Journal of Education and e-Learning Research
Vol. 12, No. 3, 460-468, 2025
ISSN(E) 2410-9991 / ISSN(P) 2518-0169
DOI: 10.20448/jeelr.v12i3.7386

Impact of the COVID-19 pandemic on digital communication among secondary mathematics students

Mohamed-Chemlali, N.[1]
Hossein-Mohand, H.[2]
Hossein-Mohand, H.[3]
Osuna-Acedo, S.[4]


(Corresponding Author)

[1,4]*Department of Didactics, School Organization, and Special Didactics, Faculty of Education, National University of Distance Education, Spain.*
[1]*Email: nmohamed63@alumno.uned.es*
[4]*Email: sosuna@edu.uned.es*
[2,3]*Department of Mathematics Didactics, Faculty of Education, University of Granada, Spain.*
[2]*Email: hassan.h.m@ugr.es*
[3]*Email: hossein.h.m@ugr.es*

Abstract

The study examines the impact of the COVID-19 pandemic on mathematical communication among secondary education students focusing on digital interactions with peers and teachers, using social networks for educational purposes, and the utilization of technological devices for studying mathematics. A non-experimental, quantitative, ex post facto research design was employed, analyzing data from 2728 secondary school students in Melilla, Spain. Data were collected through a structured questionnaire administered in 2019 and 2024 measuring variables related to digital communication, social network usage, and device-based learning. Statistical analyses were performed using generalized linear models to evaluate the significance of observed trends. Results reveal a significant increase in peer communication and the use of social networks for sharing educational resources. Teacher-student communication also increased though the improvement was moderate and uneven across educational levels. The use of technological devices for learning mathematics at home grew notably among lower secondary students but less so in upper secondary. Findings underscore the transformative role of digital platforms in fostering academic interaction during the pandemic and highlight persistent challenges including teacher preparedness and equitable access to technology. The results highlight the need for targeted policies to strengthen digital competencies and bridge the digital divide in education.

Keywords: COVID-19, Digital communication, Digitalization in education, Educational technology, Social networks, Teacher-student interaction.

Citation | N, M.-C., H, H.-M., H, H.-M., & S, O.-A. (2025). Impact of the COVID-19 pandemic on digital communication among secondary mathematics students. *Journal of Education and E-Learning Research, 12*(3), 460–468. 10.20448/jeelr.v12i3.7386
History:
Received: 19 December 2024
Revised: 3 July 2025
Accepted: 6 August 2025
Published: 8 September 2025

Publisher: Asian Online Journal Publishing Group

Funding: This study received no specific financial support.
Institutional Review Board Statement: The Ethical Committee of the National University of Distance Education, Spain has granted approval for this study on 7 November 2024 (Ref. No. 31-SISH-EDU-2024).
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

Contents

Contribution of this paper to the literature

This study presents a validated questionnaire designed to assess digital communication, social networks, and device usage in mathematics education, providing insights into their impact during and after the COVID-19 pandemic. It addresses gaps in understanding how digital platforms influence academic interactions and highlights challenges related to inequitable access to technology.

1. Introduction

The COVID-19 pandemic has profoundly transformed teaching and learning methods in education and communication among students, accelerating the transition towards digitalization in education which was previously considered gradual or supplementary (Drijvers et al., 2021). This change has highlighted both the potential and limitations of digital education, particularly in areas with high cognitive demands such as mathematics (Pozo, Pérez Echeverría, Cabellos, & Sánchez, 2021). In the context of secondary and high school education, the importance of proper adaptation to digital tools for social and academic interaction has become evident (Drijvers et al., 2021) emphasizing the role of emerging forms of communication and collaboration through virtual platforms (Alonso-Garcia, Garrido-Letran, & Sanchez-Alzola, 2021). This transformation has altered the student behavior in student interactions with peers and teachers (Knopik & Oszwa, 2021) and the way they access and share academic information through social networks and messaging applications (Alonso-Campuzano et al., 2021).

The pandemic triggered unprecedented shifts in education compelling the rapid adoption of digital tools to sustain learning continuity. Limited attention has been given to its specific impact on mathematics education, a discipline deeply reliant on interaction and collaboration. Previous research has addressed the broader implications of remote education (Mulenga & Marbán, 2020). Understanding how these digital transitions influenced communication practices, peer collaboration and technological integration are critical to addressing challenges inequitable access to quality education (Moldavan, Capraro, & Capraro, 2022). The pandemic not only exacerbated existing inequalities but also underscored the urgency of strengthening digital competencies in teaching and learning processes, especially in complex disciplines like mathematics (Rodríguez-Muñiz, Burón, Aguilar-González, & Muñiz-Rodríguez, 2021). Gaps remain in understanding its differential effects across educational levels and socio-economic contexts despite the recognized importance of digital learning for maintaining academic continuity (Mukuka, Shumba, & Mulenga, 2021).

Recent studies highlight the significant role of tools such as Google Classroom, WhatsApp and Zoom which were essential for educational continuity during the pandemic, enabling immediate and constant peer communication (Gomes, Tarouco, da Silva, & Roesler, 2021). This communication had a notable impact on the teaching of mathematics, a discipline traditionally dependent on direct interaction and collaborative work to solve complex problems and build solid knowledge (Bond, 2021; Cicha, Rizun, Rutecka, & Strzelecki, 2021). However, digital interaction with teachers faced greater challenges due to factors such as workload overload and teachers' lack of technological skills (Røe, Wojniusz, & Bjerke, 2022) and unequal access to quality devices and connectivity (Pokhrel & Chhetri, 2021; Zierer, 2021). The quality of teaching and learning in complex subjects may have been limited exacerbating inequality in access to effective education (Engzell, Frey, & Verhagen, 2021; Salas, Álvarez, & Toparlak, 2021).

