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Achieving Excellence in Computational Thinking: Insights from the ICILS 2023 Study

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***Abstract*— Computational thinking (CT) is often associated with computer science, but its versatility makes it a valuable tool for navigating life in a technology-driven world. CT serves as an essential educational skill, promoting problem-solving, critical thinking, and student engagement across various disciplines. Advanced CT skills help prepare students for the challenges of modern life and contribute to success in both professional and personal spheres. Previous studies show a strong connection between computational thinking and academic achievement, suggesting that developing these skills can enhance overall educational outcomes. The latest findings from the International Association for the Evaluation of Educational Achievement (IEA) International Computer and Information Literacy Study (ICILS) 2023, highlight significant differences in how students develop CT skills, raising important questions about equal access to quality education. This study uses data from ICILS 2023 to examine differences between schools where students excel in CT and those where these skills are less developed. Across nine participating countries, no significant differences were found in access to ICT resources or in teachers' use of ICT in and outside the classroom. Moreover, no specific curriculum topics stood out as key factors driving high CT performance in certain schools. However, students in top-performing schools were more likely to engage in independent learning on internet-related topics and demonstrated better focus during lessons. These schools also tended to accumulate students from higher socioeconomic backgrounds (SES) and were often located in larger cities or more affluent areas. In some countries, including Latvia, selective admission processes may further contribute to these students' strong performance—not just in CT but across a range of subjects.**

Keywords*— *ICILS 2023, Computational Thinking (CT), International Large-scale Assessment, High CT Achievement Schools.

I. Introduction

Technology has profoundly transformed many aspects of modern life, making computational thinking an essential skill that extends beyond the field of computer science [1]. As digitalization continues to shape industries and everyday interactions, equipping students with computational thinking skills has become critical for success in the modern world.

Computational thinking provides individuals with the problem-solving tools needed to navigate complex challenges across various domains [2], [3], [4], [5] Today, proficiency in computational thinking is not only a key factor in academic achievement but also a crucial competency for thriving in various professional fields [6].

As the demand for strong analytical, problem-solving, and algorithmic thinking skills continues to rise, educational institutions play a vital role in preparing students for the future. Schools must actively integrate computational thinking into their curricula, ensuring that students develop these critical skills at a level that enables them to confidently navigate both their personal and professional lives.

However, findings from the IEA ICILS 2023 study has exposed the uneven distribution of computational thinking skills among students, exposing significant disparities [7] sparking concerns that not all students are adequately prepared for success in a digital world.

This raises an important questions: Are all students equally prepared to tackle everyday tasks and challenges in a digital world?

This study aims to explore the differences between schools where students excel in computational thinking — referred to as top schools—and those with relatively lower performance. By examining the factors that contribute to the success of high-performing schools, this study seeks to identify key elements that impact student achievement. These findings could foster targeted interventions that improve academic performance in all educational environments, promoting equal access to quality education and enhancing student overall academic achievement.

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A. The Importance of Computational Thinking

In the realm of education, computational thinking is broadly understood as the ability to break down complex problems into smaller, manageable components and developing structured solutions [8], [9], [10], [11], [6], [12], [5].

The definition of computational thinking in the first cycle when it was introduced to the ICILS study as a separate domain in 2018 described it as a problem-solving approach in which problems are broken down into algorithmic, step-by-step solutions that can be executed by a computer. Following a review of recent literature and expert consultations, the definition of computational thinking remained consistent also in the 2023 ICILS cycle. It defines computational thinking as "an individual's ability to recognize aspects of real-world problems that are suitable for computational formulation and to evaluate and develop algorithmic solutions to those problems, enabling the solutions to be operationalized with a computer" [13, p.38]

However, computational thinking goes well beyond just coding or programming. While often considered a skill tied to computer science, it is highly versatile and extends across various educational domains and subjects [14], [15], [10], [16]. Beyond simply imparting technical knowledge, the goal of computational thinking in education is to inspire creativity and innovation, encouraging students to become active problem-solvers. Many scholars trace the roots of computational thinking to Papert's work in the late 20th century, which laid the foundation for much of the research in this field. Papert's perspective on computational thinking is deeply intertwined with his constructionist educational philosophy, which emphasizes not only technical skills but also the social and emotional dimensions of learning. According to this approach, meaningful learning happens when students engage hands-on in creating systems and concepts [17]. By framing learning as a process of building and designing, constructionism fosters the development of problem-solving, debugging, and creative design skills—key elements of computational thinking.

