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The effect of digitalization on mathematical literacy during the COVID-19 pandemic: Reflections from PISA-2022

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Highlights

- The effect of live lessons given by a teacher at school through a video communication programme on mathematical literacy scores was positive.
- Students who use their laptops, desktop computers, or tablets in their lessons and students who use their smartphones have high levels of mathematical literacy.
- Digitalization in education is important for student's mathematical literacy scores

Article Info: Research Article

Keywords: *PISA-2022, COVID-19 pandemic, mathematical literacy, digitalization, online education.*

Abstract

This study aims to assess the mathematics literacy levels of 15-year-old students participating in the PISA-2022 test, considering the impacts of the frequency of digital device usage, and the influence of printed and digital learning resources in the educational context across Estonia, Finland, China (Hong Kong), Croatia, and Turkey during COVID-19 pandemic. Utilizing a correlational survey research design, data were sourced from the PISA-2022 dataset, with the sample drawn from the specified target population encompassing students in the selected countries. The analysis involved one-way analysis of variance (ANOVA) and multiple linear regression modeling. Across all countries examined, students using personal laptops, desktop computers, or tablets demonstrated higher levels of mathematical literacy compared to those utilizing other digital tools, except in Turkey where students employing their smartphones exhibited superior mathematical literacy. Furthermore, findings indicated a positive association between live lessons delivered by teachers at school through video communication platforms (e.g., EBA, Zoom™, Skype™) and mathematics literacy levels in all countries.

1. Introduction

The Programme for International Student Assessment (PISA), initiated by the Organisation for Economic Co-operation and Development (OECD) in 2000, evaluates the proficiency of 15-year-old students who have completed their compulsory education in utilizing acquired knowledge and skills in practical, everyday contexts. PISA focuses on three core domains: mathematical literacy, scientific literacy, and reading skills. Its primary aim is to provide insights into the educational systems of participating countries, rather than assessing individual students or schools. Consequently, PISA serves as a diagnostic tool, offering data that inform national education policies rather than functioning as a traditional examination (Gürbüz, 2014). In each assessment cycle, PISA emphasizes one specific domain. For the PISA-2022 cycle, the primary focus was on mathematical literacy. The cognitive tests designed to measure mathematical literacy yield critical data on students' abilities to solve complex problems, handle real-life situations, apply critical thinking, and utilize communication skills effectively (MoNE, 2024). This emphasis provides researchers with a comprehensive understanding of student performance in mathematics and its application

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in daily life, contributing valuable information for the development and refinement of educational strategies and policies.

The triennial implementation of the PISA was postponed in 2021 due to the COVID-19 pandemic and subsequently conducted in 2022. The PISA-2022 results revealed a general decline in the average mathematics scores across all participating countries due to the pandemic's impact; however, the mathematics performance of students in Turkey remained stable (MoNE, 2024). According to the report published by the International Society for Technology in Education (ISTE) and revised in 2008, the effective integration of technologies into educational environments is crucial, emphasizing their transfer into the learning process (ISTE, 2008). The advent of Industry 4.0 and the sudden onset of the pandemic accelerated the digitalization of education and training sectors (Sürer, 2020). As a result of the pandemic, traditional face-to-face education globally and in Turkey transitioned to distance education. Previously considered an alternative to formal education, distance education technologies, encompassing both synchronous and asynchronous learning, have become mandatory due to the pandemic (Esendemir, 2023). It is evident that nations struggling to integrate this rapidly spreading technology into their education systems will fall behind the times (OECD, 2019). For countries adept at embracing this digitalization process, PISA results indicate a positive impact on mathematics literacy levels (MoNE, 2024).

The digitalization process has led to the widespread use of the concept of educational technologies. Educational technologies is an interdisciplinary field of science that evolves in the process, facilitates the education and training process by using appropriate resources and technological tools in education, and increases the performance of the process (Çakır, et al. 2013; Januszewski & Molenda, 2013). One of the terms that plays an active role in this field and in the pandemic process is online learning. Online learning, which is an information communication-based learning model, is a model that provides interaction between student-student, student-teacher, teacher-teacher by utilizing technological tools such as computers in educational processes (Wang, 2008; Satrio, 2011). Online learning, which is a flexible model that enables face-to-face education in a traditional structure to take place face-to-face in a virtual environment with cameras and makes students feel like they are in the classroom environment, has played a major role in keeping students' academic achievement stable during the COVID-19 pandemic. The fact that online learning is flexible in terms of time and space and saves costs prevented students from falling behind in their education and training processes during the pandemic (Varol & Türel, 2003). Therefore, its use in all educational institutions has become widespread in this process. PISA which was held in 2022, is a large-scale test that provides data on the use of technology in education and training and online education during this period.