The use of technological devices at home for studying mathematics has increased significantly among younger students who found these devices indispensable tools for adapting to remote learning (Muñoz-Muñoz, Poza, & Briceño, 2023). Dependence on devices such as computers, mobile phones and tablets has become more pronounced in lower secondary levels (Faura-Martínez, Lafuente-Lechuga, & Cifuentes-Faura, 2022) while at higher levels where students were already familiar with these tools (Morocho-Lara, Miranda-Ramos, Neto-Chusin, & Iza-Pazmino, 2022) and the impact was less evident (Aristovnik, Keržič, Ravšelj, Tomaževič, & Umek, 2020). These changes suggest that the pandemic has affected study habits among students (Naidoo, 2020) and has revealed the existing digital divide (Huachara-Martinez, Erazo-Moreno, Paz-Checa, Chomba-Sung, & Nina-Cuchillo, 2023) as well as the limitations in access to quality devices which unequally impact students' opportunities for effective learning (Bardach et al., 2021; Zierer, 2021).

This research examines Melilla, a Spanish autonomous city located on the north coast of Africa. As a multicultural region with significant socio-economic disparities and technological limitations (Bono, 2022), Melilla offers a distinctive context for analyzing how the pandemic reshaped academic and social interactions in mathematics education. These characteristics amplify the relevance of this research as the city's challenges are emblematic of broader global inequalities in access to digital resources. This study provides valuable insights into the evolving role of digital platforms in fostering academic interactions and addressing educational disparities by examining changes in communication practices from 2019 to 2024.

The research seeks to answer the following key questions: How has the frequency and quality of digital communication between students and teachers evolved in the post-pandemic context? What role has social networks and digital platforms played in facilitating academic interactions in mathematics education? Finally, how has the use of technological devices for studying mathematics varied across educational levels before and after the pandemic? These questions guide the exploration conducted in the study of the challenges and opportunities presented by digital learning aiming to inform policies and practices that can bridge equity gaps and enhance educational outcomes.

2. Literature Review

2.1. Secondary Education in Spain and the Challenges of Digital Communication

Secondary education in Spain is governed by the Organic Law of Education (OLE) and its most recent version, the Organic Law Amending the Organic Law on Education (OLAOLE). Both establish a legal framework to ensure inclusive, equitable and high-quality education. The OLAOLE, approved in 2020 emphasizes the importance of integrating digital competencies into the school curriculum, identifying Information and Communication Technologies (ICT) as key tools for fostering interaction, creativity and critical thinking among students (Lamza, 2023; Palau, Fuentes, Mogas, & Cebrián, 2021). However, implementation varies significantly across autonomous communities leading to educational inequalities (Pozo et al., 2021; Velasco, Venegas, & Sánchez-Miranda, 2022).

Challenges in achieving effective digital communication in secondary classrooms remain significant despite these legislative advances. During the COVID-19 pandemic, tools such as Google Classroom and Microsoft Teams facilitated educational continuity but the lack of teacher training in digital competencies limited their effectiveness (Baladrón Pazos, Correyero Ruiz, & Manchado Pérez, 2020; Sánchez-Cruzado, Santiago Campión, & Sánchez-Compaña, 2021). In regions such as Andalusia, more than 35% of teachers reported feeling insecure about using these platforms directly impacting digital interaction between students and teachers (Sánchez-Cruzado et al., 2021).

The use of ICT has implications not only for content delivery but also for the development of interpersonal and collaborative skills. A national study in Spain found that secondary students who used interactive platforms like Google Classroom developed significant competencies in communication and teamwork while those in regions with limited access to technology experienced more pronounced educational inequalities (Valverde-Berrocoso, Rivas-Flores, Anguita-Martínez, & Montes-Rodríguez, 2023; Vázquez-Cano, León Urrutia, Parra-González, & López Meneses, 2020). The disparities analyzed were particularly evident in Melilla, a region with technological and social limitations that exacerbate digital divides. Moreover, the legislative framework underscores the need to ensure teacher training in digital competencies. The OLAOLE sets clear objectives in this area but recent studies indicate that many teachers in Spain still lack the necessary skills to implement innovative methodologies such as flipped learning or gamification (Lamza, 2023; Pozo et al., 2021). The lack of preparation among teachers limits opportunities to promote effective digital interaction, particularly in subjects like mathematics where communication and collaboration are essential (Hossein-Mohand, Gómez-García, Trujillo-Torres, Hossein-Mohand, & Boumadan-Hamed, 2021; Velasco et al., 2022).

2.2. Digital Interaction in Mathematics Education

The COVID-19 pandemic accelerated the transition to digital platforms in mathematics education, a discipline traditionally reliant on direct interaction and classroom collaboration. Digital platforms such as Zoom and Microsoft Teams enabled educational continuity but their effectiveness varied depending on the socioeconomic context and the technological readiness of schools (Baladrón Pazos et al., 2020; Pozo et al., 2021). In a national study, 84.5% of students identified these platforms as essential for learning although 27% of teachers reported significant difficulties in using them interactively due to limited digital training (Moreno-Fernández & Gómez-Camacho, 2023; Sri Supiyati, Halqi, & Ahmad Rasidi, 2022).

Social media platforms like WhatsApp and Telegram played a significant complementary role to formal educational platforms, facilitating communication between students and teachers. Notably, 65% of students used these platforms to exchange information and solve problems collaboratively while 40% of teachers employed them as alternative spaces for emotional support (Hossein-Mohand et al., 2021; Moreno-Fernández & Gómez-Camacho, 2023). However, the effectiveness of these digital tools was inconsistent. Over 50% of mathematics activities reported remained reproductive such as memorizing formulas, limiting opportunities for critical and collaborative learning (Hossein-Mohand et al., 2021; Pozo et al., 2021).