More over, computational thinking plays a crucial role in enhancing students' overall cognitive abilities, particularly their critical thinking skills [12]. These advanced thinking skills serve as a strong foundation for improving students' academic performance and cognitive development. Supporting this, study conducted by Lei et al. [15] found a significant correlation between computational thinking and academic achievement. This highlights the importance of promoting computational thinking to strengthen both student learning and academic outcomes.

Furthermore, computational thinking promotes the development of essential abilities such as collaboration and communication [5], which support both intellectual and emotional growth. Previous studies show that collaborative problem-solving significantly enhances cognitive, social, and affective competencies [18], [19]. Collaboration not only deepens students' understanding of CT concepts but also boosts emotional engagement and motivation, making CT tasks more accessible and rewarding [19]. Collaborative problem-solving provides a practical context for students to develop and apply essential computational thinking competencies, preparing them for complex, cross-disciplinary problem-solving.

In summary, computational thinking is a valuable skill that extends beyond coding and programming, improving critical thinking, cognitive abilities, and academic performance. By fostering computational thinking, education can inspire creativity and innovation, promote problem-solving, debugging, and design skills, as well as to enhance collaborative problem-solving, communication and overall student academic performance.

II. Materials and Methods

To investigate the variances among schools, this study utilized data from the IEA ICILS 2023.

The IEA ICILS 2023 is an international large scale assessment study, designed to evaluate students' ability to use information and communication technology (ICT) effectively for various purposes beyond basic usage. It focuses on measuring student digital skills and competencies through realistic, computer-based assessments administered to eighth-grade students. ICILS has its roots in two earlier IEA studies: COMPED (*Computers in Education Study*) and SITES (*The Second Information Technology in Education Study*). These studies, conducted in the late 20th and early 21st centuries, laid the groundwork for a more comprehensive approach to assessing students' digital competencies now known as ICILS [1].

Fraillon and Rožman [1] further explain that the ICILS study was officially launched in 2013, marking the beginning of a systematic international effort to evaluate students' computer and information literacy (CIL) skills. The second cycle followed in 2018, introducing an optional computational thinking component – which is analysed in this study. CT module aimed to assess students' ability to tackle real-world problems using ICT-based strategies. ICILS 2023 cycle included both CIL and CT module assessments, though participation in the computational thinking module remained optional.

ICILS 2023 used several instruments to collect data, with the primary source being the student assessment. This assessment is divided into two modules: the CIL assessment module and the CT assessment module.

CIL in ICILS 2023 is defined as "an individual's ability to use computers to investigate, create, and communicate in order to participate effectively at home, at school, in the workplace, and in society" [20, p.26]. The CIL assessment is structured around four strands: Strand 1, *Understanding computer use*, which includes the aspects of Foundations of computer use and Computer use conventions; Strand 2, *Gathering information*, consisting of Accessing and evaluating information and Managing information; Strand 3, *Producing information*, covering transforming information and creating information; and Strand 4, *Digital communication*, comprising sharing information and using

information safely and securely. In parallel, Computational Thinking is organized into two main strands: Strand 1 *Conceptualizing problems* and Strand 2 *Operationalizing solutions*. These strands are further divided into key processes that define CT. Strand 1, focusing on conceptualizing problems, includes understanding digital systems, formulating and analyzing problems, and collecting and representing relevant data. Strand 2, dealing with operationalizing solutions, encompasses planning and evaluating solutions and developing algorithms, programs, and interfaces [7], [1].

