Central European Journal of Educational Research 7(2) 2025. 115–128.

Research Paper

The role of digital background factors in academic achievement. A comparative study of students from three countries based on the PISA 2022 database

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Recommended citation:

Csajkos, B. J., & Kovács, K. (2025). The role of digital background factors in academic achievement. A comparative study of students from three countries based on the PISA 2022 database. *Central European Journal of Educational Research*, *7*(2), 115–128. https://doi.org/10.37441/cejer/2025/7/2/15662

Abstract

This study investigates the impact of students' digital background factors on mathematical achievement using data from the 2022 PISA assessment. The analysis focuses on 15-year-old students from Austria, Estonia, and Hungary with particular attention given to the interplay between home financial conditions, ICT availability and usage, digital attitudes, and mathematics performance. Drawing on student questionnaire responses, we constructed composite indices and factor scores representing digital access, usage frequency, and digital competence at both home and school settings. Descriptive statistics, ANOVA, and linear regression models were applied to explore the relationships between digital background variables and students' mathematics proficiency scores. The results reveal that home financial status consistently predicts higher achievement across all three countries, whereas the frequency of school-based ICT use shows a negative correlation with performance. Conversely, home-based ICT usage and positive attitudes towards online platforms correlate with higher mathematics outcomes. The Estonian data challenge the initial hypothesis of a country-specific positive effect of ICT usage in schools, suggesting instead that the quality and context of digital integration matter more than frequency. The findings also highlight the importance of learning orientation and student motivation in shaping mathematics performance. Despite some methodological limitations – such as the cross-sectional nature of the data and reliance on self-reported measures – the study offers reliable insights into how digital background factors influence academic outcomes. The results underscore the need for more effective integration of ICT tools in classrooms, informed by students' learning habits and preferences.

Keywords: digital background; mathematics achievement; PISA 2022; ICT usage

Introduction

In the 1990s, the concept of the information society emerged as a new paradigm in social science research. To explain the distinction between the industrial society as the old model and the information society as the new one, scholars developed theories emphasizing either continuity or paradigm shift. Those arguing for a paradigm shift primarily emphasize that entirely new social layers replace the older ones, whereas proponents of continuity reject this notion outright (Castells, 1996). According to the latter view, the different ways in which information is processed do not fundamentally alter the structure of societies.

In 2001, DiMaggio and Hargittai argued that new information technologies – particularly the Internet – are not comparable to earlier communication technologies but are instead more similar to various service platforms. They supported this claim by suggesting that new tools and technologies foster new forms of education and provide access to academic literature, potentially replacing the traditional roles of communities (DiMaggio & Hargittai, 2001).

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Digital tools have the potential to foster students' creativity, accelerate access to information, and promote collaboration, thereby enhancing peer learning. Nevertheless, the confident and effective use of information and communication technologies (ICTs) in the classroom depends largely on educators' expertise with these tools and their readiness to assume a coordinating role during lessons. Without these conditions, the integration of technology may produce counterproductive effects both in the immediate learning process and in long-term academic performance. At the same time, empirical evidence shows that when effectively embedded in collaborative activities, digital tools significantly increase student engagement, critical thinking, and peer interaction (Oskarita & Arasy, 2024).

DiMaggio and his colleagues are primarily associated with the conceptualization of digital inequality. They identified five key dimensions necessary to observe real mechanisms of inequality. According to their framework, we must examine: the quality and autonomy of the devices used, the presence of relevant competencies and knowledge, the availability of social support, and the specific purpose of use. Digital inequalities are also present in education and can similarly be analysed through multiple dimensions. In this context, four aspects can be identified: institutional resources, ICT infrastructure, teacher qualifications and professional development, and the acquisition of digital competencies (DiMaggio & Hargittai, 2001; Erdős, 2015).

The aim of our research is to examine the role of digital and social inequalities in the mathematical competencies of 15-year-old students using data from Austria, Estonia, and Hungary, as reflected in the international PISA assessment. Austria and Hungary are neighbouring countries with intertwined histories up to the end of the First World War. However, their historical, economic, and social development has significantly diverged over the past century. While Austria identified itself as part of the community of independent nations in the post–World War II period, Hungary's political and educational systems were shaped by Soviet oppression and socialist ideology under a dictatorial regime. Today, after 35 years of independence, Hungary often looks to Austria as a model in several areas, including education. The two countries are comparable in terms of population size, geographic area, and location.

Estonia, a country annexed by the Soviet Union in the 1940s and independent since 1991, with a population of fewer than 1.5 million, was quick to recognize the opportunities of digitalization in both governance and education. This led to the emergence of what is now referred to as the "Estonian miracle." Estonians embraced the internet early in the post-socialist transition, as it is not bound to rigid infrastructure and operates within a decentralized system. They were among the first to launch a digital government initiative, the "e-Estonia" project. Estonia's first information society strategy, titled Estonia's Way to the Information Society, was published in 1994, and four years later, the parliament adopted the main document outlining the country's information policy (Principles of Estonian Information Policy). This program was reinforced in 2004, and a new strategy was introduced in 2013, which mandated that inequalities and digital divides must not be allowed to develop during progress, and existing ones should be reduced.

