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# How effective is Google Earth Pro in teaching and learning geography to high school students?

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A R T I C L E I N F O

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A B S T R A C T

This research aimed to assess the effectiveness of using Google Earth Pro in teaching and learning Geography on school results and on the development of three core skills: spatial skills, argumentation of an explanatory approach and establishing correlations/sequences between elements and phenomena in nature and society. The research methods used were questionnaire-based surveys, factorial statistical analysis and statistical tests to compare proportions and means. The research results showed that the experimental group using Google Earth Pro achieved better results in the summative test, expressed both in terms of the sample mean and the minimum, maximum and pass rates. Factor analysis—Principal Component Analysis—demonstrated that the results of the summative test were dependent on the use of Google Earth Pro and that this digital tool had a significant positive impact on the development of the three specific skills. The benefits of Google Earth Pro for learning Geography and developing fundamental Geography skills, as highlighted by the results of this research carried out with a target group of lower secondary school students (14–16 years old), opens new avenues for reflection on the need to introduce GIS tools in the teaching of Geography in secondary education at an earlier age, as students of the current generation are capable of meeting this challenge.

## Introduction

Geography, like any other science in the school curriculum, aims at developing specialised skills and shaping the graduate's profile. At the end of compulsory education, the learning outcomes are a set of subject-specific skills that students should have acquired. These skills are included in the school curriculum for each level of study, so teachers have to plan lessons that focus on these skill sets. Geography curricula are designed to ensure that specialist competences are gradually developed from primary and lower secondary school through to upper secondary school. Among the key competences of Geography are the development of spatial skills, the ability to present an explanatory argument and the ability to establish correlations between elements and phenomena in reality (nature and society).

The spatial characteristics of learning Geography currently aim to prepare students' abilities to face the challenges of the 21st century [1]. Cognitive psychologists consider that spatial ability comprises two dimensions: spatial visualisation and spatial orientation [2], to which geographers have proposed a third dimension, that of spatial thinking, which involves an understanding of spatial relationships [3–6]. Spatial abilities are fundamental cognitive abilities for spatial thinking, consisting of spatial visualisation, spatial orientation and spatial relations [4]. According to [7], spatial thinking encompasses three elements: concepts of space, tools of representation and processes of reasoning. Spatial thinking is the ability to transform knowledge by manipulating, reconstructing and navigating physical objects to achieve academic and intellectual success [8–10]. Spatial cognition is described as a spatial representation of the environment, its contents and the organization of spatial knowledge needed to manipulate and process spatial information [11]. Although we find several relatively similar definitions of the concept of spatial thinking in the literature, starting with Gersmehl and Gersmehl [12], Golledge et al. [13] and Janelle and Goodchild [14], after [15], there is still no consensus on the definition of this concept. One reason for this could be its interdisciplinary nature, as spatial thinking is a subject of interest for psychologists, educators and geographers alike. In the absence of clear tools for assessing spatial thinking, researchers continue to debate the structure of spatial thinking, the number of major components of spatial thinking and the relationship, if any, between spatial ability and spatial thinking [2] or whether spatial thinking can be considered separately from spatial ability [16].

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The development of spatial abilities and spatial thinking is essential for the study of Geography. Jo & Bednarz [17] suggest that integrating spatial thinking abilities into the teaching and learning of Geography will help students achieve the learning objectives of the course. Bednarz et al. [18] also believe that learning Geography in the 21st century should focus on spatial thinking and specific core skills.

Geography provides a rich context for the formation of students' argumentation skills and their development during teaching and learning processes on social and environmental issues [19]. Rapanta et al. [20] summarise three main definitions of what argumentation is and how it can be assessed: argumentation as form, strategy and goal. Argumentation as structure or form implies that an argument is a unit of reasoning; as a procedure or strategy, it requires special attention to the dialogical aspects of argumentation, such as the use of reasoning in context [21]; as a process, it involves taking into account the particular circumstances in which the argument is used [22]. According to Constructive Learning Theory [23,24], argumentation reflects how each individual organizes and expresses their knowledge, with learning taking place in concrete contexts and through the integration of new ideas into prior knowledge.

Applied argumentation skills help build and consolidate subject-specific knowledge [25] while information is integrated into existing individual knowledge networks [26]. According to Aufschnaiter [27] and his colleagues, complex argumentation depends largely on students' prior knowledge. Argumentation skills focus on understanding and formulating written and oral arguments in various subjects in both a single-subject and an interdisciplinary context [28]. It is believed that formulating arguments helps to develop knowledge and strengthens networked and systemic thinking [29]. Studies show that traditional methods of teaching science do not sufficiently support the development of students' argumentation skills [27,30].