The *Student Questionnaire* assesses students' backgrounds, access to ICT, experiences with technology, and attitudes toward its use at home and in school. The *Teacher Questionnaire* collects information about teachers' backgrounds, their use of ICT in the classroom, professional development experiences, confidence in using technology, and their emphasis on computer and computational thinking skills in their teaching. The *School Principal Questionnaire* provides insights into school characteristics, policies, ICT integration in teaching, and leadership in technology use. The *ICT Coordinator Questionnaire* is designed to gather data from ICT coordinators on available resources, technical support, and the overall integration of ICT in teaching and learning. Finally, the *National Contexts Survey*, completed by national research centers, captures information about the structure of the education system, the role of CIL in the national curriculum, ICT policies, and how computational thinking is incorporated into educational strategies [7], [1].

Data evaluation relies on two methods. The first is an automated process, where a computer program assesses responses based on predefined criteria. The second involves manual evaluation, in which trained assessors review and score responses according to specific guidelines. Additionally, the study uses a representative sample, ensuring that the findings accurately reflect the broader student population. This approach enhances the reliability and validity of the results, offering meaningful insights into students' competencies in computational thinking and computer and information literacy [21].

This study examines ICILS 2023 data from nine countries where students' average achievements in computational thinking are statistically higher than the overall study average: Belgium (Flemish), Chinese Taipei, the Czech Republic, Denmark, Finland, France, Latvia, the Republic of Korea, and the Slovak Republic. On average, each of these countries had approximately 150 participating schools, with numbers ranging from 136 in Belgium to 210 in the Czech Republic.

In each country, the top 10% of schools with the highest achievements (referred to as "top schools") were compared to the remaining schools ("other schools"). The achievement gap in the CT module between top schools and other schools was highest in Latvia, Slovakia, and the Czech Republic, with respective differences of 143, 122, and 116 points. Conversely, the smallest gaps were observed in Denmark and Korea, with differences of 74 and 77 points, respectively.

Among these countries, Latvian students had the lowest overall average achievement. However, when focusing on top schools, Latvian students performed only slightly below those in the Czech Republic and Chinese Taipei and outperformed their peers in Korea and several other countries.

These significant disparities in achievement highlight a broader educational opportunity gap in these countries.

Apart from the CT achievement module, this study also utilized data from questionnaires completed by students, teachers, school ICT coordinators, and school principals across nine countries analyzed: Belgium (Flemish), Chinese Taipei, the Czech Republic, Denmark, Finland, France, Latvia, the Republic of Korea, and the Slovak Republic.

Both individual responses to survey questions and indices constructed from specific responses were used in this study to identify differences between top-performing schools and their students compared to other schools and their students.

Greater achievement dispersion in a country indicates a higher level of inequality in educational opportunities. Notably, the analysis revealed significant differences in student scores, particularly in the CT module.

A significant achievement gap in CT was observed in Latvia, where top-performing schools demonstrated substantially higher scores in the CT module compared to other schools. The average difference in CT module scores between these two groups reached 143 points, the largest gap among the nine countries analyzed.

III. Results and Discussion

One of the key characteristics of schools are their location. Do certain locations, such as large cities or small villages, offer any advantages? There is a common perception that students from wealthier backgrounds—typically found in urban areas—benefit from greater access to high-quality resources, such as private tutoring and advanced educational opportunities, etc., which can enhance their academic success. In contrast, rural schools frequently face challenges that urban schools may not, including fewer extracurricular opportunities, difficulties in recruiting and retaining qualified teachers, lower teacher salaries, and, consequently, persistent teacher shortages [22], [23]. These disadvantages contribute to disparities in student performance and educational outcomes. Furthermore, rural students may lack access to the same social networks, learning resources, and support systems that are more readily available in urban settings, further exacerbating the academic achievement gap and negatively affecting the overall quality of education. Research across various disciplines consistently indicates that rural schools tend to have lower academic achievement and fewer educational opportunities

compared to their urban counterparts [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [21].

