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

### Abstract

...

### 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. 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.

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. This, coupled with a lack of transparency in data handling and result interpretation, poses significant ethical and operational challenges.

### Instruction 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. 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.
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 detrimental effect on student performance (cf. Trenholm, 2022).
4. Small group study or practice (2 to 7 students) (želel bi vir, ki bi bil vezan na additional instrction in ne med poukom): 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 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. Ne najdem raziskave, ki bi morda rekla, da večina dijakov pri mat. ne sodeluje izven klasičnih okvirjev.

In the context of the PISA 2022 research, these instructional practices were measured to evaluate their impact on student performance in mathematics.

### 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. 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. 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 613744). Following data cleaning procedures to remove incomplete or inconsistent entries, the final dataset 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.

## Results

For preliminary analysis, the histogram distribution of learning method usage can be found in Figure 1. We can observe thatmost of the participants imploy no additional instruction methods, and that group learning practices are badly represented. We performed the same analysis for all particiapants. 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 graph of different colored bars

Description automatically generated

Figure 1: Comparison of selected learning method usage.

A graph of different colored bars

Description automatically generated

Then, we employed clustering techniques, utilizing the *elbow method* and *silhouette scores* to determine that the optimal number of clusters was three (both methods are visualized in supplementary material). This conclusion aligns with the prevailing consensus (to mi ni všeč, saj gre le za “moje” mnenje in ne za kakšne postavljene hipoteze) that categorizes the instructional methods into group practices, ICT and video instruction, and non-participation.

Cluster means centroids using *k-means* can be found in Figure 2. Cluster 0 represents students who engage heavily with video-recorded instruction and moderately with other supplementary methods, cluster 1 students who do not participate in any additional mathematics instruction, and cluser 2 students who prefer one-on-one tutoring and small group study sessions, with minimal engagement in other forms of additional instruction. Given that the chosen method was a multiple choice anwser, the results align sensibly.

A screenshot of a graph

Description automatically generated

Figure 2: Cluster centroids data.

A diagram of a cluster of dots

Description automatically generated

## Discussion, conclusions, and limitations

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 intervined. Most participants in included PISA study utilizes no additional instructional methods. Some use methods of utilizing ICT and one-on-one tutoring, and group learning practices are least represented. Cluster analysis showed that three distinct groups emerged: students heavily engaged with video-recorded instruction, students not participating in any additional instruction, and students preferring one-on-one tutoring and small group sessions.

Nekje vriniti primerjavo z drugimi državami. Razlika predvsem v videu, kar lahko atributiramo na popularnost ASTRA?

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 2 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.

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, which represents a significant gap that future research should address to fully understand the efficacy of these instructional practices.

## References

Andrade, M. S. (2020). Cross-cutting skills: Strategies for teaching & learning. *Higher Education Pedagogies*, *5*(1), 165–181. https://doi.org/10.1080/23752696.2020.1810096

Bieber, T., & Martens, K. (2011). The OECD PISA Study as a Soft Power in Education? Lessons from Switzerland and the US. *European Journal of Education*, *46*(1), 101–116. https://doi.org/10.1111/j.1465-3435.2010.01462.x

Carrillo, C., & Flores, M. A. (2020). COVID-19 and teacher education: A literature review of online teaching and learning practices. *European Journal of Teacher Education*, *43*(4), 466–487. https://doi.org/10.1080/02619768.2020.1821184

Cheng, I., Basu, A., & Goebel, R. (2009). Interactive Multimedia for Adaptive Online Education. *IEEE Multimedia*, *16*(1), 16–25. https://doi.org/10.1109/MMUL.2009.11

Cuder, A., Živković, M., Doz, E., Pellizzoni, S., & Passolunghi, M. C. (2023). The relationship between math anxiety and math performance: The moderating role of visuospatial working memory. *Journal of Experimental Child Psychology*, *233*, 105688. https://doi.org/10.1016/j.jecp.2023.105688

Hopfenbeck, T. N., Lenkeit, J., El Masri, Y., Cantrell, K., Ryan, J., & Baird, J.-A. (2018). Lessons Learned from PISA: A Systematic Review of Peer-Reviewed Articles on the Programme for International Student Assessment. *Scandinavian Journal of Educational Research*, *62*(3), 333–353. https://doi.org/10.1080/00313831.2016.1258726

Hussein, M. H., Ow, S. H., Elaish, M. M., & Jensen, E. O. (2022). Digital game-based learning in K-12 mathematics education: A systematic literature review. *Education and Information Technologies*, *27*(2), 2859–2891. https://doi.org/10.1007/s10639-021-10721-x

Jerez, O., Orsini, C., Ortiz, C., & Hasbun, B. (2021). Which conditions facilitate the effectiveness of large-group learning activities? A systematic review of research in higher education. *Learning: Research and Practice*, *7*(2), 147–164. https://doi.org/10.1080/23735082.2020.1871062

Jerrim, J., Lopez-Agudo, L. A., & Marcenaro-Gutierrez, O. D. (2024). How Did Spain Perform In PISA 2018? New Estimates Of Children’s PISA Reading Scores \*. *British Journal of Educational Studies*, *72*(2), 177–198. https://doi.org/10.1080/00071005.2023.2258184

