

DIGITAL TOOL USE AND MATHEMATICS PERFORMANCE: EVIDENCE FROM PISA 2022

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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.*

1. Introduction

The emergence of the information society in the 1990s transformed how knowledge is produced, accessed, and used in education. While some scholars emphasized structural change, others highlighted continuity, arguing that developments in information processing do not necessarily reshape social foundations (Castells, 1996). With the spread of digital technologies, especially the Internet, new forms of learning and knowledge access have emerged, reshaping educational environments (DiMaggio & Hargittai, 2001).

Digital tools can enhance creativity, collaboration, and access to information, but their effectiveness depends on pedagogical integration and teacher preparedness. Without these, ICT use may even negatively affect student performance. Research on digital inequality also shows that disparities extend beyond access to include competencies, usage patterns, and social support (DiMaggio & Hargittai, 2001; Erdős, 2015).

This study examines the relationship between digital background factors and mathematical achievement using PISA 2022 data from Austria, Estonia, and Hungary, providing a comparative perspective. Special attention is given to Estonia, often referred to as the “Estonian miracle” due to its high performance and advanced digitalization.

Mathematical competence is selected as the main outcome variable because of its role in problem-solving and real-life decision-making, and its relatively limited exploration in relation to digital background factors. Understanding how ICT usage and digital competencies influence performance is essential in increasingly digitalized education.

2. The role of the educational environment in the development of student competencies

Research on educational effectiveness has long examined the relationship between school resources and student performance, often conceptualizing achievement as an output and institutional factors

as inputs. While early studies found only limited effects of school-level variables, later analyses have confirmed that factors such as school infrastructure, location, and teacher quality do influence student outcomes (Knowledge and Skills for Life, 2001; Lannert, 2006). In addition, family background – particularly parental education – remains a strong determinant, with its impact varying across countries.

With the increasing integration of digital technologies, the role of the educational environment has become more complex. Evidence suggests that ICT tools can make teaching more engaging and support the development of problem-solving and self-directed learning skills; however, their impact on academic performance remains inconsistent (Antal et al., 2015). Cross-national analyses indicate that higher-performing education systems tend to use ICT more effectively, often supported by teachers who are confident and open to digital innovation (Lannert, 2014). At the same time, empirical findings highlight a paradox: while moderate and purposeful use of digital tools may support learning, excessive or unstructured use is often associated with lower achievement (Erdős, 2015). Large-scale studies and experimental programmes have consistently shown that the mere availability of digital devices does not lead to improved academic outcomes (Cristia et al., 2012; Beuermann et al., 2015).

Overall, the literature suggests that the effectiveness of ICT in education depends not on access alone, but on its pedagogically meaningful integration and the preparedness of teachers to use these tools effectively.

3. Research questions and hypotheses

This study investigates the relationship between students' digital background and their mathematical performance in the PISA 2022 assessment. It aims to explore how access to ICT tools, patterns of use, digital competencies, and attitudes toward digital technologies influence achievement across Austria, Estonia, and Hungary. Particular attention is given to cross-country differences and to whether the “Estonian miracle” reflects more effective digital integration in education. Based on these research questions, the following hypotheses are formulated:

H1. Students with a stronger digital background achieve higher mathematics competency scores in all three countries.

H2. Higher levels of digital competence are associated with better mathematics performance.

H3. Positive attitudes toward school-based ICT use are associated with higher performance, while more intensive or less structured use at home is associated with lower performance.

H4. School-based ICT use is negatively associated with performance in Austria and Hungary but positively associated in Estonia.

4. Methodological background and database of the study

This study is based on data from the PISA 2022 assessment, using the Student Questionnaire Database to analyze the relationship between students' digital background and mathematical performance. The sample includes students from Austria (n=6151), Estonia (n=6392), and Hungary (n=6198), resulting in a total of 18,741 participants.

Mathematical achievement was measured using plausible values provided by PISA, while digital background variables were constructed from questionnaire data. These variables capture multiple dimensions, including home financial status, ICT availability, ICT usage at home and at school, digital competencies, and attitudes towards digital technologies.

Composite indices were created for financial background and ICT access, and factor analysis was used to identify key dimensions of digital background. The analysis distinguishes between home, school, and individual-level factors. All variables were standardized and categorized into terciles (lower, middle, upper groups) to enable comparative analysis. Statistical methods included descriptive analysis, ANOVA, and linear regression models to examine the relationships between digital background factors and mathematical performance.

5. Empirical results

The results show that home financial status is one of the strongest predictors of mathematical performance across all three countries, with substantial performance gaps between students from lower and higher socioeconomic backgrounds. This effect is somewhat weaker in Estonia, suggesting a more balanced education system.

Regarding ICT usage, a clear pattern emerges: school-based ICT use is generally negatively associated with performance, while home ICT use shows a positive relationship. Students who use digital

tools moderately or less frequently in school tend to achieve better results, whereas more intensive use is often linked to lower performance. Digital competencies reveal contrasting effects. While the use of online platforms is positively associated with achievement, content creation shows a negative relationship, indicating that not all forms of digital engagement support mathematical learning equally. In addition, stronger support for strict ICT control in schools is associated with lower performance, whereas students favoring less restrictive environments tend to achieve better results. Finally, learning orientation emerges as a consistently strong positive factor, with more motivated students achieving significantly higher scores.

Regression analyses confirm these patterns, highlighting positive effects of home-related factors and learning motivation, and negative effects of school-based ICT use and certain forms of digital engagement.

6. Conclusion

The findings confirm that home financial background is one of the strongest determinants of mathematical performance across all three countries, while the effect of digital access is less pronounced, highlighting the continued importance of socioeconomic inequalities.

A consistent pattern appears in ICT usage: school-based use is negatively associated with performance, whereas home use shows a positive relationship. This suggests that digital tools are more effective in flexible, self-directed contexts, while classroom integration is not always pedagogically optimal. Students using ICT less frequently during mathematics lessons tend to perform better.

Differences also emerge in digital competencies. The use of online platforms is positively related to achievement, while content creation shows a negative association, indicating that not all forms of digital engagement equally support learning. The results do not support the assumption that higher levels of digitalization lead to better outcomes. Although Estonia performs at a high level, this is not explained by ICT frequency, suggesting that the quality of integration matters more than usage.

Regarding attitudes, strong support for strict ICT control is linked to lower performance, while learning orientation is consistently associated with higher achievement across all countries.

Hypothesis testing shows that H1 is confirmed, H2 is partially confirmed (only certain digital competencies have positive effects), while H3 and H4 are not supported.

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