One of the key pillars of the so-called "Estonian miracle" is the consistent improvement in educational outcomes. In reading, mathematics, and science, Estonian students consistently perform significantly above the OECD average in every PISA cycle. The essence of the Estonian miracle, in the context of our topic, lies in the implementation of a lifelong learning strategy, which encompasses children, young people, and adults alike. The core principle of this strategy is that learning should be an integral part of an individual's life, with learners taking responsibility for their own learning. (PISA 2022 Results [Volume I and II] – Country Notes: Estonia, 2023).

One of the foundations of the outstanding performance of the Estonian education system is transparency and data-driven governance. Through the Estonian Education Information System (EHIS) and the Haridussilm statistical portal, up-to-date information is available on every institution, learner, and educational programme, supporting decision-making and ensuring the continuous monitoring of educational quality. This integrated, publicly accessible, and data-driven approach makes Estonia's educational model unique in Europe. Among the distinctive features of the Estonian education system are the innovative approaches to student training and teacher education. For students, the curricula place a strong emphasis on the development of key competences, such as digital literacy, problem-solving, and foreign language proficiency. Teacher education is likewise of a high standard, with a strong focus on pedagogical practice and continuous professional development. The structure of the education system supports teachers' methodological autonomy and the introduction of innovative teaching tools. Furthermore, competence-based education aims to strengthen students' critical thinking and independent learning skills, providing a competitive advantage also in an international comparison (Eurydice Estonia, 2024).

All three countries participate in the PISA assessments, which allows for comparisons of students' skill levels and questionnaire data. The question of whether the use of ICT tools has a positive impact on students' academic performance has long been a subject of debate (Bulman & Fairlie, 2016; PISA 2022 ICT Framework). This study aims to contribute to this ongoing discussion, while also taking into consideration the influence of students' social backgrounds.

In our study, we chose mathematical competence results as indicators of student performance. Although both national and international literature more frequently emphasises reading literacy, given its crucial role in everyday life and labour market success, considerably less attention has been devoted to the background factors influencing mathematical competences. It is also important to note that many mathematics test items appear in the form of word problems, where reading comprehension and interpretive skills play a pivotal role. At the same time, mathematical competence encompasses abilities that enable individuals to address and interpret real-life problems, including issues related to personal financial matters. According to the Royal Society (2011), mathematics is becoming increasingly relevant in numerous modern professions and fields of higher education, which further underlines the importance of mathematical competences for future social and economic participation.

With the integration of digital technologies into mathematics education, it has become increasingly common for students to simultaneously use and develop their mathematical and digital competencies (Geraniou & Jankvist, 2019).

PISA also conceptualizes mathematics as a tool for navigating real-life situations, making decisions, and taking action. Its assessment of mathematical literacy employs three interrelated dimensions: content, cognitive processes, and difficulty levels. These dimensions are mapped onto one another to create a wide array of tasks, providing a comprehensive picture of the mathematical performance of 15-year-old students. It is common for assessments of mathematical literacy to highlight socioeconomic and family-cultural factors as influential variables (Csíkos & Vidákovich, 2012).

The Role of the Educational Environment in the Development of Student Competencies

As early as the 1960s, scholars began employing models in the analysis of educational infrastructure in which student performance represented the output, and school resources served as the input. The introduction of PISA assessments gave new momentum to such research. The OECD ties student performance partly to school-level indicators (such as teacher qualifications and school size); however, in the early phases of the assessments, only minimal statistically significant relationships were found in this area. Over time, and with the increasing prominence of international assessments, more studies have confirmed that a school's location and its level of equipment do have an impact on student achievement and competencies (Knowledge and Skills for Life, 2001; Lannert, 2006). According to PISA data, parental educational attainment has varying levels of influence across countries, and in Hungary, this influence is stronger than the OECD average (Csíkos & Vidákovich, 2012).

In Austria, where ongoing research into the interaction between education and digital tools has been conducted since 2008, a survey involving 137 teachers investigated how new technologies have affected teaching methods and student outcomes. It was evident from their responses that digital tools make lessons more varied and engaging. However, the majority of the respondents stated that these tools neither improved nor distracted from student performance. At the same time, teachers observed notable improvements in students' problem-solving abilities and self-directed learning skills among those using ICT tools (Antal et al., 2015).

Analysing the data from the 2012 PISA assessment, Lannert observed that in countries where students performed above average in problem-solving, the potential of ICT tools was utilized more effectively. These countries also tend to have educators who are both open to and proficient in using ICT tools, thereby serving as motivators for their students (Lannert, 2014).