As part of the ICILS 2023 study, school principals were asked about the population size of the area where their school is located. The response options included the following population size ranges: 3,000, 15,000, 100,000, and 1,000,000 residents.

In Belgium and Denmark, the distribution of top-performing schools did not significantly differ from that of other schools. However, in other countries, top schools were less commonly found in smaller communities and were more often located in medium-sized or large cities. For instance, in Latvia, 45% of all schools were located in cities with up to 15,000 residents, yet only 15% of the top schools are in such areas. Similarly, in Korea, while 42% of all schools were in cities with a population of one million, 62% of the top schools were situated in these larger urban centres.

Overall, there is a clear tendency for top schools to be more prevalent in larger cities and less common in smaller inhabited areas. This pattern suggests that students attending top schools may represent a selective segment of the overall student population in their respective regions. As previously mentioned, smaller communities may lack the necessary resources or conditions to support the same level of academic excellence as larger urban areas.

In four of the nine examined countries, private schools were more prevalent among top-performing institutions than among other schools. For instance, in Belgium, 78% of top schools were private, compared to 55% of other schools. A similar trend was observed in Denmark, where 64% of top schools were private, while only 35% of other schools fell into this category. In France and Slovakia, private schools accounted for 63% and 21% of top schools, respectively, compared to just 15% and 10% among other schools.

In contrast, private schools in Latvia made up only about 6% of all schools, and none were ranked among the top-performing institutions. In the remaining countries, the distribution of public and private schools among top schools was relatively similar. These variations suggest that the role of private schools in academic achievement differs across countries, likely due to differences in educational policies, school missions, and student selection processes

For example, in Latvia, private schools are not primarily focused on high-achieving students. Instead, many primarily serve students who face learning difficulties or social disadvantages. Conversely, in other countries, private schools can contribute to significant academic inequalities, particularly when they emphasize academic excellence. Green [34] argues that students in private schools often have greater opportunities for higher academic achievement compared to their counterparts in state schools, primarily due to the extensive resources that enable a broad range of educational and extracurricular opportunities. However, academic advantage is just one aspect of the issue. Socioeconomic segregation is another critical factor in educational equity, and it should not come at the cost of academic excellence. Private schools, which are often expensive, tend to be accessible mainly to students from affluent families, thus exacerbating disparities in educational opportunities.

Beyond variations in school type and socioeconomic factors, the quality of education is also shaped by the availability of essential resources, including teaching aids, learning materials, classrooms, and laboratories. In an increasingly digital world, access to information and communication technology (ICT) resources—such as computers, the internet, and specialized software—plays a crucial role in enriching both teaching and learning.

To evaluate the availability and utilization of ICT resources in schools, a targeted survey was conducted among school ICT coordinators participating in the ICILS 2023 study. The most important questions were consolidated into five indices to represent key aspects of the data, providing a comprehensive evaluation of schools' technological capabilities, infrastructure, and readiness to support ICT-based learning.

The first index *Availability of ICT Resources at School* measured the accessibility of school infrastructure for both teachers and students. It encompassed various aspects, such as internet access through the school network, allocated space for file storage, internet-based applications for collaborative work, remote access to the school network from home, and the use of a learning management system, among other factors.

The second index, *Available Tools*, integrated ICT coordinators' responses to questions regarding the availability of ICT resources within schools. This included a range of tools such as practice programs or apps, where teachers have the flexibility to select and design the questions posed to students, as well as multi-user digital learning games that incorporate graphics and inquiry-based tasks. Additionally, other technological resources and platforms that support interactive and engaging learning experiences were considered, providing a comprehensive view of the technological infrastructure available for educational purposes.

In a similar manner the third index was developed to assess the *Utility Software Available In Schools*. This index included a variety of essential tools, such as word processors for creating and editing documents, presentation software for developing multimedia-rich presentations, video editing software to support the creation of visual content, and digital textbooks that provide interactive learning resources.