Moreover, teacher digital literacy emerged as a key challenge. In Andalusia, only 35% of teachers felt prepared to integrate digital tools into their teaching practices with this percentage being even lower in regions such as Melilla (Sánchez-Cruzado et al., 2021). These deficiencies directly impacted digital interaction and exacerbated educational inequalities in disadvantaged communities (Hossein Mohand & Hossein Mohand, 2022).

2.3. Educational and Technological Context in Melilla

Melilla, with its geographical location and cultural diversity faces unique challenges that impact digital communication in the educational sphere. A study found that 63.81% of students use ICT for studying mathematics while 36.19% reported that these tools do not significantly contribute to improving their academic performance. Additionally, 30.22% of students who do not use ICT failed mathematics underscoring the importance of optimizing these tools to foster interaction and effective learning (Hossein-Mohand et al., 2021).

According to teachers' perspective, limited technological infrastructure and a lack of digital competencies represent significant barriers. In Melilla, it was reported that 47.54% of teachers consider the technological resources available in classrooms insufficient. However, those who successfully integrate tools such as project-based learning or gamification report improvements in digital interaction and academic performance (Gómez-García, Hossein-Mohand, Trujillo-Torres, & Hossein-Mohand, 2020; Hossein Mohand & Hossein Mohand, 2022).

The cultural diversity of Melilla entails an additional difficulty in terms of digital communication. Linguistic barriers and differences in access to technological resources amplify educational inequalities. Studies conducted in multilingual contexts emphasize the importance of designing inclusive digital strategies to overcome these barriers (Vázquez-Cano et al., 2020). In this regard, Melilla serves as a relevant case study for exploring how socioeconomic and cultural challenges affect digital interaction in mathematics education.

Finally, Melilla experiences a technological delay compared to other regions in Spain. Although significant progress has been made in reducing the digital divide, reliance on basic tools, such as WhatsApp, remains common for maintaining contact whereas more sophisticated platforms like Google Classroom continue to be underutilized (Hossein Mohand & Hossein Mohand, 2022; Sánchez-Cruzado et al., 2021).

3. Methodology

This study employs a non-experimental, quantitative, ex post facto design selected for its suitability in retrospectively analyzing variables without altering existing conditions. Such a methodological approach enables the examination of naturally occurring variations in digital communication practices among secondary and high school students across different educational levels and temporal contexts. This design was chosen to generate robust evidence on the long-term effects of the COVID-19 pandemic on mathematical communication, minimizing experimental bias and ensuring the findings accurately reflect real-world phenomena. Moreover, the retrospective nature of the design is particularly advantageous for comparing data from 2019 and 2024, facilitating the identification of temporal trends and their broader implications for educational practices and policy development.

3.1. Sample Description

The sample data is representative of secondary and high school students from the city of Melilla (Spain) who participated in this research during the academic years 2019 and 2024. The sample includes students from all secondary educational centers in the city covering both Compulsory Secondary Education (CSE) and Upper Secondary Education (USE). Table 1 provides an overview of the gender distribution of participants highlighting that 52.8% identified as female, 46.6% as male and 0.5% as another gender.

Table 1. Gender distribution by year

Gender	2019 (n)	2024 (n)	Total (n)	% within gender (2019/2024)	% of participants by year (2019/2024)	% of total participants (2019/2024/Total)
Male	953	319	1272	74.9% / 25.1%	46.7% / 46.3%	34.9% / 11.7% / 46.6%
Female	1086	355	1441	75.4% / 24.6%	53.3% / 51.5%	39.8% / 13.0% / 52.8%
Other	0	15	15	0.0% / 100.0%	0.0% / 2.2%	0.0% / 0.5% / 0.5%
Total	2039	689	2728	74.7% / 25.3%	100.0% / 100.0%	74.7% / 25.3% / 100.0%

Regarding the collection process, 25.3% of the data were obtained in 2024 (n = 689) while 74.7% correspond to the year 2019 (n = 2039). The total sample is composed of 2728 participants, aged between 11 and 20 years with a mean of 14.82 years (SD [Standard Deviation] = 1.772; SEM [Standard Error of the Mean] = 0.034). Table 2 details the age distribution where 25.9% of participants were aged between 11 and 13 years, 56.6% were in the range of 14 to 16 years and 17.6% were between 17 and 20 years.

Table 2. Age distribution by year

Age range (years)	2019 (n)	2024 (n)	Total (n)	% within age range (2019/2024)	% of participants by year (2019/2024)	% of total participants (2019/2024/Total)
11–13	543	163	706	76.9% / 23.1%	26.6% / 23.7%	19.9% / 6.0% / 25.9%
14–16	1159	384	1543	75.1% / 24.9%	56.8% / 55.7%	42.5% / 14.1% / 56.6%
17–20	337	142	479	70.4% / 29.6%	16.5% / 20.6%	12.4% / 5.2% / 17.6%

Regarding distribution by academic year, 20.1% of participants were in the 1st year of CSE, 23.5% in the 2nd year of CSE, 17.8% in the 3rd year of CSE, 20.8% in the 4th year of CSE and 17.9% were in USE. These details are summarized in Table 3 which presents the educational level distribution by year emphasizing the differences in participant numbers across academic years and the temporal variations between 2019 and 2024.

Table 3. Educational level distribution by year

Educational level	2019 (n)	2024 (n)	Total (n)	% Within level (2019/2024)	% Of participants by year (2019/2024)	% Of total participants (2019/2024/Total)
1st year of CSE	422	125	547	77.1% / 22.9%	20.7% / 18.1%	15.5% / 4.6% / 20.1%
2nd year of CSE	478	164	642	74.5% / 25.5%	23.4% / 23.8%	17.5% / 6.0% / 23.5%
3rd year of CSE	398	87	485	82.1% / 17.9%	19.5% / 12.6%	14.6% / 3.2% / 17.8%
4th year of CSE	421	146	567	74.3% / 25.7%	20.6% / 21.2%	15.4% / 5.4% / 20.8%
USE	320	167	487	65.7% / 34.3%	15.7% / 24.2%	11.7% / 6.1% / 17.9%
Total	2039	689	2728	74.7% / 25.3%	100.0% / 100.0%	74.7% / 25.3% / 100.0%

3.2. Instrument

For data collection, a digital questionnaire was implemented through the online tool Google Forms. This instrument consists of 10 items that evaluate the dependent variables using a four-point Likert scale where the response options are: nothing (1), little (2), quite a lot (3) and always (4). Additionally, the questionnaire includes extra questions to gather sociodemographic information such as the educational level and age of the respondents.