According to an analysis of the 2015 PISA data, students who indicated in the background questionnaire that they dislike digital tools or are reluctant to use them consistently achieved significantly lower scores across all three knowledge domains. However, 44% of those students who claimed not to like digital devices still identified themselves as confident users of ICT. Students who reported never or rarely using digital tools for homework or subject preparation tended to achieve higher results. By contrast, students who used digital tools daily performed the lowest in mathematics, reading, and science compared to their peers (Erdős, 2015).

The mere presence of ICT tools is not sufficient to ensure their effective use in enhancing students' cognitive performance and ICT competencies. The question of whether ICT use has a positive impact on student achievement remains unresolved (Bulman & Fairlie, 2016; PISA 2022 ICT Framework).

With the advent of ICT technologies, the activities and toolsets of educators have undergone significant transformation. Traditional methods, once effective, are increasingly insufficient today. According to Buda's findings, although textbooks and chalkboards still play a key role in teaching, their importance is steadily declining (Buda, 2019).

Numerous studies have shown that digital devices – such as laptops and tablets – do not, by themselves, lead to improved student performance. Randomised evaluations of OLPC-type initiatives (One Laptop per Child – international programmes aimed at providing every child with a laptop) have found no significant improvements in either mathematics or reading outcomes (Cristia et al., 2012; de Melo et al., 2014), and other large-scale implementation projects have reached similar conclusions (Beuermann et al., 2015). These findings highlight that the mere provision of devices is insufficient; meaningful learning gains can only be achieved when pedagogical approaches and teacher preparedness are closely aligned with technology use.

Research Questions and Hypotheses

Our research seeks to answer whether there is a relationship between students' digital backgrounds and their PISA performance. Do students with greater access to ICT tools and higher levels of digital tool usage (both at school and at home) achieve better results in mathematics? Which factors influence mathematical competencies in the three countries under study, and to what extent? What differences exist in these relationships across Hungary, Estonia, and Austria? Does the so-called "Estonian miracle" reflect a process of catching up or true advancement? These core questions form the basis of our hypotheses.

H1. Students with a stronger digital background achieve higher competency scores than those with a weaker digital background in all three countries. This hypothesis is rooted in the framework of digital inequalities (DiMaggio & Hargittai, 2001), which highlights the role of device quality, competencies, and social support in shaping educational outcomes. Previous PISA analyses have also confirmed that socioeconomic background, including access to digital resources, significantly influences student performance (Csíkos & Vidákovich, 2012; Erdős, 2015).

H2. Students with higher levels of digital competence achieve better results in all three countries. This proposition builds on the conceptualization of "mathematical digital competency" (Geraniou & Jankvist, 2019), which emphasises the synergy between digital and mathematical skills. Empirical findings also suggest that the confident and effective use of ICT tools contributes to higher student engagement and improved cognitive skills (Oskarita & Arasy, 2024).

H3. More positive attitudes toward the use of digital tools at school are associated with higher competency outcomes, while more positive attitudes toward digital tool use at home are associated with lower competency outcomes. This hypothesis reflects findings from earlier PISA cycles, where daily use of digital tools for leisure or homework was negatively correlated with academic achievement, while moderate and structured school-based use was linked to better outcomes (Erdős, 2015; Bulman & Fairlie, 2016). The duality of beneficial versus detrimental contexts of use underpins this assumption.

H4. The use of digital tools at school is associated with lower competency outcomes in Austria and Hungary, but with higher outcomes in Estonia. This assumption is informed by comparative studies of ICT integration. In Austria and Hungary, empirical evidence suggests that while digital tools diversify teaching methods, they do not consistently translate into improved performance (Antal et al., 2015; Buda, 2019). By contrast, Estonia's education system is characterised by a strong digital infrastructure, data-driven governance, and competence-based curricula, which align digitalisation with broader educational goals (Eurydice Estonia, 2024; PISA 2022 Results – Country Notes: Estonia, 2023). This structural difference provides the rationale for expecting divergent outcomes across the three countries.

Methodological Background and Database of the Study

Data Collection and Sample Characteristics

This study utilizes data from the 2022 PISA assessment, specifically the PISA 2022 Database. Within this database, we primarily used elements from the Student Questionnaire Data, which provide insights into students' backgrounds and academic performance. PISA collects information through background questionnaires on the socio-cultural and economic variables influencing performance, including family and home-related factors, and the level of institutional resources (PISA 2022 summary report, 2024).

The target population of our analysis consists of students who participated in the 2022 PISA study in Austria (n=6151), Estonia (n=6392), and Hungary (n=6198), totalling 18741 students. The questionnaire was administered in a digital format. As mathematics was the main focus of the 2022 cycle, while reading and science were considered supplementary domains, most of the questions in the student questionnaire were centred around mathematics.

From the PISA 2022 student database, we extracted the data relevant to our research questions using the national and individual student identification codes. (The questionnaire includes numerous question blocks not relevant to our study; therefore, only the question areas directly related to our topic are presented.)

Variables Examined and Statistical Methods Applied

In our study, we examined students' digital background across multiple domains using data from the PISA 2022 Database. These background data were linked to the composite mathematics competency variable. In the analysis, our independent variables were digital indices related to the home and school environments, while the dependent variable was the composite measure of mathematical competence.