The fourth index summarized *The Hindrances Related To Computer Resources* while the last, fifth index integrated answers to the questions about *Pedagogical Resources That Affect The Use Of ICT In Teaching And Learning.*

A comparison of index values between top-performing schools and other schools did not reveal any consistent advantages for either group. The index *Available Tools*

showed no statistically significant differences between the two school groups in any of the countries analyzed. However, the index *Utility Software Available In Schools* recorded higher values in Chinese Taipei and the Czech Republic ($p < 0.05$), suggesting a greater presence of such resources in these countries.

The values of the *Hindrances Related to Computer Resources* and *Pedagogical Resources That Affect the Use of ICT in Teaching and Learning* indices showed statistically significant differences in only one country. Notably, these differences followed opposite trends: in Latvia, the lack of pedagogical resources was less pronounced in other schools, whereas in the Slovak Republic, computer resource shortages had a smaller impact on teaching and learning in other schools.

The results from the index *Hindrances Related to Computer Resources* varied across countries, with top schools in the Czech Republic and Finland receiving higher ratings, while in Korea, other schools reported better ICT resource availability. This suggests that top-performing schools are not necessarily better equipped with ICT resources compared to other schools. Consequently, the substantial differences in student achievement cannot be solely attributed to disparities in access to pedagogical or computer resources, indicating that other factors may contribute to these variations in performance.

Overall, these findings indicate that top schools are not necessarily better equipped with ICT resources than other schools. Likewise, the lack of pedagogical or computer resources does not appear to be a determining factor in the significant differences observed in student achievement. This aligns with ICILS 2018 results, which indicates that merely providing students and teachers with ICT equipment is insufficient for improving digital skills. Students need structured guidance on using digital tools effectively, while teachers require support in integrating ICT into their teaching practices to maximize its benefits [35].

In addition to ICT-related challenges, equity in education is also reflected in variations in student achievement, including gender-based differences. One key equity indicator examined in ICILS 2023 is gender equality in educational outcomes. Among the participating countries, girls outperformed boys in three countries — Chinese Taipei, Finland, and Korea. In two countries, Latvia and Denmark, no significant gender differences were observed. In the remaining four countries, boys had higher achievement levels, with statistically significant differences ($p < 0.05$) recorded in the Czech Republic and Belgium.

Despite these variations in overall performance, the proportion of girls and boys in top-performing schools was generally balanced, with two notable exceptions. In the Slovak Republic, boys comprised only 41% of students in top schools, whereas in Belgium, they accounted for 66%.

However, an interesting trend emerged when analyzing the performance of students in top schools. Although girls achieved higher scores on average in some countries, boys in top schools consistently outperformed their female peers across all participating countries, with score differences ranging from 8 to 17 points. This gap was statistically significant in the Czech Republic, the Slovak Republic, and Belgium.

Given the increasing emphasis on promoting female participation in ICT-related fields, such as the EU's digital transformation goals for 2030—which aim to employ 20 million ICT specialists across the EU, ensuring equal gender representation in the field—these findings highlight the urgent need for greater focus on girls' engagement in ICT subjects from an early age [36]. Strengthening efforts to encourage girls' interest and confidence in technology-related disciplines, particularly at the primary and lower secondary school levels, is essential in addressing current gender imbalances and fostering more balanced representation in ICT careers in the future.

By analyzing students' responses to survey questions, it is possible to gain insight into the skills taught in schools as well as those developed independently outside of school. It can be assumed that higher achievements in the CT test are linked to a more comprehensive study of relevant CT topics in the school curriculum. These responses were gathered in the *Learning About CT in Class* index, which combines students' answers to questions about what was taught in school, including:

- Use a solution that works for one problem to help solve a different problem.
- Solve a hard problem by splitting it into a few easier problems.
- Make diagrams that explain concepts or systems.
- Plan tasks by making a list of the tasks in the order they need to be completed.
- Detect patterns in data.
- Use simulations to help understand concepts or systems.
- Make flow diagrams to show how a computer program should work.
- Systematically test computer programs to find bugs, errors, or other problems.
- Use data to better understand real-world problems.

