# Enhancing PISA 2022 Mathematics Performance in Slovenia: A Cluster Analysis Approach to Additional Instruction Methods

### Abstract

### The PISA 2022 datasets offer great possibilities for a deeper understanding of the additional factors that might help predict students’ outcomes on the mathematics assessment. This study explores the impact of additional mathematics instruction methods on Slovenian students' performance in the 2022 PISA assessment. The research examines various instructional approaches, including one-on-one tutoring, digital resources, and group study sessions, analyzing their prevalence and effectiveness. Utilizing cluster analysis, three distinct student engagement profiles emerged: those heavily utilizing ICT and video methods, those not participating in additional instruction, and those preferring personalized tutoring and small group study. Results reveal that Slovenian students favor video-based instruction, while internationally, one-on-one tutoring is more common. Notably, large group sessions are the least utilized method in both samples, with significant differences in proportions. Gender differences were also observed, with males gravitating towards ICT and video methods and females towards more traditional practices. This study underscores the importance of understanding diverse instructional preferences and their implications for educational practices. It calls for a balanced integration of digital and traditional learning methods to foster comprehensive educational outcomes. This study provides valuable insights for educators and policymakers aiming to optimize mathematics instruction and enhance student achievement.

### Keywords

Assessment, mathematics education, instruction methods, cluster analysis

## Introduction

As nations strive to elevate educational standards and outcomes, the assessment of student performance on an international scale becomes increasingly pivotal (Kirsch et al., 2013; Ramirez et al., 2018). The Programme for International Student Assessment (PISA), coordinated by the Organisation for Economic Co-operation and Development (OECD), serves as a crucial benchmark in evaluating the efficacy of educational systems worldwide (Hopfenbeck et al., 2018). This triennial assessment measures 15-year-old students' abilities in reading, mathematics, and science, providing valuable insights into how educational policies and practices can be refined to better support student learning.

The significance of PISA extends beyond mere assessment; countries value the results so highly that they have prompted changes in school network legislation and policy adjustments aimed at enhancing educational outcomes (Bieber & Martens, 2011; Hopfenbeck et al., 2018). Slovenia, like many other countries, participates in PISA to gauge its educational progress and identify areas needing improvement. Particularly, mathematics education has been an area of focus due to its critical role in fostering analytical and problem-solving skills essential for the 21st century (Cuder et al., 2023; Piccirilli et al., 2023). The 2022 PISA results offer a fresh dataset to explore the impacts of educational strategies implemented across Slovenia and globally.

However, the influence of PISA is not without its controversies (see Jerrim et al., 2024 for all of the below cons of such international assessments). The focus on PISA scores has led some countries to craft narratives that may not fully reflect the broader educational context, potentially leading to a narrowed curriculum that prioritizes PISA-related subjects at the expense of a more holistic educational approach. Furthermore, the involvement of private companies in the administration and development of PISA assessments raises concerns about commercial interests possibly overriding educational objectives (Lingard & Sellar, 2013; Seppänen et al., 2020). This, coupled with a lack of transparency in data handling and result interpretation, poses significant ethical and operational challenges.

In the 2022 mathematics PISA assessment, specific questions about students' instructional methods were asked (OECD, 2023a). In particular, participants were asked whether, during the school year, they participated in additional mathematics instruction in the form of (1) one-on-one tutoring with a person, (2) internet or computer tutoring with a program or application, (3) video-recorded instruction by a person, (4) small group study or practice (2 to 7 students), (5) large group study or practice (8 or more students), or (6) did not participate in additional mathematics instruction. Students had the possibility of selecting more than one option. Therefore, the question arises whether macrocategories (i.e. clusters) of students exist and whether their achievements on the PISA mathematics assessments significantly differ. Thus, the aim of the present paper is to shed light on the distribution of Slovenian participants in the PISA 2022 assessment among the instructional methods, compare them to international data, and verify whether the results differ with gender.