The study variables include a combination of independent and dependent variables. The independent variables are as follows:

- DCD (Data Collection Date): Indicates the year of data collection with two possible values: 2019 and 2024.
- ELA (Educational Level Attended): Represents the educational level of participants coded as follows: ELA = 1 corresponds to the 1st year of CSE, ELA = 2 to the 2nd year of CSE, ELA = 3 to the 3rd year of CSE, ELA = 4 to 4th year of CSE, and ELA = 5 to Upper Secondary Education (USE).

The dependent variables include the following:

- CPI (Communication with Peers through the Internet).
- CTI (Communication with Teachers through the Internet).
- SEISNC (Sharing Educational Information on Social Networks and Chats).
- UDSM (Use of Devices [mobile, computer, or tablet] for Studying Mathematics).

The interactions between the data collection date (DCD) and the educational level attended (ELA) serve as key independent variables as they allow the examination of how different educational levels and the temporal context (before and after the pandemic) influence the dependent variables which cover various aspects of interaction during mathematics learning (CPI, CTI, SEISNC and UDSM).

The psychometric properties of the questionnaire fall within acceptable parameters. Reliability was assessed using the omega coefficient, yielding a value of $\omega = 0.715$ which indicates adequate internal consistency. Construct validity was determined using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy which produced a value of 0.602 indicating that the data are appropriate for performing an exploratory factor analysis. The percentage of explained variance (PEV) was 60.4%. Additionally, Bartlett's test of sphericity was significant ($\chi^2 = 1504.458$, $p < 0.01$) confirming a good fit of the underlying model.

3.3. Data Collection Procedure

Before data collection, the questionnaire was reviewed and approved by the commission of the Educational Programs Unit of the Provincial Directorate of the Ministry of Education and Vocational Training of Melilla.

Coordination was carried out with the principals of all schools ensuring access during school hours following the acquisition of informed consent from parents or legal guardians.

Data collection took place in computer classrooms involving only students whose parents had authorized their participation. The sessions were conducted between April and June of 2019 for the first sample and between May and June of 2024 for the second. Before the study, verbal information was provided to participants regarding the objectives, voluntary nature and anonymity of their participation. Data were collected through Google Forms with the presence of at least one researcher at all times to supervise the process.

As the study involved human participation, ethical approval was sought and obtained to ensure adherence to ethical research standards. The Ethical Committee of the National University of Distance Education, Spain approved this study on November 7, 2024 (Ref. No. 31-SISH-EDU-2024).

3.4. Analysis Techniques

For data analysis, both descriptive and inferential analyses were performed using the statistical software IBM SPSS Statistics 25. First, descriptive analyses were conducted for sociodemographic variables and other key variables in the study. For categorical variables such as gender and educational level, frequencies and percentages were calculated. For continuous variables, such as age, position statistics (mean) and dispersion statistics (standard deviation, standard error of the mean) were computed. Next, the psychometric properties of the questionnaire were evaluated. The omega coefficient was calculated through internal consistency analysis to assess reliability. Construct validity was assessed using the Kaiser-Meyer-Olkin (KMO) sampling adequacy index and Bartlett's test of sphericity.

Subsequently, Generalized Linear Models (GLM) with a multinomial distribution and cumulative logit links were applied to evaluate the interactions between independent and dependent variables. Various indicators were used to assess the models. For goodness of fit, the Akaike Information Criterion (AIC) value with the deviance and Pearson chi-square, were calculated to evaluate how well the models fit the observed data. Omnibus tests were performed to verify the overall significance of the fitted models ensuring that the included factors had a significant effect on the dependent variables. Finally, parameter estimation provided the model coefficients to describe the magnitude and direction of the relationships between independent and dependent variables.

4. Results

The goodness- of- fit of the GLMs used in the analysis is evaluated.

Table 4. Goodness- of- fit

Metric	CPI	CTI	SEISNC	UDSM
Deviance	24.380	44.980	16.361	56.952
χ^2 Pearson	24.393	45.518	16.565	61.879
Log- likelihood	-91.980	-95.525	-86.921	-98.908
AIC	207.960	215.051	197.842	221.815

Analysis of Table 4 reveals that Sharing Educational Information on Social Networks and Chats (SEISNC) has the best fit with the lowest deviance (16.361) and an AIC of 197.842 indicating that the model describes the data well. It is followed by Communication with Peers through the Internet (CPI) with a deviance of 24.380 and an AIC of 207.960 is also shows a good fit. In third place is Communication with Teachers through the Internet (CTI) with a deviance of 44.980 and an AIC of 215.051 reflects a reasonable fit. Finally, Use of Devices for Studying Mathematics (UDSM) is the variable with the worst fit with a deviance and an AIC of 56.952 and 221.815, respectively indicating a less precise model for this variable.

The results of the omnibus tests which allow for evaluating the overall significance of the GLMs are presented below.

Table 5. Omnibus tests

Dependent variables	Likelihood ratio chi-square	p-value
CPI	19.045	0.025
CTI	135.574	0.000
SEISNC	34.262	0.000
UDSM	358.182	0.000

The analysis of Table 5 of omnibus tests reveal that all dependent variables exhibit statistically significant effects as the significance values are below 0.05 indicating that the adjusted model provides a notable improvement over the null model.