2. Literature

A literature review reveals numerous studies investigating the impact of digitalization on academic achievement, particularly during and following the pandemic period. Utilizing the PISA-2012 dataset, Dibek et al. (2016) found a positive correlation between the use of information and communication technologies (ICT) both at home and in schools, with students' mathematical literacy. Moreover, students introduced to the internet and computers at an early age demonstrated higher levels of success compared to their peers. Further analysis of the PISA-2015 dataset with a focus on scientific literacy, by Huang et al. (2021), indicated a positive relationship between increased ICT usage and science literacy achievement among students in Asian countries. Similarly, Özkan (2021), based on the PISA-2018 dataset, concluded that enhancing ICT usage in science classes and ensuring its availability at home significantly improved students' performance in science courses. In another study leveraging the PISA-2018 dataset, Özkan (2022) observed that increased ICT usage in mathematics classes and greater accessibility to these technologies at home were associated with higher levels of mathematical literacy among students.

A review study by Canoğulları (2023) on the internet usage of students and their families during the pandemic highlighted both the positive and negative aspects of distance education. Positive aspects included access to lessons regardless of space and time, and continuity of lessons. Negative aspects

encompassed internet connection problems, lack of access to digital devices, and communication breakdowns between students and teachers. Bilim (2020) found that students with advanced computer skills had higher academic achievement during the distance education period. Ağırtaş and Çavuş (2022) concluded that lecturers with a positive outlook on distance education exhibited significantly higher levels of digitalization. Additionally, Çağırkan and Albaş (2024) found that the compulsory distance education process enhanced both students' and academicians' use of basic information technologies, integrating new applications and programs into their educational practices and positively affecting course diversity due to the increased use of information technologies.

Aktürk (2017) found that emergency distance education had a positive effect on the academic achievement of pre-service teachers in faculties of education. Akkuş and Gök (2024) observed that the use of digital technology tools in primary school mathematics teaching positively influenced academic achievement. Kör et al. (2013) concluded that interactive materials such as videos, animations, and simulations made distance education more efficient by engaging students with the subject matter. Hamidy and Lam (2022) revealed that online learning platforms significantly impacted university students' mathematics achievement in Indonesia, with online learning being more effective due to the flexibility it offers. Bączek et al. (2021) found that online learning allowed students to learn at their own pace, access materials continuously, and study in a comfortable environment. Karaman and Konyalıar (2024) identified internet connection issues and insufficient internet packages as major barriers to class attendance during the pandemic. Blaskó (2022) found that academic achievement was higher in European countries where students had access to the internet, books, reading devices, personal study space, and parental support at home during the COVID-19 process.

When the literature was examined, it was seen that there are many studies showing that online learning generally has a more positive effect on mathematics achievement than traditional face-to-face education (Ezemonyih et al, 2021; Huda et al, 2021; Hamidy & Lam, 2022; Fadzil et al, 2024). Another important point is that the pandemic also had an impact on the results in these studies. In their study, Fadzil et al (2024) offered online learning at home to students who preferred online learning at home in addition to traditional face-to-face education, although they were not in the pandemic process. As a result of the study, they found that the self-discipline of students who preferred online learning at home increased, and this increase in self-discipline positively increased their mathematics achievement. In contrast to the results of these studies, Moliner et al (2022) found that the mathematics achievement of ninth grade students who started high school during the pandemic in Spain was negatively affected due to both the start of a new level of education and the differentiation of the educational environment due to the pandemic. Joshi et al (2024), on the other hand, in their study conducted in Nepal, found that students' mathematics achievement showed a negative result due to technological inadequacies such as lack of digital literacy in students and insufficient internet in students' homes. As a result of the studies, it is seen that online learning has both positive and negative effects on mathematics achievement. It is concluded that studies on this subject are lacking due to the rapid transition to online learning as a result of an unexpected pandemic all over the world. Although online learning tools are powerful resources in this regard, it is noteworthy that studies between online learning and mathematics achievement during the pandemic period are still inadequate. Therefore, considering all these factors, it is thought that the study will contribute to the literature.

The COVID-19 pandemic has profoundly affected various aspects of life, particularly education and training activities. Factors such as students having their digital devices, schools providing educational support, the development of students' ICT skills, reliable internet access, and synchronous lessons conducted by school teachers are expected to enhance the quality of education and positively impact academic success during the pandemic. Digital devices, along with printed and digital learning resources, have been crucial in educational activities during this period.