There are several empirical studies on argumentation in Geography lessons [25,29,31]. Budke and his team have conducted extensive research on how argumentation can be used in teaching Geography. In 2010 they proposed a model showing that every argument must contain facts, explanations and a conclusion. Budke et al. [31] highlighted deficiencies in the abilities of students, teachers and textbooks to address argumentation skills. The results of a pilot study showed that the level of written argumentation among students in the 7th and 11th grades is equally low [31]. Budke believes that argumentation can change students' perspective on a particular way of seeing the world [29]. The argumentation skills model developed by Budke et al. [31] was tested and modified by [32] for argumentation skills in social discourses on local spatial conflicts in Geography teaching. The argumentation skills could be promoted to analyze maps, texts, images and other materials and to deconstruct the perspectives represented and their intentions [25]. Argumentation is considered to be related to critical thinking [33]. Some specialists consider it an indicator of critical thinking skills, and people learn better when they argue [34,35].

The development of these skills is closely linked to learning activities and the teaching methods and resources used in the educational process. Digital tools play an important role and can contribute to the development of these specific skills as learning outcomes in Geography. For example, in argumentation one could use geospatial tools, Google Earth, GIS and digital geo-media [36,37]. Digital geo-media provides a variety of information on a daily basis which, when used reflectively and reflexively, can develop our own argumentative standpoints [38]. In teaching and learning spatial thinking in primary and secondary education, GIS tools can be particularly useful [7] and Google Earth Pro is an example of this.

This is a virtual globe application, initially designed for the general public as an exploration and search tool [39]. Due to the accessibility of its functions and ease of use, GE has become a working tool for researchers in the field of Earth sciences and for teachers in geosciences [40]. Its intuitive interface allows users to explore its features without extensive prior training [41]. Although virtual globes such as Google Earth offer more limited functionality than other geospatial technologies such as GIS systems, they are easier to use and more intuitive [40]. This simplicity and functional accessibility has made them a popular tool in the early stages of geospatial education [42]. GE is particularly useful in teaching geomorphology and map interpretation [43], as students can observe large- and small-scale topographic features from different perspectives [43,44]. Hsu et al. [40] consider that the intuitive interface effectively reduces the learning curve and improves users' geographical concepts and skills. Another advantage of GE is that it provides pre-processed data, significantly reducing teachers' need for support and the time required for lesson planning [40]. Since 2015, Google has been offering a new version of Google Earth, Google Earth Pro, to the public free of charge. GEP is an application similar to GIS, very similar to the previous version of GE, which uses satellite images of the Earth's surface in 3D format, maps, models, and GIS-compatible thematic layers imported in Kmz, Kml, shape file, etc. formats. Thanks to GEP's ability to import and open KMZ, Kml, and shape file profiles, and to overlay thematic maps (topographic, geomorphological, climatic, demographic, etc.) over terrain layers, the application helps students develop a strong sense of place in terms of how relief affects human activities [45], in the development of geovisualisation and spatial thinking skills [46,47]. GEP facilitates student engagement in spatial geodata visualisation and research activities in a spatially oriented learning environment [40,44,48,49]. For example, Hsu et al. [40] conducted an experimental study with 10th grade students at a public high school in Hualien, Taiwan, which indicated that teaching with GE significantly improved students' topographic map reading ability, facilitated learning through 3D landscape visualisation and prior knowledge connections.

Google Earth software was released to the public in 2005 and quickly became very popular due to its ability to visualise the earth in three dimensions, using a combination of digital elevation models, satellite imagery and 3D building envelopes [50].

The cognitive role of virtual globes stems from their realistic representation of real places [50]. Google Earth offers several advantages, such as free and fast access to huge amounts of information that were previously privately owned; improved understanding of spatial, reference or scientific information by contextualising it in the user's local, real-world conditions [50]. Viewing information using Google Earth Pro has the cognitive benefits of collaborative visualisation and analysis [51], stimulates exploratory behaviour [52] and extends perceptual scalability [53]. While the literature establishes the importance of spatial thinking and argumentation and separately suggests the potential of digital tools, there is a lack of rigorous, quasi-experimental research that empirically measures the simultaneous impact of a widely accessible tool like Google Earth Pro on these distinct yet interrelated competencies in a secondary school setting. This study aims to address this specific gap.