The PISA 2022 student questionnaire included several questions related to students' financial situation at home and the number of ICT tools available to them, both of which were considered indicators of economic status. Based on these variables, we constructed a financial resources index ranging from 0 to 23.

The number of ICT tools was analysed in a similar way, resulting in an ICT availability index with a maximum possible score of 18. Long and Freese (2014) propose two common approaches for incorporating ordinal-level variables, such as educational attainment, into multivariate regression analysis: assigning values that reflect the magnitude of progression and treating these variables as continuous. Following this principle, we constructed composite variables for both financial background and ICT access.

Digital background was analysed at the home, school, and individual levels. During the data processing phase, we identified five dimensions. The first was access to digital devices, as outlined above. The second concerned the use of ICT tools at home and at school, measured by a total of 13 items; internal consistency for these indices was Cronbach's $\alpha = 0.773$ and 0.681, with KMO values of 0.833 and 0.724, and statistical significance at $p < 0.001$; the explained variance was 43.109% and 40.123%, respectively. The third dimension involved students' perceptions of their school's digital infrastructure and the digital preparedness of teachers, based on 9 items; this dimension showed high reliability with Cronbach's $\alpha = 0.891$, KMO = 0.908, $p < 0.001$, and explained variance of 53.948%. The fourth dimension assessed students' digital competencies, with 18 items grouped into two factors: content creation and the use of online platforms. Internal consistency was strong (Cronbach's $\alpha = 0.916$, KMO = 0.942, $p < 0.001$), and explained variance was 50.722%. The fifth dimension explored attitudes toward digital device usage, again grouped into two factors. One factor covered statements emphasizing the responsibility of schools and teachers in guiding proper device use (particularly smartphones), often through prohibition or close supervision. The other factor captured students' interest in learning about digital tools and basic programming skills, both in general and in hopes of improving future employment prospects. This attitude dimension was measured using 9 items, with Cronbach's $\alpha = 0.743$, KMO = 0.776, $p < 0.001$, and explained variance of 54.785%.

All principal components and factors were rescaled to a 0-100 metric and subsequently categorised into lower, middle, and upper thirds (terciles) based on their distribution. Table 1 presents the means and standard deviations of these indices, factors, and components by country.

Table 1. Country-level Differences in Students' Financial and Digital Background Factors (Means and Standard Deviations of Indices and Factor Scores, $p < 0.001$)

Financial and Digital Background Variables	Austria		Estonia		Hungary		F	N
	Mean	SD	Mean	SD	Mean	SD		
Household Financial Status	13,79	4,1	12,4	3,44	12,05	3,86	359,452	18741
ICT Availability at Home	7,27	2,37	6,38	1,96	6,5	2,28	289,114	18741
ICT Use at School	46,02	19,28	40,5	17,62	48,12	18,27	260,224	16805
ICT Use at Home	52,48	16,71	52,25	15,79	55,22	16,32	57,543	16679
School Digital Infrastructure and Teacher Preparedness	58,88	21,85	60,73	15,68	58,49	17,07	23,759	16223
Content Creation	39,4	17,28	35,24	17,25	40,86	17,86	141,626	14777
Use of Online Platforms	54,08	16,25	61,75	16,67	61,41	16,81	323,204	
School ICT Control	23,69	22,19	30,81	20,27	29,67	21,91	164,481	15711
Learning Motivation	55,74	27,29	60,11	22,97	49,69	24,57	233,984	

(Source: PISA 2022 Database)

The financial indices suggest that students in Austria are in the most favourable position in terms of both economic conditions and ICT availability. However, the standard deviation suggests a greater degree of variation among students within the country. Hungary follows Estonia with a slight lag. The disparity in ICT access is lowest among Estonian students, which may be attributed to the previously mentioned national development and digital inclusion programs.

Students in Estonia and Hungary report the most frequent use of online platforms for learning purposes, while Austria lags slightly behind in this area. A similar pattern is observable in attitudes toward school-level digital control. The highest levels of in-school ICT usage are found in Hungary, closely followed by Austria. Interestingly, although Estonia reports the lowest index value for ICT tool use at school among the three countries, it ranks highest in terms of school digital infrastructure and teacher preparedness.

Hungary shows outstanding values in both content creation and the use of online platforms, although Estonia is comparable in terms of online platform usage, and Austria nearly matches Hungary in content creation. The highest level of agreement with the need to regulate digital device use at school is found in Estonia, where the school control index is also the highest – although Hungary shows similarly high values. Austria, in contrast, differs significantly from the other two countries in this respect.

Digital learning is clearly most widespread in Estonia. In this factor, Hungary ranks behind both Austria and Estonia.

The statistical analyses were performed using IBM SPSS Statistics 29. We applied factor and principal component analysis, ANOVA, and linear regression. Normality was tested using the Kolmogorov-Smirnov test.