This study aims to evaluate the use and frequency of students' use of digital devices and the role of printed and digital learning resources in education during the pandemic in Estonia, Finland, China (Hong Kong), Croatia, and Turkey, with a focus on the reflections of the COVID-19 pandemic on PISA-2022

mathematical literacy levels. During the COVID-19 pandemic, schools worldwide faced closures, prompting a shift towards remote learning facilitated by digital devices and learning resources. This study aims to investigate the impact of students' usage of digital devices and learning resources during school closures on their mathematical literacy levels assessed in the PISA-2022 test. Specifically, the research seeks to address the following subproblems:

1. Do PISA-2022 test mathematical literacy levels differ according to the digital devices that students used for their studies during the period when their schools were closed due to the coronavirus?

2. What is the relationship between the printed and digital learning resources that students used during the period when their schools were closed due to the coronavirus and their PISA-2022 test mathematical literacy levels?

By exploring these subproblems, the study aims to contribute to our understanding of how the adoption of digital devices and learning resources during the pandemic influenced students' mathematical literacy levels, informing educational policies and practices for future disruptions or remote learning scenarios.

3. Methodology

3.1. Research Design

The study utilized a correlational survey research design, a quantitative research method, to analyze secondary data from the PISA-2022 test. This approach examined the predictive power of digital devices and printed and digital learning resources on the mathematics achievement of 15-year-old students in Estonia, Finland, Hong Kong, Croatia, and Turkey. Survey research involves the investigation of large samples to determine various characteristics such as opinions, abilities, and attitudes within a specific community regarding a particular event or subject (Büyüköztürk et al., 2021).

PISA is defined as a large-scale assessment (MoNE, 2024). Consequently, the use of relational survey research was appropriate due to the large-scale nature of both the PISA-2022 test and the target population. The ability of secondary data analysis to facilitate research across different social groups and cultures, at various time intervals, and in diverse contexts, while adhering to similar research principles as studies using primary data, justified the model's selection for this study (Corti, 2008; Johnston, 2017).

3.2. Data Collecting Tools

The data for the study were obtained from the responses of students from Estonia, Finland, China (Hong Kong), Croatia, and Turkey who participated in PISA-2022. This included data from the student questionnaire (computer-based) and cognitive tests (mathematical literacy test).

There were 91 questions in the computer-based student questionnaire. Two of these questions were addressed in the study. The first one, coded ST349Q01, asked “During the time when your school building was closed because of COVID-19, which of the following digital devices did you use most often for your school work?”. The five categories of the digital devices variable are “My laptop, desktop computer, or tablet”, “My smartphone”, “A digital device that was also used by other family members”, “A digital device that my school gave or lent to me”, “I did not have any digital device for my schoolwork” (PISA 2022 Database, 2023, p.87). The second question, coded ST351Q01, sought to answer “During the time when your school building was closed because of COVID-19, how often did you use the following learning resources?”. Printed and digital learning resources; “Paper textbooks, workbooks, or worksheets”, “Digital textbooks, workbooks, or worksheets”, “Real time lessons by a teacher from my school on a video communication program (e.g. EBA, Zoom™, Skype™)”, “Real time lessons by a private tutor on a video communication program (e.g. EBA, Zoom™, Skype™)”, “Learning material my teachers sent via Short Message or WhatsApp™”, “Recorded lessons or other digital material provided by teachers from my school”, “Recorded lessons or other digital material from other sources”, “Lessons broadcast over television

(e.g. EBA TV) or radio". The second question had four answer options: "Never", "A few times", "About once or twice a week" and "Every day or almost every day" (PISA 2022 Database, 2023, p.89).

3.3. Sampling

The sample for the study was drawn from the target population of 15-year-old students in Estonia, Finland, China (Hong Kong), Croatia, and Turkey who participated in the PISA-2022. The selection of these five countries was based on their performance in the PISA rankings: Estonia, Finland, and China (Hong Kong) are among the top performers, while Croatia and Turkey are at similar levels of achievement in the PISA.

The sample design for the PISA-2022 test employs a two-stage stratified sampling method for each country. In the first stage, a sample of at least 150 schools is selected, considering factors such as school location and education level (middle or high school). In the second stage, approximately 42 15-year-old students are selected from each of these schools (OECD, 2023).

In the PISA-2022 dataset, the sample set representing Estonia consists of 6,392 students; Finland, 10,239 students; Hong Kong, 5,907 students; Croatia, 6,135 students; and Turkey, 7,250 students, totaling 35,923 students.