This study offers a unique contribution to the existing body of PISA research by specifically examining the impact of diverse instructional methods on mathematics performance among Slovene students in the 2022 assessment. Unlike previous studies that often focus on general educational outcomes, this research focuses into the effects of various supplementary learning strategies. By employing cluster analysis, the study identifies distinct student profiles based on their engagement with additional instructional practices, offering valuable insights for educators and policymakers. The findings mostly highlight the current trends and preferences in mathematics education. This is particularly significant as it addresses the gap in understanding the specific instructional practices that can enhance mathematics learning, thereby contributing to the ongoing efforts to optimize educational strategies and improve student performance.

### Instructional methods

In the pursuit of educational excellence, educators continuously seek innovative instructional methods to enhance student learning outcomes (Raj Sharma et al., 2023), particularly in subjects like mathematics (Ogbuehi & Fraser, 2007). Additional mathematics instruction plays a pivotal role in providing students with supplemental support and opportunities for enrichment beyond the traditional setting (Satsangi & Sigmon, 2023; Slavin & Lake, 2008). These supplementary methods encompass a diverse range of approaches, from personalized one-on-one tutoring to collaborative group study sessions, facilitated by both human instructors and digital resources.

Understanding the effectiveness of these instructional methods is essential for educators and policymakers aiming to optimize educational practices and improve student performance. By examining the prevalence and impact of various instructional approaches, educators can tailor their strategies to better meet the diverse needs of learners and foster a deeper understanding of mathematical concepts.

Additional instructional methods in mathematics encompass a variety of approaches aimed at enhancing students' understanding and proficiency in the subject. These methods may include:

1. One-on-one tutoring with a person (Kochmanski & Cobb, 2023): Individualized instruction provided by a tutor tailored to the specific needs and learning styles of the student. Previous PISA study by Liao & Huang (2018) concluded that science-related private tutoring has not significantly improved the overall scientific literacy scores of students, and that tutoring has widened the performance gap among students from different socioeconomic backgrounds, with students from socioeconomically advantaged family experiencing more significant gains from tutoring.
2. Internet or computer tutoring with a program or application (Hussein et al., 2022; Saha et al., 2020): Utilization of online platforms or software designed to deliver interactive and personalized mathematics instruction.
3. Video-recorded instruction by a person (Ndungo & Nazziwa, 2023): Accessing pre-recorded video lessons or tutorials delivered by an instructor, allowing students to review content at their own pace. Some studies however found that access to recorded video lectures have a detrimental effect on student performance (cf. Trenholm, 2022).
4. Small group study or practice (2 to 7 students) (Bonesrønning et al., 2022): Collaborative learning environments where students work together in small groups, engaging in problem-solving activities and discussions often under the guidance of a facilitator. It is a common practice during school lessons but is also used as an additional instructional method.
5. Large group study or practice (8 or more students) (Jerez et al., 2021): Group-based instruction involving a larger number of students, typically led by a teacher or instructor, focusing on reinforcing mathematical concepts through collective participation.
6. Non-participation in additional mathematics instruction: Students who do not engage in any supplementary mathematics instruction beyond regular classroom activities. Data on the number of students who do not participate in additional instruction is limited.

In the context of the PISA 2022 research, these instructional practices were measured to evaluate their impact on student performance in mathematics (OECD, 2023a). For analytical purposes, we could categorize these instructional methods into three macro categories: group practices (which included one-on-one tutoring with a person, small group study or practice, large group study or practice), ICT with video (), and non-participation.

### Brief background of cluster analysis

Cluster analysis is a powerful statistical technique widely used in educational research to identify patterns and groupings within datasets (Perrotta & Williamson, 2018). In the context of mathematics education, cluster analysis can reveal distinct profiles of student performance, instructional strategies, or educational outcomes, offering valuable insights for educators and policymakers. By clustering similar entities together based on predefined criteria, such as mathematical proficiency levels or instructional methodologies, researchers can uncover meaningful relationships and trends that may not be apparent through traditional analytical methods. This enables a better understanding of the factors influencing student achievement and facilitates the development of targeted interventions tailored to specific student needs (Käser et al., 2013). One common method used in cluster analysis is *k-means*, which partitions the dataset into a predefined number of clusters by minimizing the variance within each cluster (for more detailed description see Ikotun et al., 2023). In the forthcoming research, cluster analysis will serve as a key tool to explore the relationship between additional mathematics instruction methods on the PISA 2022 assessment in Slovenia.