Only in Chinese Taipei and Latvia were the index values statistically higher for students in top schools. In three countries—Czech Republic, Denmark, and France—the index value was statistically higher for students in other schools. None of the examined questions yielded responses in which students from top schools across all analyzed countries consistently provided more positive answers. In four countries, top school students were more likely to have learned how to make diagrams that explain concepts or systems. However, the activities of making flow diagrams to show how a computer program should work and systematically testing computer programs to find bugs, errors, or other problems were performed significantly more

often by students in other schools in almost all countries (except for Chinese Taipei and Belgium).

On the other hand, in all countries, students in top schools more frequently used word processing software (with statistically significant differences in five countries) and computer-based information resources (with statistically significant differences in seven countries). In seven countries, students in top schools also more often used presentation software (with statistically significant differences in four countries).

We can conclude that teaching CT topics in schools is not critical for achieving high skills in this field. Equally important are tasks related to computer literacy. It should be noted that the ICT self-efficacy regarding the *Use Of General Applications* index values were higher for top school students in all countries, whereas the values for the *ICT Self-Efficacy Regarding The Use Of Specialist Applications* index were not statistically significantly higher for top school students in any country.

High achievements are more likely to be explained by students' activities outside of school. Students in top schools across all the examined countries more frequently engaged in internet-related tasks outside of school (with statistically significant differences in five countries). They also searched for information online more often in all countries except Denmark. In all countries, students in top schools outside of school were more likely to evaluate whether the information they received was truthful. In eight countries, students in top schools were more likely to manage privacy settings for their internet accounts and ICT devices at home.

Attention should also be given to the learning styles of students in top schools. During class time, these students were significantly less likely to engage in activities such as text chatting with others, using social media to post or view content, checking social media for new posts or responses to their posts, or watching online videos, live streams, or television. The corresponding index for *Academic Media Multitasking* showed lower values for top school students in all countries, with six countries showing statistically significant differences.

This pattern suggests that students in top-performing schools may have greater opportunities or motivation to develop self-directed learning skills. During class, these students are less likely to engage in activities such as texting, browsing social media, or watching videos. This behavior could indicate a stronger focus on academic tasks, which may contribute to their overall academic success. By minimizing multitasking and distractions, these students may engage more effectively with the material. They also seem to have a stronger sense of digital responsibility, which affects not only their academic engagement and achievement but also their safety and security in digital environments. These findings highlight the crucial role that out-of-school engagement with technology plays in academic success. The evidence emphasizes the importance of cultivating digital literacy, critical thinking, and responsible online behaviors outside of school hours. Additionally, top-performing students are often more disciplined in managing their time and media consumption, which may contribute to their higher academic achievements.

Finally, but no less importantly, the socio-economic status (SES) of students in top schools should be highlighted. In all the countries examined, the average SES of students in top schools was significantly higher ($p < 0.01$). This indicates that, in most of these countries, top schools have developed as institutions that select students in some way. They may be private schools or located in areas (districts) with relatively wealthy populations. In Latvia, six of the top schools are gymnasiums, which require entrance exams and competitions for admission to the seventh grade. In contrast, neighbouring Estonia adopts a different approach: schools do not categorize students based on academic performance during admissions. Instead, they operate under the premise that all primary education students have mastered the curriculum at a minimum standard. Remarkably, despite this inclusive admission policy, Estonian students still achieve high results in the OECD PISA assessments [37].

However, not all top schools are associated with high socioeconomic status (SES), and this cannot be generalized to all top schools. For instance, one of the top schools in Latvia is situated in a small settlement where the average SES of its students is very low.

To sum up - the concentration of high-achieving students in selective schools creates an environment that nurtures excellence. However, it also raises concerns about unequal access to quality education.