3.4. Data Analysis

3.4.1. Data Analysis of First Subproblem

IBM SPSS Statistics 24 was employed to investigate how the mathematical literacy levels of students, the first subproblem of the study, vary based on the digital devices they utilize for school-related studies. The distribution of mathematical literacy levels was assumed to be normal, following the rationale proposed by Shatskikh and Melkumova (2016) that the sample mean of a large number of observations tends to approximate normality. A one-way analysis of variance (ANOVA) was conducted to assess whether the data exhibited differences based on the digital devices used by students (Büyüköztürk, 2023). Post hoc analysis was conducted using the Scheffe test to ascertain the significance of differences between mean scores across more than two unrelated groups (Büyüköztürk, 2023).

3.4.2. Data Analysis of Second Subproblem

To address the second subproblem of the study, which aimed to uncover the predictive power of printed and digital learning resources utilized by students on mathematical literacy, a multiple linear regression model was employed. Multiple linear regression analysis is commonly utilized in social sciences research to elucidate relationships between variables, allowing for the interpretation of the dependent variable based on two or more independent variables that are associated with the dependent variable (Nimon, 2010; Büyüköztürk, 2023). These analyses were conducted using the IEA International Database Analyzer (IDB Analyzer) software. Developed by the International Association for Evaluation (IEA), the SPSS-based IDB Analyzer program is specifically designed to analyze large-scale test data, such as the PISA test. It incorporates features to account for sample weights and potential values (IEA, 2019). In standard algebraic notation, the general expression of the multiple linear regression model is as follows:

$$y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6+\beta_7X_7+\beta_8X_8$$

In this model;

y: Mathematics literacy score (PV1MATH-PV10MATH),

β_n : Partial regression coefficient,

X_1: Paper textbooks, workbooks, or worksheets (Paper),

X_2: Digital textbooks, workbooks, or worksheets (Digital),

X_3: Real time lessons by a teacher from my school on a video communication program (e.g. EBA, Zoom™, Skype™) (A teacher),

X_4: Real time lessons by a private tutor on a video communication program (e.g. EBA, Zoom™, Skype™) (A private tutor),

X_5: Learning material my teachers sent via Short Message or WhatsApp™,
X_6: Recorded lessons or other digital material provided by teachers from my school (Recorded lessons),
X_7: Recorded lessons or other digital material from other sources (Other digital material),
X_8: Lessons broadcast over television (e.g. EBA TV) or radio (TV or radio)

3.5. Validity and Reliability

PISA stands as the most comprehensive and rigorous international program for evaluating student achievement while gathering data on student, family, and institutional factors that may elucidate disparities in achievement. The scope and design of assessments, along with the collection of background information, were determined by leading experts in participating countries. Governments of these nations collectively guided the program based on shared, policy-driven interests. Extensive efforts and resources were dedicated to ensuring cultural and linguistic diversity and balance in assessment materials. Rigorous quality assurance mechanisms were implemented for translation, sampling, and data collection processes. Consequently, PISA results boasted a high degree of validity and reliability (OECD, 2019).

4. Findings

4.1. Findings Related to the First Subproblem

To address the first problem of the study, which investigates whether PISA-2022 test mathematics literacy levels vary based on the digital devices used by students during the period when their schools were closed due to the coronavirus, Table 1 presents a frequency table detailing the digital devices utilized by the students.

Table 1.
Frequencies and percentage of Digital Devices Used

Digital Devices N (%)	Estonia	Finland	Hong Kong	Croatia	Turkey
My laptop, desktop computer, or tablet	3656 (68.8%)	3506 (34.2%)	3144 (53.2%)	2523 (41.1%)	1723 (23.8%)
My smartphone	1212 (22.8%)	1593 (15.6%)	1034 (17.5%)	1276 (20.8%)	2768 (38.2%)
A digital device that was also used by other family members	293 (5.5%)	413 (4.0%)	116 (2.0%)	212 (3.5%)	594 (8.2%)
A digital device that my school gave or lent to me	118 (2.2%)	1037 (10.1%)	204 (3.5%)	219 (3.6%)	189 (2.6%)
I did not have any digital device for my schoolwork	35 (.7%)	76 (.7%)	55 (.9%)	47 (.8%)	338 (4.7%)

Note. N: number of participants, %: Percent

Table 1 presents the frequencies of the most commonly used digital devices by students, categorized by country. In Estonia, the predominant digital device utilized by students is their laptop, desktop computer, or tablet (68.8%), whereas the least utilized device is a digital device gifted or lent by their school (2.2%). Similarly, in Finland, students primarily utilize their laptop, desktop computer, or tablet (34.2%), with the least used device being one also used by other family members (4.0%). In Hong Kong, the most commonly used digital device is again their laptop, desktop computer, or tablet (53.2%), while the least utilized device is one also used by other family members (2%). In Croatia, students predominantly use their laptop, desktop computer, or tablet (41.1%), while the least used device is one also used by other family members (3.5%). Conversely, in Turkey, the most frequently used digital device is their smartphone (38.2%), with the least utilized device being one gifted or lent by their school (2.6%).