Empirical Results

The analysis began with the country-level mean scores of mathematical competence, as presented in Table 2. The mathematics competence outcome was constructed on the basis of the ten plausible values (PV1–PV10 MATH) provided in the database, which represent estimates of students' performance on different mathematics tasks. These plausible values reflect the probabilistic distribution of student achievement, as each learner completed only a subset of the test items. In order to obtain unbiased population-level estimates, statistical analyses were conducted separately on each of the ten values, and the results were subsequently aggregated.

Table 2. Country-Level Mean Scores in Students' Mathematical Competence (Means, Standard Deviations, $p < 0.001$)

	Austria		Estonia		Hungary		F	N
	Mean	SD	Mean	SD	Mean	SD		
Competency Score	4909	881,8	5127	803	4797	885,2	242	18741

(Source: PISA 2022 Database)

The results indicate that Estonia achieved the highest mean scores in mathematical competence among the three countries examined, while Hungary recorded the lowest. At the same time, based on the standard deviation values, the greatest variation in student performance was observed in Hungary and Austria.

We compared the mathematics proficiency scores with the variables related to digital background. The results of this comparison are presented in Table 3.

Table 3. Students' Mathematics Proficiency Scores by Digital Competencies and School- and Home-Based ICT Usage Factors, by Country (Means, Standard Deviations, p < 0.001)

		Austria			Estonia			Hungary		
		Mean	**SD**	**F/N**	**Mean**	**SD**	**F/N**	**Mean**	**SD**	**F/N**
Home Financial Status Index	Lower third	4508	868,9	309,4/ 6151	4920	775,9	148,3/ 6392	4511	893,6	282,5/ 6198
	Middle third	4936	851,7		5220	789		4927	827,3	
	Upper third	5143	816,1		5309	793,5		5108	792,7	
Home Digital Equipment Index	Lower third	4572	883,4	133,9/ 6151	4990	801,5	40,7/ 6392	4524	900,6	123,2/ 6198
	Middle third	4907	871,2		5178	790,5		4876	842,6	
	Upper third	5061	847,5		5199	807,8		4941	872	
School-Based ICT Usage	Lower third	4963	842,7	15,4/ 5466	5290	788,6	100/ 5757	4791	932,4	10,1/ 5582
	Middle third	5087	816,2		5188	790,8		4927	864,1	
	Upper third	4943	862,4		4918	766,9		4861	816,3	
Home-Based ICT Usage	Lower third	4865	831,2	41,3/ 5369	5074	779,3	25,1/ 5750	4596	866,4	119,6/ 5560
	Middle third	5102	826,3		5209	803,9		4947	838,4	
	Upper third	5057	860,2		5245	790,7		5008	823,6	
Frequency of ICT Usage During Mathematics Lessons	Never or almost never	4962	788,6	39,8/ 5565	5230	798,1	58,7/ 5892	4935	820,6	36,4/ 5780
	Less than half of the lessons	5121	884		5257	778,1		4890	889	
	About half of the lessons	4868	890,1		4940	758,3		4694	861,8	
	More than half of the lessons	4915	915,6		4747	742,7		4668	892,1	
	Every or almost every lesson	5119	845,7		4685	706,5		4630	965,8	
	Does not currently take mathematics	4354	598,4		4697	828,6		3825	770,9	
Satisfaction with School Digital Infrastructure	Lower third	4995	886	11,2/ 5130	5105	812,9	18,6/ 5654	4846	910,8	18,8/ 5439
	Middle third	5139	758,5		5265	777,1		4997	817,3	
	Upper third	5016	819,1		5150	797,7		4830	831,7	
Content Creation	Lower third	5116	806,6	64,8/ 4580	5302	796,8	81,3/ 5170	4973	888,4	47,3/ 5027
	Middle third	5202	827		5257	788,6		5034	846,1	
	Upper third	4879	825,1		4973	758,2		4774	810	
Use of Online Platforms	Lower third	4935	847,3	45,1/ 4580	4970	783,3	96,9/ 5170	4588	876,5	151,9/ 5027
	Middle third	5181	804		5229	794,8		5045	828,3	
	Upper third	5140	801,9		5337	769,3		5042	790,6	
School ICT Control	Lower third	5124	806,4	82,5/ 5024	5216	775,7	10,8/ 5542	4972	826,7	86,1/ 5145
	Middle third	5073	818,3		5214	799,5		5007	823,9	
	Upper third	4767	874,7		5113	805,7		4668	871,8	
Learning Orientation	Lower third	4771	781,1	156/ 5024	4928	776,3	135,1/ 5542	4687	805,9	147,8/ 5145
	Middle third	4990	822		5138	781		4908	825,2	
	Upper third	5252	844,3		5374	777,9		5210	890,6	

(Source: PISA 2022 Database)

Based on the indices of home financial situation and digital resources, students were classified into the lower, middle, and upper terciles, and were examined accordingly. In all three countries, it can be established that one of the most influential factors of student performance is the home financial situation and access to digital resources at home. In Austria and Hungary, there is a difference of nearly 600 points between students in the lowest and highest terciles of the financial situation index. In Estonia, this gap is somewhat more moderate. It is evident that the Estonian education system is more capable of mitigating social disadvantages in the field of education. This is confirmed by the fact that the difference between students in the middle and upper terciles of the digital resources index is only 21 points.