## Methods

### Study design

This study employs an empirical causal non-experimental exploratory design, utilizing a quantitative research approach to assess the impact of additional mathematics instruction on the 2022 PISA results in Slovenia. The primary objective is to explore potential patterns and outcomes associated with enhanced mathematics teaching strategies through clustering analysis techniques.

### Data collection

The dataset for this research was derived from the 2022 PISA results in Slovenia. The Slovenian sample for the 2022 assessment was selected through a multi-stage stratified sampling technique (OECD, 2023b). This method involved selecting a representative cohort of schools followed by random sampling of students within those schools. The sampling procedure aimed to ensure a broad representation across different regions and school types, including both public and private institutions. Schools participated on a voluntary basis, and no institution was financially compensated for their participation.

### Participants

The initial sample included 6,721 Slovenian students (from an international pool of 613,744). Following data cleaning procedures to remove incomplete or inconsistent entries, the final dataset (of only Slovene participants) comprised 6,355 responses, with 2,999 male (47.19%) and 3,356 female (52.81%) participants. Most participants (96.85 %) were in Grade 10, corresponding to the first grade of high school or gymnasium in the Slovene educational system.

### Ethical Considerations

All participants provided informed consent, with minors obtaining consent from their guardians. Participation was strictly voluntary, and no financial incentives were offered. The study strictly adhered to the ethical standards laid out in the 1964 Declaration of Helsinki, complied with the European General Data Protection Regulation (GDPR UE 2016/67), and followed the European Code of Conduct for Research Integrity. These frameworks ensured the protection of participant data and the integrity of research practices.

### Data analysis

Data analysis was conducted using the *Python* programming language (version 3.12.4). The *pandas* library (version 2.2.2) was utilized for data manipulation and cleaning, while the *scikit-learn* library (version 1.5.1) was employed for clustering analysis using the *Lloyd* algorithm. The *scipy* library (version 1.14.0) was used to perform chi-squared tests. Clustering validation was performed using *silhouette scores* and the *elbow method* to determine the optimal number of clusters. Additionally, a random seed was set to ensure the reproducibility of the results.

## Results

For preliminary analysis, the histogram distribution of learning method usage can be found in Figure 1. We can observe that most of the participants employ no additional instruction methods, and that group learning practices are badly represented. We performed the same analysis for participants worldwide as can be seen in Figure 2. While the extrinsic picture is the same, the main difference lies in Slovene students prioritizing video instructional methods, while other participants in the study mostly do not. A chi-squared test was conducted to assess the observed differences in the proportions of various methods between the two datasets (i.e., Slovenia and all participants). The results indicated no significant difference in the proportion of one-on-one methods (*p* > .05). However, significant differences were found for ICT, video, small, and large groups, and 'none' methods (*p* < .05). In particular, the most commonly used additional instruction method by Slovenian students is video recordings by an instructor. In the sample of all participants, however, the most used additional instruction method is one-on-one tutoring. Large group sessions are the least used method both in Slovenia and among the students in the entire sample, but the proportions differ: large group sessions are used much less in Slovenia than in the rest of the world.

A graph of different colored bars

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Figure 1: Comparison of selected learning method usage using Slovene participants.

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Figure 2: Comparison of selected learning method usage using participants worldwide.

Chi squared za gender med samimi metodami..l ne gre ker multiple choice!

Then, we employed clustering techniques, utilizing the *elbow method* (Ashari et al., 2023) and *silhouette scores* (Ashari et al., 2023) to determine that the optimal number of clusters was three – both methods are visualized in the supplementary material (Figure 5 and Figure 6).

Cluster means centroids using *k-means* can be found in Figure 2. Cluster 0 represents students who show balanced engagement across various activities and moderate engagement in one-on-one tutoring along with small group sessions, cluster 1 includes students with predominantly no engagement in activities, and cluster 2 groups students with high engagement in individual and technological activities, as well as moderate in group activities. It is important to note that there were different numbers of instances in each cluster: specifically, cluster 0 had 2,319 instances, cluster 1 had 2,613 instances, and cluster 2 had 1,423 instances.