The aim of this study was to quantitatively determine the effectiveness of a Google Earth Pro-based instructional intervention compared to traditional teaching methods on the academic performance and the development of core geographical skills among high school students.

**Working hypothesis 1:** There are statistically significant differences between the experimental and control groups in terms of the results obtained by students in the summative test.

**Working hypothesis 2:** The results obtained by students in the summative test depend on the use of Google Earth Pro in the teaching-learning process of Geography.

**Working hypothesis 3:** Google Earth Pro had a significant impact on the development of the three specific Geography skills.

**Research questions:**

1. To what extent did Google Earth Pro facilitate learning and influence students' results in the summative test?
2. How effective was Google Earth Pro as a teaching-learning-assessment tool capable of facilitating the development of specific Geography skills?

## Methodology

As part of the COLABTEACH research project, a national working group was formed, consisting of Geography and ICT teachers who experienced teaching Geography with Google Earth Pro from November to December 2024 in 6 high schools. The availability sample consists of a control group of 107 students and an experimental group of 122 students. The availability sample comprises a total of 229 subjects with different socio-demographic characteristics. An experimental group and a control group were formed. The distribution by class was as follows: the experimental group consisted of 72 students in the ninth grade and 50 students in the tenth grade, while the control group consisted of 56 students in the ninth grade and 51 students in the tenth grade. The experimental group experienced collaborative learning using Google Earth Pro, which the students used for the first time. The control group used the tools available in the classroom: wall maps, textbooks, digital maps and printable worksheets. The collaborative group was organised in a unitary way within the sample: students were grouped into small teams of 3–4, with members selected by the teacher based on their level of preparation so as to avoid exacerbating inequalities [54]. At least one student had a lower level of achievement with learning difficulties, and the others had a higher level of achievement. We paid special attention to respecting gender identity, encouraging collaborative learning in mixed-gender teams and promoting gender collaboration and diversity. We paid special attention to the structure of the team because the implementation of this teaching strategy took place over a period of 5 weeks. The experimental group conducted Geography lessons in the Computer Science lab, while the control group conducted them in classrooms. At the end of the five weeks of activity, both groups of students took a summative test to assess their knowledge and specialised skills. The questions in the summative test were designed to assess the level of training in three skills specific to Geography: argumentation of an explanatory approach, spatial skills and establishing correlations between elements and phenomena in reality (nature and society).

The research was conducted over a period of five weeks. Both groups studied the same content and completed identical tasks, but the teaching tool used in the teaching-learning process was different. The contents taught to ninth grade students were Physical Geography and those taught in tenth grade were Human Geography. Several features offered by Google Earth Pro were used at the 9th grade level, both from the Layers section and by importing and opening thematic files in kmz and shape file formats in Locations to help students understand the composition of the Earth's crust from tectonic plates (macro and micro plates) and the phenomena associated with plate tectonics, such as subduction, volcanism, earthquakes, ocean ridge formation, fold mountains and coastal relief. Students received printed worksheets with exercises that required opening and importing these thematic layers, which formed the digital support for geographical analysis and investigation. Students searched for answers to the questions in the worksheets using the thematic layers, with their help exploring the topic of plate tectonics and related phenomena. Once familiar with the 3D form of the Earth's surface and maintaining the North-South orientation, the following lessons gradually moved on to exploring the toolbar. Topics related to landforms were analysed using the functions in the toolbar. The Add Path function allowed students to draw transverse lines along mountain ranges, enabling them to visualise and analyse the profile of the elevation. Using the Ruler and Polygon functions, they measured mountain ranges, volcanic craters, river mouths and similar features. Another particularly useful tool for analyzing the Earth's surface was Show historical images. This feature allows for the temporal analysis of physical and geographical elements of the Earth's crust. We applied this temporal analysis to observe the evolution of the natural environment over time. The students were divided into teams and measured the surface areas of glaciers in the Himalayas, Pyrenees and Alps over the last year and compared them with those from the 1980s. This temporal comparison was also very useful for content related to coastal relief. We basically combined several features offered by Google Earth Pro to help students analyse and better understand the concepts taught. This made Geography classes practical and applicable, as each student had access to a computer. Furthermore, students were encouraged to continue their geographical investigation at home using Google Earth Pro. The teacher sent all students an archive with the thematic files they had used in class. Google Earth Pro thus had the great advantage of importing thematic layers in the form of kmz and shape file files for tectonic plates and phenomena such as volcanism and earthquakes, thus introducing students to GIS functions. Some maps and layers downloaded from QGIS or ArcGIS can now be imported into Google Earth Pro. In this context, the teaching of physical geography by geography teachers becomes much more innovative thanks to these compatibilities with GIS. Students solved exercises involving the analysis and interpretation of landforms, observed the topography of the Earth's crust, performed measurements and terrain profiles, and the geo-browser helped them visually correlate the characteristics of the landform (height, slope) with the distribution and shape of settlements, the distribution of the hydrographic network, and vegetation. The application allows data to be viewed at any resolution by changing the scale, so that students collect and analyse information through a single interface that supports the establishment of correlations between elements and phenomena in reality (nature and society).