Regarding the frequency of ICT use at school, it can be observed that in Austria and Hungary, students who fall into the middle tercile in this respect achieve higher results. In Estonia, however, those students perform better who make the least use of digital tools at school. In contrast, home use of digital devices shows the opposite trend. Students with higher levels of home ICT use (upper tercile) achieve higher scores in the PISA assessment. In Hungary, the performance gap between the upper and lower terciles of ICT use at home is the largest among the three countries examined, yet even these students do not, on average, reach the performance levels of their Estonian peers.

Concerning the use of ICT tools during mathematics lessons, only slight differences were observed between countries. In Austria, students who use digital tools during less than half of their mathematics lessons achieve the highest mean scores, closely followed (by just two points) by those who use ICT tools during every or almost every lesson. The lowest scores were recorded among students who use digital devices during about half of the lessons (accompanied by a notably high standard deviation). In Estonia, a similar trend can be observed: students using digital tools during less than half of the lessons performed the best, followed by those who reported never or almost never using such tools. The lowest proficiency scores were seen among Estonian students who used ICT tools during every or almost every mathematics lesson. In Hungary, the highest scores were achieved by students who reported never or almost never using digital tools during mathematics classes. The weakest scores were recorded among students who, at the time of the survey, did not have mathematics lessons at all, with significantly lower results.

According to students' satisfaction with the digital equipment of schools, no significant differences in performance can be observed. In all countries, students whose satisfaction falls into the middle tercile achieve slightly better results.

With regard to students' digital competences, content creation and the use of online platforms were examined. In all three countries, students whose self-reported competence in content creation placed them in the lower or middle terciles achieved higher results. In contrast, the use of online platforms produced an opposite pattern: students who ranked in the middle or upper terciles in competences related to the use of such platforms obtained the best results on the mathematics test items.

When examining the relationship between control over the use of ICT tools in schools (particularly the use of mobile phones) and student performance, a similar pattern emerges across all three countries. In Austria and Hungary, students who were supportive of stricter regulation clearly achieved lower mathematics scores. Among Austrian students, those who favoured a less strict control achieved the highest scores, while the weakest performance was observed among those supporting the strictest regulation. In Hungary, this difference proved even more pronounced: students who supported a highly controlled environment were at a disadvantage of nearly 350 score points compared to those who expressed less agreement. In Estonia, the pattern was more balanced, with smaller differences; however, even here, students most supportive of stricter control tended to perform lower.

Overall, the findings indicate that learning orientation towards the use of ICT tools is clearly and positively associated with mathematics performance in all three countries. It can be stated that in each case, students in the upper tercile performed best in the assessment, and that those most motivated towards learning achieved the highest results. While the differences are most striking in Hungary, it is observable in all countries that a positive attitude towards learning and openness to development strongly contribute to student achievement.

A linear regression analysis was conducted to examine the relationships between the explanatory variables and mathematics proficiency scores separately for each country. The results are presented in Table 4.

Table 4. The Impact of Digital Background Variables on Mathematics Proficiency Scores (N=18741).

	Austria β Coefficients	**Estonia β Coefficients**	**Hungary β Coefficients**
Home Financial Status Index	0,038*	0,058***	0,062***
Home Digital Equipment Index	0,002	-0,010	-0,011
School-Based ICT Usage	-0,082***	-0,147***	-0,061***
Home-Based ICT Usage	0,047*	0,071***	0,099***
Frequency of ICT Usage During Mathematics Lessons	-0,015	-0,097***	-0,071***
Satisfaction with School Digital Infrastructure	0,040*	0,051***	0,037**
Content Creation	-0,154***	-0,091***	-0,133***
Use of Online Platforms	0,076***	0,118***	0,075***
School ICT Control	-0,103***	-0,055***	-0,089***
Learning Orientation	0,167***	0,128***	0,168***

$^{***}p \leq 0,001$, $^{**}p \leq 0,01$, $^{*}p \leq 0,05$.
(Source: PISA 2022 Database.)

Analysing the results of the linear regression, we found that in most cases, the outcomes were statistically significant. The Home Digital Equipment Index did not lead to significant results in any of the countries or models examined. Interestingly, Austria yielded the fewest significant results.

Following the explanatory variables, a positive relationship was observed between home financial status, home-based ICT usage, satisfaction with school digital infrastructure, use of online platforms, and learning orientation in relation to mathematics proficiency scores.

Conversely, the regression analysis revealed a negative relationship between mathematics proficiency and school-based ICT usage, ICT usage during mathematics lessons, content creation as a digital competency, and school-level control as an attitude factor.

In the following sections, we further explore the differences between the three countries based on these results.