Among the variables, Use of Devices for Studying (UDSM) stands out with the highest likelihood ratio chi-square value (358.182) suggesting that this model explains the observed variance the most. The variables Sharing Educational Information on Social Networks and Chats (SEISNC) and (Communication with Peers through the Internet (CPI) have lower values but remain significant, particularly SEISNC with 34.262 and CPI with 19.045.

The parameter estimates obtained in the following section through the GLMs with interaction between the DCD and ELA factors are presented.

Table 6. Estimates with interaction DCD * ELA for CPI.

Parameters	B	p-value
[DCD=2019] * [ELA=1]	-0.006	0.971
[DCD=2019] * [ELA=2]	-0.038	0.819
[DCD=2019] * [ELA=3]	0.000	0.998
[DCD=2019] * [ELA=4]	0.060	0.723
[DCD=2019] * [ELA=5]	0.423	0.018
[DCD=2024] * [ELA=1]	0.270	0.234
[DCD=2024] * [ELA=2]	0.129	0.534

Parameters	B	p-value
[DCD=2024] * [ELA=3]	0.010	0.968
[DCD=2024] * [ELA=4]	0.316	0.149
[DCD=2024] * [ELA=5]	0[a]	-
(Scale)	1[b]	-

Note: [a] Set to zero because this parameter is redundant. b Fixed at the displayed value.

Analysis of the results in Table 6 indicates that for the year 2019, the coefficients across the different grade levels show a general trend of little variation, with the highest coefficient recorded in USE (B = 0.423) indicating that mathematics students in Melilla at this level had a greater tendency to communicate with peers through the Internet compared to other grade levels. This change in USE is also significant with a p-value = 0.018 reflecting a relevant trend in the behavior of students at this level before the pandemic.

In contrast, in 2024, a similar pattern is not evident in any of the grade levels. The coefficients for 1º CSE to 4º CSE indicate slight increases compared to 2019 such as in the case of 1º CSE where the coefficient rises from -0.006 in 2019 to 0.270 in 2024. However, none of these changes are statistically significant as the p-values remain above 0.05 indicating that the observed variations could be due to chance. In 2º CSE and 3º CSE, the changes are even smaller with coefficients showing minimal variation compared to 2019 and also failing to reach statistical significance.

Table 7. Estimates with interaction DCD * ELA for CTI

Parameters	B	p-value
[DCD=2019] * [ELA=1]	-1.569	0.000
[DCD=2019] * [ELA=2]	-1.410	0.000
[DCD=2019] * [ELA=3]	-1.095	0.000
[DCD=2019] * [ELA=4]	-1.327	0.000
[DCD=2019] * [ELA=5]	-0.563	0.002
[DCD=2024] * [ELA=1]	-0.510	0.028
[DCD=2024] * [ELA=2]	-1.013	0.000
[DCD=2024] * [ELA=3]	-0.567	0.026
[DCD=2024] * [ELA=4]	-0.584	0.009
[DCD=2024] * [ELA=5]	0[a]	-
(Scale)	1[b]	-

Note: [a] Set to zero because this parameter is redundant. b Fixed at the displayed value.

When exploring the results in Table 7, during the year 2019, the coefficients are consistently negative across all educational levels, indicating a reduced frequency of communication with mathematics teachers through the Internet compared to other grades or periods. This pattern is most pronounced in 1º CSE where the coefficient is -1.569 and remains highly significant reflecting a marked trend of reduced communication at this level. Similarly, 2º CSE and 4º CSE show negative and significant coefficients with -1.410 and -1.327, respectively. USE also exhibits a negative trend though of lesser magnitude (-0.563, p-value = 0.002).

In 2024, certain changes in this trend are evident although the coefficients remain predominantly negative. In 1º CSE, the coefficient decreases to -0.510 indicating a slight improvement in communication with mathematics teachers compared to 2019 although this difference remains statistically significant. Similarly, in 2º CSE, while the coefficient remains negative (-1.013), its magnitude has decreased compared to 2019 but continues to be significant. For 3º CSE and 4º CSE, the changes are more subtle, with coefficients of -0.567 and -0.584, respectively indicating a slight improvement in communication in these grades relative to 2019 though both results remain significant.

Table 8. Estimates with interaction DCD * ELA for SEISNC

Parameters	B	p-value
[DCD=2019] * [ELA=1]	-0.505	0.003
[DCD=2019] * [ELA=2]	-0.406	0.017
[DCD=2019] * [ELA=3]	-0.136	0.431
[DCD=2019] * [ELA=4]	-0.125	0.468
[DCD=2019] * [ELA=5]	0.143	0.423
[DCD=2024] * [ELA=1]	-0.042	0.855
[DCD=2024] * [ELA=2]	-0.036	0.863
[DCD=2024] * [ELA=3]	-0.227	0.365
[DCD=2024] * [ELA=4]	-0.299	0.175
[DCD=2024] * [ELA=5]	0[a]	-
(Scale)	1[b]	-

Note: [a] Set to zero because this parameter is redundant. b Fixed at the displayed value.

Table 8 shows that in 2019, the coefficient for 1º CSE is -0.505 indicating a lower tendency to share educational information on social networks at this level and this result is statistically significant. A similar pattern is observed in 2º CSE where the coefficient is -0.406 also with notable significance, reinforcing the idea that, in 2019, mathematics students in lower levels were less likely to use social networks to share educational information.

However, the coefficients for 3º CSE, 4º CSE, and USE in 2019 are lower and not statistically significant indicating that behaviour at these levels was less differentiated or more balanced with regard to using social networks for educational purposes. The coefficient for 3º CSE is -0.136 and for 4º CSE is -0.125 both failing to reach statistical significance.