At the 10th grade level, Google Earth Pro was used in teaching Human Geography lessons such as geographical distribution of population and population concentration. We took advantage of this opportunity to import thematic files such as climate types, water networks and population density, all at a global level. Importing these thematic files into locations complemented the classic layer functionalities. When teaching the factors that influence population distribution, Google Earth Pro requires thematic layers to support explanations, arguments and correlations between natural factors and population. The primary database of Google Earth Pro only includes a topographic map of the Earth with administrative elements (borders and names), topographic elements (terrain, landforms), human settlements (localities, buildings), communication routes (roads) and photos, weather and similar features. This primary database is not sufficient for teaching the above-mentioned content, which is why this inconvenience has been remedied by importing thematic layers. These thematic layers were taken from *eduterre* website. On the other hand, the role of natural factors (relief, climate, hydrographic network, vegetation) in the geographical distribution of the population can be taught using Google Earth Pro, as can population density. Like the 9th grade students, the 10th grade students used the toolbar in the menu (ruler, path, topographic profile, overview, historical images). They also received worksheets which they completed by searching for answers using Google Earth Pro.

At the end of the module, the students were given a summative test to assess their level of knowledge and the skills they had acquired. The questions in the summative test were designed to assess the level of training in three skills specific to Geography: argumentation of an explanatory approach, spatial skills and establishing correlations between elements and phenomena in reality (nature and society). The summative tests were identical for both groups (control and experimental). At the end of the module, the experimental group was asked about their perception of the teaching tool used (in this case Google Earth Pro). It included multiple-choice questions (Likert scale) and open-ended questions. The open-ended answers were coded and sorted into categories. The multiple-choice questions focused on students' perceptions regarding: the importance of how students are organised during class, their level of satisfaction with teamwork, the benefits of using Google Earth Pro for learning and the technical/functional characteristics of Google Earth Pro. The open-ended question aimed to assess students' perceptions of the main advantages of collaborative learning.

The research data were collected by processing the results obtained by the students in both groups in the summative test and after applying the perception questionnaire to the experimental group.

The research methods used are statistical analysis and questionnaires. The statistical analysis was performed using SPSS 28 software. The statistical analysis of the data used the statistical test for comparing proportions and mean values as well as PCA factor analysis.

## Results

The statistical analysis involved the validation of three research hypotheses:

**Working hypothesis 1:** There are statistically significant differences between the experimental and control groups in terms of the results obtained by students in the summative test.

The descriptive analysis (Tables 1.a) shows that the experimental group made up of 9th grade students got better results on the summative test, both in terms of the overall average of the sample and in terms of the maximum and minimum values. The average of the experimental group is 7.20 compared to 5.7 for the control group, the maximum value is 9.75 compared to 9.0 and the minimum value (3.00) is also higher than that of the control group (1.50). The control group recorded lower results in the summative test than the experimental group. On the other hand, the average score obtained by the 10th grade students in the experimental group is slightly lower (8.00) than that of the control group (8.50). In the 10th grade, we note several positive aspects: both groups of students obtain maximum values of 10 and the minimum grade of the experimental group (5.10) is higher than that of the control group (3.80), which indicates that it has a 100% pass rate on the summative test.

The average scores obtained by each sample provide an overall picture of the final results obtained by students on the summative test, but knowledge of the proportion of students with very poor results is particularly useful, which is why we have ranked the students' results on the summative test on four levels of performance: grade below 5 (fail), low grade (5–6.9), average grade (7–8.9) and high grade (9–10). The statistical analysis aimed to determine the frequency recorded for each of the four performance levels in order to compare the two groups with the aim of identifying statistically significant differences between them.

The results highlighted significant differences (Table 1.b). Thus, in the 9th grade, significant differences were found in favor of the experimental group, which recorded a much higher frequency of students with high grades (16.7%), a lower frequency of low grades (29.2%) and those with grades below 5 (16.7%). Practically, no differences were recorded in the segment of students with average grades, while significant differences were recorded in all other three performance levels.