Discussion

Among the three countries examined, Austrian students achieved a mean score of 4909 in mathematical competence, Estonian students scored 5127, and Hungarian students 4797. When comparing the indices of home financial status and digital access, it becomes clear that both factors influence academic achievement. The home financial status index exerts the greatest influence in Austria and Hungary, while in Estonia the effect is weaker. The data suggest that students' academic performance is more strongly affected by their home financial conditions than by digital access. However, this conclusion does not imply that the presence, quantity, or quality of digital devices has no effect on success in learning mathematics. Regression analysis revealed a weak but statistically significant relationship between home financial status and mathematics proficiency, confirming Hypothesis 1: students with a stronger digital background achieve higher competence scores than those with a weaker background in all three countries. While this statement is generally supported by the data, no significant relationship was found in the regression results between academic performance and digital device use.

When examining digital background factors, an unexpected pattern emerged. In Estonia, students who belonged to the lower third in school-based ICT use, but to the upper third in home ICT use achieved higher levels of mathematics competence. In Austria and Hungary, students in the middle third of school-based ICT use performed better than those in the other groups. In Austria, the same middle-third advantage was observed regarding home ICT use, whereas in Hungary a pattern fully identical to Estonia was found with respect to the role of home ICT access and use. However, concerning the use of digital tools during mathematics lessons, a similar trend appeared across all three countries: students who never or almost never used such tools in maths lessons achieved higher scores. The regression analyses confirmed these results: school-based ICT use showed a negative, while home ICT use showed a positive association with mathematics performance. These findings are consistent with those of Antal and colleagues in Austria (Antal et al., 2015), who also concluded that the integration of ICT tools into education contributes only to a limited extent to improving student performance.

Although school-based ICT usage during mathematics lessons did not yield significant regression results in Austria, the findings were statistically significant in Estonia and Hungary. Austrian students in the upper third of satisfaction with their school's digital infrastructure achieved higher mathematics scores compared to those in the middle and lower thirds. This pattern had already been observed in the 2000 PISA cycle, and it was reaffirmed by the 2022 assessment (Knowledge and Skills for Life, 2001).

According to Hypothesis 3, more positive attitudes towards school-based digital device use are associated with higher competence scores, while more positive attitudes toward home-based digital device use are associated with lower scores. However, our findings contradict this hypothesis. A likely explanation is that ICT tools are not always properly integrated into the learning process. It is possible that the digital tools or software used in mathematics lessons are not suitable for supporting students' learning. In contrast, the positive contribution of home ICT use to student performance may be due to the fact that students can work with digital tools more comfortably at home, using their own devices and at their own pace.

Our fourth hypothesis stated that school-based digital device usage reduces mathematics proficiency scores in Austria and Hungary, while increasing them in Estonia. This hypothesis was based on the assumption of the so-called "Estonian miracle". While the hypothesis was confirmed in the cases of Hungary and Austria, it was clearly contradicted in Estonia. Therefore, it can be considered only partially confirmed. In fact, school-based digital device usage was found to negatively impact mathematics proficiency scores in all three countries. Despite the phenomenon of the Estonian miracle and its associated achievements, the data from the 2022 PISA assessment suggest that Estonian students did not outperform their Austrian and Hungarian peers due to frequent digital device usage. It is likely that the improvement in Estonia was not driven by how often tools were used, but rather by their effectiveness – through the deployment of modern technologies and the expansion of digital infrastructure, particularly with a focus on the use of online platforms. This observation points to promising directions for future research.

In examining students' digital competencies, we focused on content creation and the use of online platforms. Students who belonged to the lower third in content creation competencies but the upper third in the use of online platforms consistently achieved higher mathematics scores than those in the other groups. This suggests that online platforms may provide more effective opportunities for supporting students' mathematical development. Regression analyses further confirmed this pattern. As highlighted by Bulman and Fairlie (2016) and the 2022 PISA ICT Framework, the mere availability of ICT tools is insufficient – they must be used in ways that effectively develop the competencies that contribute to improved learning outcomes. Our findings reinforce this argument.

Hypothesis 2 – that students with higher levels of digital competence achieve better results in all three countries – was thus only partially confirmed. While students with stronger digital competencies performed better overall, the benefit appears to stem specifically from the use of online platforms and the associated positive attitudes, rather than from content creation. It is plausible that content creation primarily requires creativity and a considerable investment of time, yet these activities are not, or not necessarily, related to mathematical problem-solving. Since content creation is more time-consuming, activities such as blogging or video production may reduce the time available for studying mathematics. Content creation tends to strengthen artistic, communicative, and technical competences rather than logical-analytical thinking. Moreover, students often pursue such activities as leisure practices, which do not support academic performance or the development of mathematical reasoning. As such, content creation as a digital competency may be more relevant in the context of humanities subjects (e.g., foreign languages or history) than in mathematics. Our findings demonstrate that the use of online platforms is most beneficial for the development of mathematical competencies, as these tools provide valuable educational content and can enhance critical thinking, spatial awareness, and numeracy skills when used effectively.