Among the digital devices, Estonia has the highest usage of devices in the category of "own laptop, desktop computer, or tablet" (68.8%), while Turkey has the lowest usage in this category (23.8%). Turkey also shows the highest usage of devices in the category of own smartphone" (38.2%), whereas Finland has the

lowest usage in this category (15.6%). Regarding devices in the category of "a digital device also used by other family members" Turkey demonstrates the highest usage (8.2%), while Hong Kong has the lowest usage (2%). Finland has the highest usage of devices in the category of "a digital device gifted or lent by my school" (10.1%), while Estonia has the lowest usage (2.2%). The highest frequency of students reporting "I did not have a digital device that I could use for my studies" is observed in Hong Kong (0.9%), whereas the lowest frequency is reported in Turkey (4.7%). If the frequencies of the most used digital devices of the students in Table 1 are interpreted on the basis of countries, the most used digital device of the students in other countries except Turkey is their laptop, desktop computer or tablet, while in Turkey, unlike other countries, the most used digital device of the students is their smartphones. When the least used digital devices by students are analyzed on a country basis, the least used digital device by students in Finland, Hong Kong, and Croatia is a digital device that is also used by other family members, while the least used digital device by students in Estonia and Turkey is a digital device gifted or lent by the school.

To address the first subproblem of the research, investigating whether PISA-2022 test mathematics literacy levels differ based on the digital devices used by students for their studies during the period of school closures due to the coronavirus, analysis of variance (ANOVA) was conducted. ANOVA was employed to examine the statistical significance of the observed mean differences in PISA-2022 mathematics test achievement across various digital devices used by students. Table 2 presents the ANOVA results.

Table 2.
ANOVA Results of PISA-2022 Test Mathematics Literacy Levels of Countries according to the Digital Devices They Use

Countries	Source of Variation	Sum of Squares	df	Mean Square	F	p	Significant Mean Difference
Estonia	Between groups	3266562.149	4	816640.537	111.029	.000	1-2,3,4,5; 2-1,3,4,5; 3-1,2,4,5; 4-1,2,3; 5-1,2,3
	Within groups	41240640.61	5607	7355.206			
	Total	44507202.760	5611				
Finland	Between groups	2295882.643	4	573970.661	74.758	.000	1-2,3,4,5; 2-1,3,4,5; 3-1,2,5; 4-1,2,5; 5-1,2,3,4
	Within groups	50826545.960	6620	7677.726			
	Total	53122428.600	6624				
Hong Kong	Between groups	995920.062	4	248980.016	24.753	.000	1-2,3,4,5; 2-1,3,4,5; 3-1,2,4,5; 4-1,2,3; 5-1,2,3
	Within groups	45745971.310	4548	10058.481			
	Total	46741891.370	4552				
Croatia	Between groups	1145078.576	4	286269.644	39.497	.000	1-2,4,5; 2-1; 3-1; 4-1; 5-1
	Within groups	30963074.540	4272	7247.911			
	Total	32108153.110	4276				
Turkey	Between groups	3266562.149	4	816640.537	111.029	.000	1-2,3,4,5; 2-1,3,4,5; 3-1,2,4,5; 4-1,2,3; 5-1,2,3
	Within groups	41240640.610	5607	7355.206			
	Total	44507202.760	5611				

Note: 1: My laptop, desktop computer, or tablet, 2: My smartphone, 3: A digital device that was also used by other family members, 4: A digital device that my school gave or lent to me, 5: I did not have any digital device for my schoolwork

A statistically significant mean difference was observed for Estonia [$F(4, 5607)= 111.029$, $p<.05$] in the mean mathematics literacy levels of the PISA-2022 test based on the digital devices used by students (Table 2). Post hoc analysis using the Scheffe test revealed significant mean differences between students in Estonia who used their laptop, desktop computer, or tablet and those who used their smartphone, a digital device also used by other family members, a digital device gifted or lent by the school, and those who did not have a digital device for their studies related to the lessons. Significant mean differences were also noted between students who used their smartphones and those who used their laptops, desktop computers, or tablets, a digital device also used by other family members, a digital device gifted or lent by the school, and those who did not have a digital device for their studies. Additionally, significant mean differences

were observed between students who used a digital device also used by other family members and those who used their laptop, desktop computer, or tablet, their smartphone, a digital device gifted or lent by the school, and those who did not have a digital device for their studies. Similar significant mean differences were found between students who used a digital device gifted or lent by the school and those who used their laptop, desktop computer, or tablet, their smartphone, and those who did not have a digital device for their studies. Moreover, significant mean differences were identified between students who did not have a digital device for their studies and those who used their laptop, desktop computer, or tablet, their smartphone, a digital device also used by other family members, and a digital device gifted or lent by the school.