In 2024, the coefficients for lower levels show a reduction in magnitude. For 1º CSE, the coefficient decreases to -0.042, and for 2º CSE it is -0.036 indicating that students at these levels are more inclined to share information on social networks compared to 2019 although these differences are no longer statistically significant in 2024.

At higher levels, such as 3º CSE and 4º CSE, the coefficients are more negative in 2024 compared to 2019 with -0.227 for 3º CSE and -0.299 for 4º CSE although these differences are also not statistically significant. This behavior could reflect a change in the dynamics of older students who may have increasingly adopted other ways of sharing educational information online.

Table 9. Estimates with interaction DCD * ELA for UDSM

Parameters	B	p-value
[DCD=2019] * [ELA=1]	-2.528	0.000
[DCD=2019] * [ELA=2]	-2.197	0.000
[DCD=2019] * [ELA=3]	-2.211	0.000
[DCD=2019] * [ELA=4]	-2.186	0.000
[DCD=2019] * [ELA=5]	-2.349	0.000
[DCD=2024] * [ELA=1]	-0.639	0.011
[DCD=2024] * [ELA=2]	-0.414	0.071
[DCD=2024] * [ELA=3]	-0.625	0.020
[DCD=2024] * [ELA=4]	-0.148	0.532
[DCD=2024] * [ELA=5]	0[a]	-
(Scale)	1[b]	-

Note: [a] Set to zero because this parameter is redundant. b Fixed at the displayed value.

In Table 9, it can be observed that in 2019, all educational levels presented negative coefficients with high statistical significance indicating that students in general used electronic devices at home to study mathematics to a lesser extent. For 1º CSE, the coefficient is -2.528 with high significance suggesting that this group had a much lower tendency to use devices for studying. This pattern remains consistent across other educational levels with similarly large and statistically significant negative coefficients. In 2º CSE, the coefficient is -2.197; in 3º CSE, the coefficient is -2.211; in 4º CSE, the coefficient is -2.186; and in USE, the coefficient is -2.349, all with significance at p-value < 0.001.

However, in 2024, notable changes are observed especially in the lower levels. For 1º CSE, the coefficient is -0.639 indicating that the use of devices for studying mathematics has increased compared to 2019, although it remains significantly lower. The same phenomenon occurs in 2º CSE where the coefficient decreases to -0.414, and in 3º CSE where it is -0.625 which is statistically significant. This change reflects an increased use of devices at these levels after the pandemic.

However, for 4º CSE, the change does not appear as marked with coefficients of -0.148 and 0, respectively, and a lack of significance at these levels in 2024. This indicates that mathematics students in Melilla at higher grade levels have not experienced a statistically significant change in the use of devices to study mathematics at home after the pandemic.

5. Discussion

The results obtained in the present study show a statistically significant increase in digital communication among students, particularly in peer interaction (CPI) and the Sharing of Educational Information on Social Networks and Chats (SEISNC) which partially confirms the first hypothesis. However, communication with mathematics teachers (CTI) showed a more moderate growth and in some levels, it was not statistically significant suggesting that barriers in digital interaction with teachers persist.

The increase in digital interaction among peers can be attributed to the forced context of the COVID-19 pandemic where mathematics students found in digital platforms as a means to maintain academic and social contact. Along the same lines, the literature indicates that the increased use of platforms such as WhatsApp, Google Classroom, Zoom, and other videoconferencing tools facilitated student collaboration reducing the physical barriers that hindered direct communication (Gomes et al., 2021). Similarly, previous studies highlight that these tools not only ensured educational continuity but also promoted collaborative learning, especially in subjects like mathematics where peer interaction is essential (Cicha et al., 2021; Muñoz-Muñoz et al., 2023).

Furthermore, the pandemic accelerated the use of social networks as a means for sharing academic information, which explains the increase in the SEISNC variable observed in the present study. In this regard, social networks provide a space for the immediate exchange of resources such as videos, notes and exercises. As a result, the use of platforms like Facebook and WhatsApp for discussing mathematical problems and sharing solutions became widespread facilitating the collaborative understanding of more complex mathematical concepts (Alonso-Campuzano et al., 2021; Sri Supiyati et al., 2022). These findings emphasize the need for educational institutions to leverage the potential of social networks and collaborative platforms as integral tools for enhancing digital communication among students. Designing specific strategies for their effective use can promote more interactive and engaging learning experiences, particularly in subjects like mathematics.

However, communication with teachers (CTI) showed more moderate growth suggesting persistent challenges. Factors such as the lack of teacher training in the use of digital technologies, work overload, and the lack of universal access to high-quality technologies among students may have limited digital contact with them. Recent studies such as that of Pokhrel and Chhetri (2021) suggest that many teachers were not prepared for fully remote teaching and that digital communication did not reach the desired levels to maintain effective teaching across all educational levels, especially in more technical areas like mathematics (Pokhrel & Chhetri, 2021). Addressing these barriers requires a targeted approach. It is essential to prioritize digital literacy programs for teachers ensuring they possess the necessary competencies to effectively integrate technology into their teaching practices. These programs can bridge existing gaps in digital communication and improve the quality of interactions between teachers and students.

Regarding the use of technological devices for studying mathematics at home, the results show a notable increase in the use of technological devices (mobile phones, computers and tablets) for studying mathematics at home in lower secondary levels after the pandemic, partially confirming the second hypothesis proposed. However, in higher levels, the results suggest that the use of these devices did not experience a statistically significant increase because these students were already relying on technology before the pandemic to support their learning. This differentiation between levels may help to understand how the pandemic unequally impacted different student groups. Similarly, Aristovnik et al. (2020) suggest that younger students adopted the use of technological devices more quickly during the pandemic due to the abrupt transition to online learning while older students were already more familiar with using technological devices (Aristovnik et al., 2020; Huachara-Martinez et al., 2023). These findings highlight the importance of addressing the digital divide to ensure equitable access to devices and resources across all educational levels. Investments in technological infrastructure are essential, particularly in underserved regions like Melilla, to provide students with equal opportunities to benefit from digital education.