Given that participants answered a multiple-choice question, the results align sensibly. This conclusion aligns with the prevailing consensus (to mi ni všeč, saj gre le za “moje” mnenje in ne za kakšne postavljene hipoteze) that ICT and video activities often go hand-in-hand, and some students may not prefer additional engagement methods. Our results show that students with high engagement in individual and technological activities also tend to have moderate engagement in group activities, while a significant portion of students display little to no engagement across the assessed activities.

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Figure 3: Cluster centroids data for Slovene participants.

To determine whether there is a significant difference in gender distribution across clusters, we utilized the chi-squared test of independence. The contingency Table 1 below summarizes the observed frequencies of gender in each cluster. Given the *p* < .05, we reject the null hypothesis. This indicates a significant association between gender and cluster membership, suggesting that the distribution of genders varies across different clusters. Qualitatively we can observe that males dominated the ICT and video cluster, while females are more present in clusters 0 and 1, i.e. not engaging with additional mathematics instruction or preferring one-on-one tutoring.

Table 1: Contingency table for chi-squared test.

|  |  |  |
| --- | --- | --- |
| **Cluster** | **Male** | **Female** |
| 0 | 1,028 | 1,291 |
| 1 | 1,219 | 1,394 |
| 2 | 752 | 671 |

We also performed clustering for all participants on an international scale, aiming to qualitatively compare these results with those obtained from the Slovene national sample. By comparing these international clusters with those from the Slovenian national dataset, we can observe similar trends, although the specific engagement levels and distributions may vary, especially regarding group practices as was already noted and observed above (see Figure 4). Similar gender analysis showed that gender also differed on international level.

A chart with numbers and a number of objects

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Figure 4: Cluster centroids data for participants worldwide.

## Discussion

In this paper we have explored the results of PISA 2022 results in Slovenia, focusing on instruction methods in learning mathematics and how they are intertwined. Most Slovene participants in the included PISA study utilize no additional instructional methods. Some use methods of utilizing video, ICT, and one-on-one tutoring. Group learning practices are less represented. Cluster analysis showed that three distinct groups emerged: students engaged with ICT and video instruction, students not participating in any additional instruction, and students preferring one-on-one tutoring along with small group sessions.

When comparing the Slovenian results with those from the international dataset, several differences emerged. Internationally, there was a notable preference for group learning methods, forming a distinct cluster that was not as prominent in the Slovenian sample. This difference highlights a potential divergence in educational practices and cultural attitudes towards collaborative learning. Slovenian students showed a higher tendency towards ICT and video methods, whereas the international data revealed a more balanced engagement across different instructional methods. This suggests that, globally, there is a growing recognition of the benefits of group learning in fostering essential skills such as teamwork, communication, and critical thinking. In Slovenia, this divergence could be attributed to the now prevailing learning network called ASTRA, which provides video lectures of mathematics for high school students (Škraba, n.d.). Despite the lack of literature analyzing the popularity of this network, making it difficult to assess its presence among students, observational data from the researchers' experience confirm its spread among young people. Internationally, several online video and ICT tools and platforms are available for learning mathematics. However, these tools might not be as well-known in local communities, resulting in students not fully relying on them to deeply understand mathematics. Additional studies are necessary to fully understand the reasons underlying this difference between the Slovenian and international prevalence of additional mathematics instruction.

Gender preferences in learning methodologies often vary, with males showing a marked inclination towards ICT and video-based learning. This preference can be attributed to the interactive and visually engaging nature of these tools, which cater to the exploratory and problem-solving tendencies commonly observed in male learners (Borgonovi & Greiff, 2020; Utz & Wolfers, 2022). Conversely, females tend to prefer traditional learning practices without additional technological enhancements, potentially valuing the interpersonal elements that these methods offer (Chang et al., 2020). This distinction highlights the importance of tailoring educational approaches to accommodate different learning preferences based on gender.