Similarly, a statistically significant mean difference was observed for Finland [$F(4,6620)= 74.758$, $p<.05$] in the mean mathematics literacy levels of the PISA-2022 test based on the digital devices used by students (Table 2). Post hoc analysis revealed significant mean differences between students in Finland who used their laptop, desktop computer, or tablet and those who used their smartphones, a digital device also used by other family members, a digital device gifted or lent by the school, and those who did not have a digital device for their studies. Significant mean differences were also found between students who used their smartphones and those who used their laptops, desktop computers, or tablets, a digital device also used by other family members, a digital device gifted or lent by the school, and those who did not have a digital device for their studies. Additionally, significant mean differences were noted between students who used a digital device also used by other family members and those who used their laptop, desktop computer, or tablet, their smartphone, and those who did not have a digital device for their studies. Moreover, significant mean differences were identified between students who used a digital device gifted or lent by the school and those who used their laptop, desktop computer, or tablet, their smartphone, and those who did not have a digital device for their studies. Lastly, significant mean differences were observed between students who did not have a digital device for their studies and those who used their laptop, desktop computer, or tablet, their smartphone, a digital device also used by other family members, and a digital device gifted or lent by the school.

A statistically significant mean difference was also observed for Hong Kong [$F(4,4548)= 24.753$, $p<.05$] in the mean mathematical literacy levels of the PISA-2022 test based on the digital devices used by the students (Table 2). Significant mean differences were found between students in Hong Kong who used their laptop, desktop computer, or tablet and those who used their smartphones, a digital device gifted or lent by the school, and those who did not have a digital device for their studies. Additionally, significant mean differences were observed between students who used their smartphones and those who used their laptops, desktop computers, or tablets. There were also significant mean differences between students who used a digital device gifted or lent by the school and those who used their laptop, desktop computer, or tablet. Moreover, a significant mean difference was identified between students who did not have a digital device for their studies and those who used their laptop, desktop computer, or tablet, and those who used their smartphone.

For Croatia, a statistically significant mean difference was observed [$F(4,4272)= 39.497$, $p<.05$] in the mean mathematical literacy levels of the PISA-2022 test based on the digital devices used by the students (Table 2). Significant mean differences were found between students in Croatia who used their laptop, desktop computer, or tablet and those who used their smartphones, a digital device also used by other family members, a digital device gifted or lent by the school, and those who did not have a digital device for their studies. Additionally, significant mean differences were observed between students who used their smartphones and those who used their laptops, desktop computers, or tablets, and those who did not have a digital device for their studies. Moreover, significant mean differences were identified between students who used a digital device also used by other family members and those who used their laptop, desktop computer, or tablet, and those who did not have a digital device for their studies. Lastly, significant mean differences were observed between students who did not have a digital device for their studies and those

who used their laptop, desktop computer, or tablet, used their smartphone, a digital device also used by other family members, and a digital device gifted or lent by the school.

Finally, in terms of Turkey, a statistically significant mean difference was observed [$F(4,5607)= 111.029$, $p<.05$] in the mean mathematics literacy levels of the PISA-2022 test based on the digital devices used by the students (Table 2). Significant mean differences were found between students in Turkey who used their laptop, desktop computer, or tablet and those who used their smartphones, a digital device also used by other family members, a digital device gifted or lent by the school, and those who did not have a digital device for their studies.

4.2. Findings Related to the Second Subproblem

Multiple linear regression analysis was performed to address the second subproblem of the study, which aims to explore the relationship between the printed and digital learning resources utilized by students during the period of school closures due to the coronavirus pandemic and their mathematics literacy levels in the PISA-2022 test. Table 3 presents the regression coefficients and standard error results obtained from the multiple linear regression analysis conducted to assess the influence of printed and digital learning resources on PISA-2022 test mathematics achievement.

Tablo 3.