6. Conclusion

The present study evaluates the impact of the COVID-19 pandemic on interaction methods during the learning of mathematics among secondary and high school students in the Autonomous City of Melilla. The findings reveal a significant increase in digital communication among peers during the pandemic with tools like social networks and messaging applications becoming central to educational interactions.

Teacher-student communication faced persistent challenges while showing some improvement. Barriers such as limited teacher training in digital technologies, increased workload, and inequitable access to quality devices constrained the effectiveness of these interactions. Additionally, the study identifies a significant increase in the use of technological devices for studying mathematics at home, particularly among lower secondary students. Conversely, minimal changes were observed among upper secondary students due to their pre-existing familiarity with these tools. This differentiation highlights the uneven impact of the pandemic across educational levels emphasizing the need to address these disparities.

The widespread use of social networks for sharing academic resources during the pandemic illustrates their potential as informal yet effective educational tools. These platforms were utilized to discuss mathematical problems, exchange solutions and support each other in understanding complex concepts.

This study presents some limitations that should be considered when interpreting the results. Firstly, the study focuses on the geographical specificity of the sample which could influence the applicability of the findings to different educational contexts. Additionally, the use of self-reported questionnaires might affect the accuracy of students' perceptions. Further research is recommended to explore larger samples and incorporate additional methods to enrich the findings.

References

Alonso-Campuzano, C., Iandolo, G., Mazzeo, M. C., Sosa González, N., Neoh, M. J. Y., Carollo, A., Gabrieli, G., & Esposito, G. (2021). Children's online collaborative storytelling during 2020 Covid-19 home confinement. *European Journal of Investigation in Health, Psychology and Education, 11*(4), 1619-1634. https://doi.org/10.3390/ejihpe11040115

Alonso-Garcia, M., Garrido-Letran, T. M., & Sanchez-Alzola, A. (2021). Impact of COVID-19 on educational sustainability. Initial perceptions of the university community of the University of Cádiz. *Sustainability, 13*(11), 5938. https://doi.org/10.3390/su13115938

Aristovnik, A., Keržič, D., Ravšelj, D., Tomaževič, N., & Umek, L. (2020). Impacts of the COVID-19 pandemic on life of higher education students: A global perspective. *Sustainability, 12*(20), 8438. https://doi.org/10.3390/su12208438

Baladrón Pazos, A. J., Correyero Ruiz, B., & Manchado Pérez, B. (2020). The digital transformation of university teaching in communication during the COVID-19 crisis in Spain: An approach from the student perspective. *Revista Latina de Comunicación Social, 78*, 265-287. https://doi.org/10.4185/rlcs-2020-1477

Bardach, L., Klassen, R. M., Durksen, T. L., Rushby, J. V., Bostwick, K. C. P., & Sheridan, L. (2021). The power of feedback and reflection: Testing an online scenario-based learning intervention for student teachers. *Computers & Education, 169*, 104194. https://doi.org/10.1016/j.compedu.2021.104194

Bond, M. (2021). Schools and emergency remote education during the COVID-19 pandemic: A living rapid systematic review. *Asian Journal of Distance Education, 15*(2), 191-247. https://doi.org/10.5281/zenodo.4425683

Bono, M. B. B. (2022). Melilla, a bit more than 12 square kilometres of singular multiculturality and interculturality. *Journal of Tourism and Heritage Research, 5*(1), 255-282.

Cicha, K., Rizun, M., Rutecka, P., & Strzelecki, A. (2021). COVID-19 and higher education: First-year students' expectations toward distance learning. *Sustainability, 13*(4), 1889. https://doi.org/10.3390/su13041889

Drijvers, P., Thurm, D., Vandervieren, E., Klinger, M., Moons, F., van der Ree, H., . . . Doorman, M. (2021). Distance mathematics teaching in Flanders, Germany, and the Netherlands during COVID-19 lockdown. *Educational Studies in Mathematics, 108*(1), 35-64. https://doi.org/10.1007/s10649-021-10094-5

Engzell, P., Frey, A., & Verhagen, M. D. (2021). Learning loss due to school closures during the COVID-19 pandemic. *Proceedings of the National Academy of Sciences, 118*(17), e2022376118. https://doi.org/10.1073/pnas.2022376118

Faura-Martínez, U., Lafuente-Lechuga, M., & Cifuentes-Faura, J. (2022). Sustainability of the Spanish university system during the pandemic caused by COVID-19. *Educational Review, 74*(3), 645-663. https://doi.org/10.1080/00131911.2021.1978399

Gomes, R. S., Tarouco, L. M. R., da Silva, P. F., & Roesler, V. (2021). Collaborative active learning in a web conferencing environment. *Revista EDaPECI, 21*(2), 18-31. https://doi.org/10.29276/redapeci.2021.21.215682.18-31

Gómez-García, M., Hossein-Mohand, H., Trujillo-Torres, J. M., & Hossein-Mohand, H. (2020). The training and use of ICT in teaching perceptions of Melilla's (Spain) mathematics teachers. *Mathematics, 8*(10), 1641. https://doi.org/10.3390/math8101641

Hossein-Mohand, H., Gómez-García, M., Trujillo-Torres, J., Hossein-Mohand, H., & Boumadan-Hamed, M. (2021). Uses and resources of technologies by mathematics students prior to COVID-19. *Sustainability, 13*(4), 1630. https://doi.org/10.3390/su13041630

Hossein Mohand, H., & Hossein Mohand, H. (2022). ICT and teaching mathematics in secondary school: Melilla. *Human Review: International Humanities Review / Revista Internacional de Humanidades, 12*(3), 1-11.