In the 10th grade, there were differences between the two groups. The experimental group had a higher proportion of students with average grades (48%) and low grades (22%) and a lower proportion of those with high grades (30%) compared to the control group. The percentage of those with grades below 5 is higher in the control group (5.9%) than in the experimental group (0.0%). Research hypothesis 1 was validated.

Regardless of the grade obtained by students on the summative test, the use of the Google Earth Pro application in Geography classes was generally very well received by them (Table 2.a). Even students who obtained grades below 5 (failed) considered that Google Earth Pro brings numerous benefits to learning, such as spatial orientation (83.3%), discovering places on the Earth's surface that they would not normally be able to see (75%), real-time visualisation of the Earth's surface (66.7%) and control over the information to be analysed (66.7%). Students who obtained low marks (5–6.9) indicated as benefits of GEP for learning the fact that the application helps them discover places on the Earth's surface that they would not normally be able to see (84.4%), real-time visualisation of the Earth's surface (71.9%) and orientation in space (65.6%). The same benefits were appreciated by students with average and high grades. However, students with high grades appreciated benefits such as help in everyday life, not only in

**Table 1b**
Percentages of grades obtained in the four categories of results.

| Garde ranking | Class | IX experiment | X experiment | IX control | X control |
|---|---|---|---|---|---|
| | Total | *72* | *50* | *56* | *51* |
| Fail (Grade below 5) | Col % | 16,7 | 0,0 | 32,1 | 5,9 |
| Low grade (5–6.9) | Col % | 29,2 | 22,0 | 33,9 | 9,8 |
| Average grade (7–8.9) | Col % | 37,5 | 48,0 | 32,1 | 35,3 |
| High grade (9–10) | Col % | 16,7 | 30,0 | 1,8 | 49,0 |

**Table 2a**
Benefits of using Google Earth Pro according to grade test hierarchy.

| Which were the main benefits obtained by using Google Earth Pro software in the teaching-learning of Geography ? | Grade test | | | |
|---|---|---|---|---|
| | Fail (Grade below 5) % | Low grade (5–6.9) % | Average grade (7–8.9) % | High grade (9–10) % |
| Total | *12* | *32* | *50* | *26* |
| orientate yourself in space | 83,3 | 65,6 | 74,0 | 80,8 |
| visualise the external appearance of the Earth's surface in real time | 66,7 | 71,9 | 76,0 | 65,4 |
| discover places on the Earth's surface that you would not normally see | 75,0 | 84,4 | 74,0 | 69,2 |
| research and collect geographic data | 41,7 | 37,5 | 40,0 | 38,5 |
| analyse geospatial data for educational purposes | 41,7 | 40,6 | 40,0 | 38,5 |
| help me in everyday life, not just for school purposes | 41,7 | 37,5 | 34,0 | 46,2 |
| have control over the information that I am analyzing (the menu helps you zoom in, zoom out, see the elevation profile, the evolution over time) | 66,7 | 40,6 | 50,0 | 46,2 |
| in the argumentation of phenomena/ relationships between man and society | 33,3 | 25,0 | 20,0 | 26,9 |
| associate the graphical/ cartographic/pictorial part with theoretical concepts | 33,3 | 43,8 | 30,0 | 42,3 |
| facilitate digital transition | 16,7 | 31,3 | 28,0 | 23,1 |

**Table 1a**
Test scores distributed according to the year of study.

| Class | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | | |
| IX experimental | 72 | 6,9583 | 1,89,108 | ,22,287 | 6,5140 | 7,4027 | 3,00 | 9,75 |
| X experimental | 50 | 8,0180 | 1,39,103 | ,19,672 | 7,6227 | 8,4133 | 5,10 | 10,00 |
| IX control | 56 | 5,6830 | 1,91,305 | ,25,564 | 5,1707 | 6,1954 | 1,50 | 9,00 |
| X control | 51 | 8,4510 | 1,62,153 | ,22,706 | 7,9949 | 8,9070 | 3,80 | 10,00 |
| Total | 229 | 7,2103 | 2,01,724 | ,13,330 | 6,9476 | 7,4729 | 3,00 | 10,00 |

school (46.2%) and the connection between graphics/maps/images and theoretical concepts (42.3%) to a greater extent.