Prediction Levels of Printed and Digital Resources for Mathematical Literacy in PISA-2022 Test

Digital and Printed Learning Resources		Estonia	Finland	Hong Kong	Croatia	Turkey
β (s.e. (β))	Constant	435,01*(9,21)	429,86*(7,53)	429,30*(8,80)	441,85*(7,97)	410,94*(5,14)
	Paper	7,13*(2,36)	15,63*(2,35)	14,27*(3,21)	8,25*(2,56)	10,94*(2,82)
	Digital	13,18*(2,26)	5,92*(2,15)	17,89*(3,24)	-,47(2,87)	1,78(2,59)
	A teacher	17,17*(2,45)	11,28*(2,88)	19,92*(3,42)	14,79*(3,08)	28,85*(2,44)
	A private tutor	-3,05*(1,28)	-3,81*(1,63)	1,66(2,22)	-9,88*(2,12)	-4,38(2,12)
	WhatsApp™	-7,08*(2,26)	-10,69* (2,49)	-8,30*(3,24)	1,77(2,79)	2,46(3,36)
	Recorded lessons	,18(2,60)	,77(2,64)	4,37(4,34)	-3,64(3,72)	-7,38*(2,93)
	Other digital material	-6,17 (2,96)	6,31 (3,03)	-6,95(3,14)	7,09(3,96)	-,45(3,17)
	TV or radio	-10,05*(3,10)	-23,40*(2,10)	-20,58*(2,82)	-20,67*(2,23)	-22,80*(2,05)

Note. Paper: Paper textbooks, workbooks, or worksheets, Digital: Digital textbooks, workbooks, or worksheets, A Teacher: Real time lessons by a teacher from my school on a video communication program (e.g. EBA, Zoom™, Skype™), A private tutor: Real time lessons by a private tutor on a video communication program (e.g. EBA, Zoom™, Skype™), WhatsApp™: Learning material my teachers sent via Short Message or WhatsApp™, Recorded lessons: Recorded lessons or other digital material provided by teachers from my school, Other digital material: Recorded lessons or other digital material from other sources, TV or radio: Lessons broadcast over television (e.g. EBA TV) or radio, * $p < .05$

The results of the multiple linear regression analyses depicted in Table 3 indicate that the factors associated with the learning resources utilized by students across the five countries contribute similarly to explaining the variability in students' mathematical literacy levels. Specifically, the factors related to learning resources account for 14% of the variability in mathematical literacy levels in Estonia, 18% in Finland, 17% in Hong Kong, 13% in Croatia, and 16% in Turkey.

Upon closer examination of the results presented in Table 3, in Estonia, among the printed and digital learning resources used by students, the variable “live lectures given by a teacher at school through a video communication programme (e.g., EBA, Zoom™, Skype™)” has the most positive effect on mathematical literacy levels, while the variable “printed textbooks, workbooks, or worksheets” has the least positive effect. Notably, the variable “video or audio lecture recordings or other digital materials prepared by teachers in our school” does not impact students mathematical literacy levels positively. Furthermore,

"course broadcasts on television (EBA TV) or radio" exhibits a negative effect on mathematical literacy levels.

Similarly, in Finland, among the learning resources, "printed textbooks, workbooks, or worksheets" has the most positive impact on mathematical literacy levels, whereas "video or audio course recordings or other digital materials from other sources" shows the least positive effect. Additionally, "lectures via television (EBA TV) or radio" negatively influence mathematical literacy levels.

In Hong Kong, "live lessons given by a teacher at school via a video communication programme (e.g., EBA, Zoom™, Skype™)" has the most positive effect on mathematical literacy levels among the utilized learning resources, while "live lessons given by a private tutor via a video communication programme (e.g., EBA, Zoom™, Skype™)" has the least positive effect. Furthermore, "lectures via television (EBA TV) or radio" negatively impact mathematical literacy levels.

Regarding Croatia, "live lectures given by a teacher at school via a video communication programme (e.g., EBA, Zoom™, Skype™)" emerges as the most positively impactful learning resource, while "learning materials sent by my teachers via text message or WhatsApp™" has the least positive effect. Moreover, "course broadcasts via television (EBA TV) or radio" negatively affect mathematical literacy levels.

Lastly, in Turkey, "live lectures given by a teacher at school through a video communication programme (e.g., EBA, Zoom™, Skype™)" has the most positive effect on mathematical literacy levels, whereas "digital textbooks, workbooks, or worksheets" has the least positive effect. "Video or audio lecture recordings or other digital materials from other sources" do not influence mathematical literacy levels positively, and "course broadcasts on television (EBA TV) or radio" negatively impact mathematical literacy levels.