In contrast, the existence of a top-performing school in a low socioeconomic status (SES) area—such as one observed in Latvia—suggests that success is not solely dependent on economic status. This situation prompts a crucial question: What is this school doing differently, and what can we learn from it? Is this correlation a coincidence, or is there a causal relationship at play?

These findings underscore the need for further research into high-performing schools in low-SES areas. Understanding the factors behind their success could inform strategies to promote greater equity in computational thinking education. Additionally, identifying the key practices that enable some lower-SES schools to thrive may offer valuable insights for creating a more inclusive and effective learning environment. By learning from these examples, policymakers and educators can develop targeted interventions that support underprivileged students and help close the achievement gap.

IV. Conclusions

The findings of this study indicate that high achievement in computational thinking is not solely determined by access to ICT resources or the formal teaching of CT topics in schools. Across the nine examined countries, a comparison between top-performing schools and other schools revealed no significant differences in ICT availability, infrastructure, or resource accessibility. Additionally, the curriculum did not appear to play a

decisive role, as there were no specific CT-related topics that consistently correlated with better student performance across all countries. This suggests that the development of computational thinking skills is influenced by a broader set of factors beyond just classroom instruction or access to technology.

Instead, the study highlights the importance of general digital literacy skills, including proficiency in word processing, presentation software, and information retrieval, as crucial components that contribute to computational thinking.

The study also highlights the importance of out-of-school engagement with technology. Students in top-performing schools were found to engage more frequently in independent, self-directed learning related to ICT outside of school. They were more likely to use online tools for educational purposes, critically evaluate digital information, and take an active role in managing their own learning. This indicates that self-directed learning and a strong sense of digital responsibility are important contributors to academic success. Moreover, these students showed better time management skills, suggesting that effective media consumption and minimizing distractions during class time can enhance academic focus and performance.

Another important finding is the strong connection between socioeconomic status (SES) and high CT achievement. In all participating countries, students attending top-performing schools tended to come from higher SES backgrounds, with these schools often being concentrated in urban or more affluent areas. In some countries, selective admission policies further contributed to this trend, leading to an environment where academically strong students were concentrated in specific institutions. This raises concerns about educational equity, as students in rural areas or from lower-income families may not have access to the same level of resources or academic opportunities that foster computational thinking development.

Additionally, gender disparities in computational thinking performance were observed. While girls outperformed boys in overall CT scores in some countries, boys in top-performing schools scored higher than their female peers. This pattern suggests that while girls demonstrate strong computational thinking abilities, they may not be equally encouraged or engaged in CT-related activities at the highest levels. Given the increasing importance of CT in future careers, targeted efforts are needed to ensure that girls receive the same level of support, confidence-building, and exposure to computational thinking opportunities as boys.

Beyond in-school learning, students' habits and behaviors during class were also linked to high achievement in CT. Students in top-performing schools were less likely to engage in distractions such as social media, messaging, and entertainment during lessons. This suggests that focused classroom engagement, better time management, and reduced digital distractions contribute to stronger academic outcomes in CT.

To sum up, this study reveals that high achievement in computational thinking is influenced by a variety of factors beyond just access to ICT resources or formal classroom instruction. While resources and curriculum did not show a clear correlation with higher student performance across countries, key factors such as general digital literacy, self-directed learning, and strong time management skills emerged as important contributors to success. Students in top-performing schools were more likely to engage in independent learning, critically evaluate digital information, and manage their own educational processes, indicating that self-motivation and digital responsibility are vital for academic achievement. Additionally, socioeconomic status played a significant role, with top-performing schools often located in more affluent areas, raising concerns about educational equity. Gender disparities in CT performance also highlighted the need for increased support for girls in the field. Ultimately, the findings suggest that while ICT resources are important, the development of computational thinking is shaped more by students' learning habits, socioeconomic backgrounds, and overall digital literacy than by the availability of technology alone.

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