Huachara-Martinez, E., Erazo-Moreno, M. M., Paz-Checa, D. P., Chomba-Sung, S. D. R., & Nina-Cuchillo, J. (2023). Digital competencies in collaborative learning of students in a public university in Lima. *Journal of Higher Education Theory and Practice, 23*(15), 121. https://doi.org/10.33423/jhetp.v23i15.6413

Knopik, T., & Oszwa, U. (2021). e-Cooperative problem solving as a strategy for learning mathematics during the COVID-19 pandemic. *Education in the Knowledge Society, 22*, e25176. https://doi.org/10.14201/eks.25176

Lamza, D. (2023). General secondary education in Spain: Administrative law aspects. *Visegrad Journal on Human Rights, 6*, 107-113. https://doi.org/10.61345/1339-7915.2023.6.18

Moldavan, A. M., Capraro, R. M., & Capraro, M. M. (2022). Navigating (and disrupting) the digital divide: Urban teachers' perspectives on secondary mathematics instruction during COVID-19. *The Urban Review, 54*(2), 277-302. https://doi.org/10.1007/s11256-021-00611-4

Moreno-Fernández, O., & Gómez-Camacho, A. (2023). Impact of the Covid-19 pandemic on teacher tweeting in Spain: Needs, interests, and emotional implications. *Educación XX1, 26*(2), 185-208. https://doi.org/10.5944/educxx1.34597

Morocho-Lara, D., Miranda-Ramos, P., Neto-Chusin, H., & Iza-Pazmino, S. (2022). *Collaborative tools web 3.0 in the teaching of mathematics in times of Covid 19 pandemic.* Paper presented at the 2022 IEEE Global Engineering Education Conference (EDUCON), http://dx.doi.org/10.1109/educon52537.2022.9766786.

Mukuka, A., Shumba, O., & Mulenga, H. M. (2021). Students' experiences with remote learning during the COVID-19 school closure: Implications for mathematics education. *Heliyon, 7*(7), e07523. https://doi.org/10.1016/j.heliyon.2021.e07523

Mulenga, E. M., & Marbán, J. M. (2020). Is COVID-19 the gateway for digital learning in mathematics education? *Contemporary Educational Technology, 12*(2), ep269. https://doi.org/10.30935/cedtech/7949

Muñoz-Muñoz, E. R., Poza, L. E., & Briceño, A. (2023). Critical translingual perspectives on California multilingual education policy. *Educational Policy, 37*(6), 1791-1817. https://doi.org/10.1177/08959048221130342

Naidoo, J. (2020). Postgraduate mathematics education students' experiences of using digital platforms for learning within the COVID-19 pandemic era. *Pythagoras*, *41*(1), 568. https://doi.org/10.4102/pythagoras.v41i1.568

Palau, R., Fuentes, M., Mogas, J., & Cebrián, G. (2021). Analysis of the implementation of teaching and learning processes at Catalan schools during the Covid-19 lockdown. *Technology, Pedagogy and Education*, *30*(1), 183-199. https://doi.org/10.1080/1475939x.2020.1863855

Pokhrel, S., & Chhetri, R. (2021). A literature review on impact of COVID-19 pandemic on teaching and learning. *Higher Education for the Future*, *8*(1), 133-141. https://doi.org/10.1177/2347631120983481

Pozo, J.-I., Pérez Echeverría, M.-P., Cabellos, B., & Sánchez, D. L. (2021). Teaching and learning in times of COVID-19: Uses of digital technologies during school lockdowns. *Frontiers in Psychology*, *12*, 656776. https://doi.org/10.3389/fpsyg.2021.656776

Rodríguez-Muñiz, L. J., Burón, D., Aguilar-González, Á., & Muñiz-Rodríguez, L. (2021). Secondary mathematics teachers' perception of their readiness for emergency remote teaching during the COVID-19 pandemic: A case study. *Education Sciences*, *11*(5), 228. https://doi.org/10.3390/educsci11050228

Røe, Y., Wojniusz, S., & Bjerke, A. H. (2022). The digital transformation of higher education teaching: Four pedagogical prescriptions to move active learning pedagogy forward. *Frontiers in Education*, *6*. https://doi.org/10.3389/feduc.2021.784701

Salas, D. G., Álvarez, R. P., & Toparlak, S. (2021). Medical education in the midst of the COVID-19 pandemic: The challenge of collaborative learning in three European countries. *European Psychiatry*, *64*(S1), S597. https://doi.org/10.1192/j.eurpsy.2021.1593

Sánchez-Cruzado, C., Santiago Campión, R., & Sánchez-Compaña, M. T. (2021). Teacher digital literacy: The indisputable challenge after COVID-19. *Sustainability*, *13*(4), 1858. https://doi.org/10.3390/su13041858

Sri Supiyati, S., Halqi, M., & Ahmad Rasidi, R. (2022). Students' perception of communication and collaboration effectiveness in online learning mathematics during the COVID-19. *Jurnal Elemen*, *8*(1), 263-275. https://doi.org/10.29408/jel.v8i1.4626

Valverde-Berrocoso, J., Rivas-Flores, J. I., Anguita-Martínez, R., & Montes-Rodríguez, R. (2023). Pedagogical change and innovation culture in secondary education: A Delphi study. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1092793

Vázquez-Cano, E., León Urrutia, M., Parra-González, M. E., & López Meneses, E. (2020). Analysis of interpersonal competences in the use of ICT in the Spanish university context. *Sustainability*, *12*(2), 476. https://doi.org/10.3390/su12020476

Velasco, E., Venegas, M., & Sánchez-Miranda, K. (2022). Social problems in the secondary classroom: Gaps in teacher initial and ongoing training in the andalusian region of Spain from the perspective of intercultural education and new technologies. *Sustainability*, *15*(1), 339.

Zierer, K. (2021). Effects of pandemic-related school closures on pupils' performance and learning in selected countries: A rapid review. *Education Sciences*, *11*(6), 252. https://doi.org/10.3390/educsci11060252