Kochmanski, N., & Cobb, P. (2023). Identifying and Negotiating Productive Instructional Improvement Goals in One-on-One Mathematics Coaching. *Journal of Teacher Education*, *74*(5), 437–450. https://doi.org/10.1177/00224871221143124

Ndungo, I., & Nazziwa, C. (2023). Characterizing the Effectiveness of Video Recordings in Mathematics Instruction within Higher Education: Minimizing Direct Teacher-Student Interaction through Technological Modalities. *Asian Journal of Education and Social Studies*, *49*(4), 95–105. https://doi.org/10.9734/ajess/2023/v49i41191

Nusir, S., Alsmadi, I., Al-Kabi, M., & Sharadgah, F. (2013). Studying the Impact of Using Multimedia Interactive Programs on Children’s Ability to Learn Basic Math Skills. *E-Learning and Digital Media*, *10*(3), 305–319. https://doi.org/10.2304/elea.2013.10.3.305

Ogbuehi, P. I., & Fraser, B. J. (2007). Learning environment, attitudes and conceptual development associated with innovative strategies in middle-school mathematics. *Learning Environments Research*, *10*(2), 101–114. https://doi.org/10.1007/s10984-007-9026-z

Pardo, A., Jovanovic, J., Dawson, S., Gašević, D., & Mirriahi, N. (2019). Using learning analytics to scale the provision of personalised feedback. *British Journal of Educational Technology*, *50*(1), 128–138. https://doi.org/10.1111/bjet.12592

Perrotta, C., & Williamson, B. (2018). The social life of Learning Analytics: Cluster analysis and the ‘performance’ of algorithmic education. *Learning, Media and Technology*, *43*(1), 3–16. https://doi.org/10.1080/17439884.2016.1182927

Pervaz Iqbal, M., Velan, G. M., O’Sullivan, A. J., & Balasooriya, C. (2020). The collaborative learning development exercise (CLeD-EX): An educational instrument to promote key collaborative learning behaviours in medical students. *BMC Medical Education*, *20*(1), 62. https://doi.org/10.1186/s12909-020-1977-0

Piccirilli, M., Lanfaloni, G. A., Buratta, L., Ciotti, B., Lepri, A., Azzarelli, C., Ilicini, S., D’Alessandro, P., & Elisei, S. (2023). Assessment of math anxiety as a potential tool to identify students at risk of poor acquisition of new math skills: Longitudinal study of grade 9 Italian students. *Frontiers in Psychology*, *14*, 1185677. https://doi.org/10.3389/fpsyg.2023.1185677

Raj Sharma, A., Mandot, M., Professor at Dept. of Computer Science & IT, Rajasthan Vidyapeeth University, Udaipur., Singh, J., & Partner at Recap Consultancy and General Supply, Dhoraji, Rajkot. (2023). IMPACT ASSESSMENT OF INNOVATIVE LEARNING APPROACHES ON EDUCATION: A CRITICAL REVIEW. *International Journal of Advanced Research*, *11*(05), 989–995. https://doi.org/10.21474/IJAR01/16955

Ramos, A., Lavrijsen, J., Linnenbrink-Garcia, L., Soenens, B., Vansteenkiste, M., Sypré, S., Boncquet, M., & Verschueren, K. (2023). Motivational Pathways Underlying Gifted Underachievement: Trajectory Classes, Longitudinal Outcomes, and Predicting Factors. *Gifted Child Quarterly*, *67*(3), 179–197. https://doi.org/10.1177/00169862221132279

Ronksley-Pavia, M., & Neumann, M. M. (2020). Conceptualising Gifted Student (Dis) Engagement through the Lens of Learner (Re) Engagement. *Education Sciences*, *10*(10), 274. https://doi.org/10.3390/educsci10100274

Saha, J., Ahmmed, S., Ali, M., Tamal, M. A., & Rezaul, K. M. (2020). ICT Based Mathematics Skill Development Program: An Initiative to Overcome Mathematics Anxiety. *International Journal of Emerging Technologies in Learning (iJET)*, *15*(14), 252. https://doi.org/10.3991/ijet.v15i14.14149

Shemshack, A., Kinshuk, & Spector, J. M. (2021). A comprehensive analysis of personalized learning components. *Journal of Computers in Education*, *8*(4), 485–503. https://doi.org/10.1007/s40692-021-00188-7

Tetzlaff, L., Schmiedek, F., & Brod, G. (2021). Developing Personalized Education: A Dynamic Framework. *Educational Psychology Review*, *33*(3), 863–882. https://doi.org/10.1007/s10648-020-09570-w

Trenholm, S. (2022). Media effects accompanying the use of recorded lecture videos in undergraduate mathematics instruction. *International Journal of Mathematical Education in Science and Technology*, *53*(11), 3015–3043. https://doi.org/10.1080/0020739X.2021.1930221

Xiao, Y., & Hew, K. F. (2022). The Relationships Among ICT-Related Psychological Factors, School Contextual Factors and Secondary Students’ Reading Performance: A Multilevel Analysis Across 47 Economies. *Journal of Educational Computing Research*, *60*(5), 1166–1196. https://doi.org/10.1177/07356331211070975