5. Discussions

Various factors influence the mathematical literacy levels of 15-year-old students, with the use of digital devices and printed and digital learning resources emerging as significant during the COVID-19 pandemic (Egan & Beatty, 2021). Notably, in countries like Finland, where students excel in the PISA-2022 test rankings, the provision of digital devices by schools significantly contributes to students' mathematical literacy levels (Blaskó, 2022). Similar disparities were observed in Europe, where students lacking internet access, books, personal study spaces, and parental support experienced declines in academic achievement (Blaskó, 2022). Schools offering support to students facing digital device and internet access challenges during the pandemic can enhance students' resilience (Karaman & Konyalıar, 2024). Köken and Duman (2024), in a study conducted with the families of not only students who are characterized as normal but also students who need special education, found that families complained about the lack of school support, which also supports this view.

Additionally, students' academic achievement is influenced by a country's welfare level and families' income levels. Access to information and communication technologies often reflects economic power, with higher-income families investing more in education-related resources (Eurydice, 2004; Bozkurt & Sarıoğlu, 2016; Durgun, 2011; Sarıer, 2010; Tomul, 2007).

Another significant finding is the potential negative impact of increased reliance on course broadcasts via television (EBA TV) or radio on 15-year-old students' mathematical literacy levels in the PISA-2022 test. Studies highlight concerns such as limited student-teacher interaction, insufficient time for lessons, and distractions during broadcasts (Aydın, 2020; Kuzu, 2020).

Conversely, increasing the use of live lessons via video communication platforms like EBA, Zoom™, or Skype™ is associated with enhanced mathematical literacy levels in 15-year-old students across all

countries. Students prefer live synchronous lectures due to increased interaction with teachers, opportunities to ask questions, and higher motivation compared to traditional television broadcasts (Kumaş & Kan, 2022).

6. Conclusion and Suggestions

When examining the prevalence of digital device usage among students across different nations, it is evident that, except for Turkey, the predominant digital device used by students is their personal laptop, desktop computer, or tablet. In Turkey, however, smartphones have emerged as the preferred digital device among students. Conversely, when analyzing the least utilized digital devices on a country-by-country basis, it is notable that in Finland, Hong Kong, and Croatia, the least utilized devices are those shared among family members, whereas in Estonia and Turkey, the least utilized devices are those provided or loaned by schools. Particularly striking is the finding that in Finland, the second most utilized digital device after personal laptops, desktop computers, or tablets is one provided or loaned by schools, which correlates with an enhancement in mathematical literacy levels among students. This underscores the significance of educational support provided by schools, especially during the pandemic, and suggests a positive association between a country's welfare level and its investments in education.

The study also concludes that increasing the utilization of live lectures delivered by teachers in schools through video communication platforms (e.g., EBA, Zoom™, Skype™) could potentially elevate the mathematics literacy levels of 15-year-old students, while a higher reliance on lectures via television (EBA TV) or radio may have a detrimental effect on these literacy levels. Furthermore, the research highlights differences in the use of digital versus printed learning resources across countries. Specifically, Estonia and Hong Kong exhibit a higher preference for digital textbooks, workbooks, or worksheets compared to printed resources, whereas Finland, Croatia, and Turkey show a greater inclination towards printed materials.

Inadequacy in digital devices used in education and training processes and students' limited access to digital devices negatively affect online learning processes. Students' lack of access to digital devices also negatively affects mathematics achievement. Therefore, it is concluded that inadequacies in online learning processes negatively affected math achievement. As access to digital devices in online learning processes becomes more difficult, the performance of online learning processes and academic achievement will be negatively affected. Considering that online learning processes will play a more active role in education in the future, it is also recommended to conduct more studies to increase academic achievement in online learning processes.

Based on these findings, it is suggested that providing students with personal laptops, desktop computers, or tablets could significantly contribute to their academic success. Additionally, offering educational support through school-provided digital devices is recommended. Moreover, the widespread adoption of live lectures delivered by teachers through video communication platforms, as opposed to broadcasts via television or radio, is advocated for enhancing students' success in their lessons.

7. Limitations and Suggestions

This study, investigating the correlation between digital device usage among 15-year-old students in Estonia, Finland, China, Croatia, and Turkey and their mathematics proficiency, along with the predictive capacity of students' printed and digital learning materials on their mathematics achievement, presents several limitations. As the PISA-2022 test operates within a cross-sectional framework, it does not permit the establishment of causal relationships between the study's dependent and independent variables. To address this limitation, future research could employ longitudinal and experimental designs to explore potential causal links between predictor and outcome variables in educational technology and online learning.

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