Regarding attitudes toward school-level ICT supervision, distinct performance patterns can be observed across countries. In Austria, students in the lower third of support for ICT control achieved higher mathematics scores than those in the upper third, with a difference of 357 points. In Estonia and Hungary, no substantial performance difference was found between students in the lower and middle thirds; however, in Estonia, students in the lower third, and in Hungary, those in the middle third scored higher in mathematics compared to their peers in the upper third (the difference amounts to 103 points in Estonia and 339 points in Hungary). The regression results indicated a negative association between school-level ICT supervision and mathematics performance in all three countries, suggesting that excessive control over device use may not effectively support learning, and may even hinder it.

Learning orientation also proved to be a highly significant factor in explaining differences in mathematics performance. Students whose motivation to acquire knowledge placed them in the upper third achieved substantially higher scores compared to their less motivated peers. The difference amounted to 481 points in Austria, 446 points in Estonia, and 523 points in Hungary. The linear regression results likewise indicated a positive association between learning orientation and mathematics performance.

In our study, we examined the role of digital background factors in the mathematics achievement of 15-year-old students. When interpreting the results of the analysis, it is necessary to take into account certain methodological and substantive limitations. Primarily, due to the cross-sectional nature of the PISA 2022 database, the relationships between background factors and academic performance cannot be interpreted as causal but rather indicate correlations. Another limitation is that information on digital background factors is based on self-reports, which may introduce bias into the responses. Although the range of variables applied is broad, it does not cover all possible background factors, particularly with regard to a more detailed mapping of home learning practices. It is also important to note that the educational systems and cultural contexts of the three countries examined differ significantly, which may also influence both student outcomes and the interpretation of background factors. The study focused on the student level and did not investigate in detail the effects arising at the level of schools, teachers, or curricula, which may likewise contribute to academic performance. These aspects point towards further directions for research. Despite these limitations, the findings of the study reliably reflect the strong associations between digital background factors and academic achievement, although caution is required in interpreting the data.

Conclusion

The most important conclusion of our results is that, with regard to the use of digital tools, it is not the frequency of use but rather the efficiency and openness to learning how to use them effectively that matter most in relation to mathematical competences. Our analysis has provided partial answers to the question of how digital tools can be used effectively in mathematics classes to positively influence achievement. Based on the findings, it would be more beneficial to integrate online platforms into mathematics education rather than content creation applications and tools. In order to give online platforms a greater role in mathematics instruction, it would be advisable to involve students in structured, learning-oriented online systems where they can monitor their progress and practice. For this purpose, even the electronic gradebook could be further developed (which could also strengthen student motivation). The results indicate that content creation activities (e.g. video production, blogging) have a rather negative impact on the development of mathematical competences. This finding is consistent with our conclusion that what matters is not how much digital technology is used in mathematics lessons, but how and for what purposes it is employed. An increased number of ICT-supported lessons does not automatically translate into improved student outcomes; in fact, negative effects may emerge if the tools are poorly integrated. In order to integrate ICT effectively into lessons, teachers' adequate preparation, methodological knowledge base, and digital competences are crucial. For this reason, greater emphasis should be placed on digital pedagogy in teacher education and professional development programmes.

Another important finding is that the use of ICT tools at school shows a negative relationship with achievement, whereas home use shows a positive one. This suggests that schools could benefit from collecting students' views on their own device use for learning purposes and integrating these insights into teaching practices. Schools should support students in using ICT tools appropriately both at home and during lessons in order to achieve better outcomes. It may even be beneficial to organise lessons where students and teachers share their device-use practices and reflect on them together.

A further key result is that students need to be continuously motivated to remain open to expanding their knowledge related to digital technologies and basic programming skills, since these areas also require mathematical-logical abilities. Indeed, the most motivated students achieved the best results. Motivation can, for example, build on the importance of these competences or on their labour market advantages.

Our findings indicate that it is not the quantity of ICT tools but their pedagogically grounded, learning-oriented integration that can improve mathematics performance. Therefore, rather than focusing solely on providing digital devices, policymakers should place greater emphasis on the development of digital pedagogy and on offering targeted, methodologically focused professional support for teachers. Accordingly, teacher professional development should prioritise training programmes and the sharing of best practices that enhance the effective integration of ICT tools into teaching and learning. Future research should examine how classroom-level digital practices, home ICT usage, and the quality of teacher-student interactions influence the learning benefits of digital tools across different educational contexts, and under which conditions these tools foster genuine knowledge development and increased student motivation.

In order to fully understand the effective use of ICT tools and the underlying mechanisms of the so-called 'Estonian miracle', further research is needed. Additional analyses are required to clarify these relationships and to determine how ICT can be integrated most effectively into the classroom context. Future research should also address factors related to classroom climate and teachers' methodological culture in relation to mathematics competences. These aspects will be the focus of the continuation of our research.

Acknowledgments: We thank Johnathan Dabney for the English language editing.

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