The insights into the contemporary landscape of learning methods underscores the increasing integration of digital resources in education, driven by their accessibility, flexibility, and the enhanced learning experience they offer through multimedia content (Cheng et al., 2009; Nusir et al., 2013). ICT's prominence can be attributed to the convenience it provides, allowing students to learn at their own pace and revisit complex topics multiple times. Furthermore, the digitalization of education has been accelerated by recent global events, such as the COVID-19 pandemic, which necessitated a swift transition to online learning environments (Carrillo & Flores, 2020). However, this shift towards ICT-based methods raises critical concerns regarding the quality of social interactions among students (Xiao & Hew, 2022). Traditional group learning practices, which are poorly represented in our data, play a vital role in developing collaborative skills, critical thinking, and the ability to work effectively in teams (Andrade, 2020; Pervaz Iqbal et al., 2020). The lack of such interactions may hinder the development of these essential skills, suggesting a need to balance digital and face-to-face learning modalities. Moreover, the preference for one-on-one tutoring and small group study sessions observed in cluster 0 reveals a subset of students who value personalized attention and tailored instruction. These methods cater to individual learning styles and provide immediate feedback, which can significantly enhance understanding and retention of material (Pardo et al., 2019). This individualized approach can be particularly beneficial for students who struggle with self-paced learning or those who require additional support beyond standard classroom instruction (Shemshack et al., 2021; Tetzlaff et al., 2021). The choice of one-on-one and small group settings also reflects the desire for a more intimate and focused learning environment, which can be less intimidating and more conducive to asking questions and engaging deeply with the content. On the other hand, Cluster 1, representing non-participation in supplementary instructional methods, highlights a potential area of concern. This group's disengagement could be due to a lack of awareness, resources, or motivation, pointing to the need for interventions that encourage the utilization of diverse learning methods to support all students effectively (Ramos et al., 2023; Ronksley-Pavia & Neumann, 2020). While ICT and video instruction offer significant benefits and are becoming increasingly integral to modern education, it is crucial to address the challenges they pose to social learning and to ensure that complementary instructional methods, such as group practices and one-on-one tutoring, are also promoted to provide a holistic educational experience.

When considering the evolution of education, it is crucial to take into account not only the needs of students but also the perspectives of teachers. Educators are increasingly recognizing the need to adapt and compete with eLearning possibilities to maintain the relevance of their profession (Rojko, 2020). This shift in mindset involves viewing their role as an enhancement and complement to what students can achieve through eLearning platforms. By integrating their expertise with digital tools, teachers can add significant value and facilitate a more comprehensive learning experience. A study by Lipovec et al., (2023) found that, while video lectures generally adhered well to pedagogical principles across various countries including Slovenia and 4 others included in PISA 2022 research, the level of interactivity was lacking. To ensure effective education, teachers must embrace the dual role of content experts and facilitators of interactive, technology-enhanced learning environments. This approach not only preserves the essence of traditional teaching but also leverages the strengths of modern eLearning.

## Conclusion and limitations

Conclusion je sicer nekako ze zajet v diskusiji…

The study is not without limitations. Firstly, it explores a novel question in PISA research, specifically focusing on the impact of additional instructional methods in mathematics, which presents a limitation as the data are not directly comparable to those from previous years. Secondly, caution must be exercised in interpreting PISA results; further research at the national level is essential to validate and expand upon our findings. Additionally, our study did not measure the direct impact of the observed instructional methods on students' grades or whether certain clusters outperformed others, which represents a significant gap that future research should address to fully understand the efficacy of these instructional practices. The latter limitation was due to the presentation of data by OECD, as the data is split into general questions (from which we sourced our data) and cognitive data with PISA results. Furthermore, the data is biased towards SPSS and R analysis and not completely compatible with other methods, such as Python, which we used in our study. This presents a gap we aim to address in future research to enhance compatibility and comprehensiveness in data analysis methodologies.

However, despite the aforementioned limitations, the present study offers novel insights into PISA data, particularly regarding additional mathematics instruction methods. Interestingly, the distribution of these instructional methods differs between Slovenia and other participating countries. Additional research should address whether the adoption of various mathematics instruction methods and their usage impact students' mathematics achievements. Specifically, future research might investigate whether one method is more efficient than another, which could, in turn, significantly influence how additional mathematics instruction is delivered. Longitudinal studies would allow us to understand the long-term effects of specific methods of delivering additional instruction.

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## Supplementary material

A graph with a line

Description automatically generated

Figure 5: Elbow method for determining the optimal number of clusters in Slovene case.

A graph with a line

Description automatically generated

Figure 6: Silhouette score method for determining the optimal number of clusters in the Slovene case.