have implications both at the cognitive level (expectations) and at the affective-emotional level (self-concept), since if someone perceives themselves as competent and capable in mathematics, they are more likely to have a positive attitude and be motivated to learn (Fernández-Lasarte et al., 2018; Pabago, 2021; Redondo & Jiménez, 2020).

This concept is consistent with the hypothetical model proposed by Pierce et al. (2007) for the MTAS-sv, where the authors argue that students' perception of their ability to achieve good results, feeling confident in themselves when solving mathematical problems, their sense of belonging, attachment, or, conversely, boredom and dislike, are related to their positive or negative attitudes toward learning mathematics mediated by technology, which directly influences whether learning improves or not. The evidence obtained in Study 2 supports the configuration of a factor on mathematics self-concept by showing relationships with similar constructs (liking for mathematics, self-confidence in mathematics), indicating convergent validity evidence.

## Limitations

The use of the questionnaire requires careful consideration of the contexts of application, as its utility is affected in educational settings where technology is not sufficiently prevalent. Using the Spanish version of the MTAS is relevant when assessing students for whom access to technology in classes is part of their educational routine. Desirable future research should focus on confirming the factorial structure of the instrument, especially to gather evidence on the test-retest reliability of the instrument, as well as reviews of invariance based on population characteristics such as gender, type of school (public or private), among others. In this endeavor, it is important to consider the selection of stratified random samples to overcome the limitations inherent in purposive sampling.

## Conclusion

Using an instrument that evaluates Attitudes toward teaching mathematics mediated by technology, as the MTAS-sv does, represents various utilities and benefits for education. Firstly, this instrument will aid in the objective evaluation of students' attitudes toward learning mathematics with ICT, providing valuable information about perceptions, beliefs, and motivations regarding new teaching methodologies. Additionally, it can be useful in studying the barriers and challenges that students face when learning mathematics with the use of technology, enabling educators and policymakers to design pedagogical intervention strategies focused on the use of ICT to improve students' attitudes and performance in mathematics.

Secondly, the instrument can be used periodically to monitor student progress in their attitudes, confidence, and self-concept toward learning mathematics mediated by technology. This will facilitate the assessment of the efficacy of implemented interventions and enable the implementation of requisite adjustments to ensure the continuous enhancement of teaching and learning processes. Finally, as a future line of study, the instrument can be standardized through comparisons between countries with representative samples of enrolled students. This would provide a broader perspective on the factors measured by the instrument and identify linguistic, cultural, and psychometric differences and similarities of the MTAS-sv scale in Latin America.

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## Appendix 1. Final Revision of the Spanish Version of the MTAS adapted to the Colombian Population

| | TD | ED | NS | DA | TA |
|---|---|---|---|---|---|
| **Actitud hacia el uso de la tecnología para aprender matemáticas** | **1** | **2** | **3** | **4** | **5** |
| Me gusta utilizar dispositivos tecnológicos para las matemáticas | | | | | |
| Vale la pena usar dispositivos tecnológicos en matemáticas | | | | | |
| Las matemáticas son más interesantes cuando se utilizan dispositivos tecnológicos | | | | | |
| Los dispositivos tecnológicos me ayudan a aprender mejor matemáticas | | | | | |
| **Autoconcepto en matemáticas** | **1** | **2** | **3** | **4** | **5** |
| Me concentro mucho en las matemáticas | | | | | |
| Tengo una mente matemática | | | | | |
| Puedo obtener buenos resultados en matemáticas | | | | | |
| Sé que puedo manejar las dificultades en matemáticas | | | | | |
| Tengo confianza en las matemáticas | | | | | |
| Me interesa aprender cosas nuevas en matemáticas | | | | | |
| Aprender matemáticas es agradable | | | | | |
| **Confianza en el uso de la tecnología** | **1** | **2** | **3** | **4** | **5** |
| Me va bien utilizando computadores | | | | | |
| Puedo solucionar muchos problemas informáticos | | | | | |
| Puedo dominar cualquier programa informático necesario para la escuela | | | | | |

TD = totalmente en desacuerdo, ED= en desacuerdo, NS = no estoy seguro/a, DA = de acuerdo, TA = totalmente de acuerdo.

## Appendix 2. Final Version of the MTAS Back-translated English-Spanish-English

| | SD | D | NS | A | SA |
|---|---|---|---|---|---|
| **Attitude Towards the Use of Technology for Learning Mathematics** | **1** | **2** | **3** | **4** | **5** |
| I like using technological devices for math | | | | | |
| The use of technological devices in math is worth it | | | | | |
| Math is more interesting when you use technological devices | | | | | |
| Technological devices help me learn better math | | | | | |
| **Mathematics self-concept** | **1** | **2** | **3** | **4** | **5** |
| I focus a lot in mathematics | | | | | |
| I have a mathematical mind | | | | | |
| I can get good results in math | | | | | |
| I know I can handle the difficulties in math | | | | | |
| I am confidence in math | | | | | |
| I am interested in learning new things in math | | | | | |
| Learning math is nice | | | | | |
| **Confidence in technology** | **1** | **2** | **3** | **4** | **5** |
| I can easily use computers | | | | | |
| I can fix many informatical issues | | | | | |
| I can master any informatical program needed for the school | | | | | |

SD = Strongly Disagree, D = Disagree, NS = Not Sure, A = Agree, SA = Strongly Agree.