We noticed that students' opinions on the technical aspects of Google Earth Pro differed depending on their test scores (Table 2.b). There are statistically significant differences between students with grades below 5, who believe that GEP facilitates the learning of fundamental elements of physical and human Geography in a much smaller proportion (25%) compared to those with low grades (65.6%), average grades (72.5%) and high grades (70.4%). The same category of students, those with scores below 5, consider that GEP is 'an application compatible with the study of Geography' in a smaller proportion (41.7%) compared to their colleagues with low scores (65.6%) and also appreciate to a small extent the fact that 'it has a practical and applicative character' (33.3%) compared to their colleagues with high grades (63%). All students, regardless of their test score, appreciated that GEP is an easy-to-use application (between 58.8% and 70.4%) and it is an attractive digital tool in terms of design and interface, modern and innovative.

**Working hypothesis 2:** The results obtained by students in the summative test depend on the use of Google Earth Pro in the teaching-learning process of Geography.

Research hypothesis 2 was statistically tested using factor analysis. The factorial analysis included as research variables the results obtained by students in the summative test and the response variables from the two questions that aimed to assess students' perception of the personal benefits of using Google Earth Pro in Geography classes and their evaluation of the Google Earth Pro application in terms of the technical functionality of the menu.

In the first factor analysis (Principal Component Analysis), the students' test scores (dependent variable) and their perception of the benefits of using Google Earth Pro (independent variable) were introduced as variables. According to the values obtained below the significance threshold of the KMO and Bartlett's indicators, it is confirmed that the correlations between the variables are strong. Following the PCA (Table 3.a) analysis by extraction from the initial test score, 78% of it can be explained by the Google Earth Pro factor, especially in the form of its benefits: it helps with spatial orientation (56%), real-time visualisation of the Earth's surface (67%) and helps in everyday life, not only in school (60%). The Varimax method extracts (Table 3.b) as statistically significant 3 components that together explain 50.16% of their contribution to 78% of the test score.

The significance of the three factors obtained by the Rotation Method, Varimax with Kaiser Normalisation (Table 3.a) indicates the factors grouped as follows: Component 1 consists of the variables grouped as follows: GEP helps in everyday life, not only in school (75%), GEP helps with documentation and collection of geographical data (69%), GEP allows the analysis of geospatial data for educational purposes (66%) and GEP facilitates digital transition (57%); Component 2 comprises several significant variables that are grouped as follows: GEP facilitates real-time visualisation of the Earth's surface (80%) and GEP helps with spatial orientation (74%); Component 3 consists of several highly significant variables that are grouped together: GEP helps in discovering places on the Earth's surface that you would not normally be able to see (42%) and test score (−87%). The way students perceived GEP in terms of the benefits of this application for personal learning had an impact on their test scores and on learning outcomes measured by the value of the scores obtained by students on the test.

In the second factor analysis (Principal Component Analysis), the students' test scores (dependent variable) and the technical characteristics/capabilities of the Google Earth Pro application (independent variable) were introduced as variables. According to the values obtained below the significance threshold of the KMO and Bartlett's indicators, it is confirmed that the correlations between variables are strong. Following the PCA (Table 4.a) analysis by extraction from the initial test score, 64% of it can be explained by the Google Earth Pro factor, more precisely by several technical characteristics such as: GEP facilitates the learning of the fundamental elements of physical and human Geography (68%), it is an application that is easy/difficult to use (73%−69%), it has a profound practical and applicative character (66%) and through its functions it is a GIS tool (67%). These five characteristics of GEP were

**Table 3a**
. Factor analysis between research variables: Test score and benefits of Google Earth Pro.

| | Communalities | | Rotated Component Matrix[a] | | |
|---|---|---|---|---|---|
| | Initial | Extraction | Component | | |
| | | | 1 | 2 | 3 |
| Grade_test | 1000 | ,781 | | | |
| orientate yourself in space | 1000 | ,569 | ,115 | ,740 | -,089 |
| visualise the external appearance of the Earth's surface in real time | 1000 | ,676 | ,130 | ,809 | ,070 |
| discover places on the Earth's surface that you would not normally see | 1000 | ,493 | ,466 | -,312 | ,422 |
| research and collect geographic data | 1000 | ,505 | ,692 | ,144 | -,073 |
| analyse geospatial data for educational purposes | 1000 | ,447 | ,666 | -,031 | -,042 |
| help me in everyday life, not just for school purposes | 1000 | ,600 | ,758 | ,157 | ,038 |
| have control over the information that I am analyzing (the menu helps you zoom in, zoom out, see the elevation profile, the evolution over time) | 1000 | ,389 | ,453 | ,259 | ,343 |
| in the argumentation of phenomena/ relationships between man and society | 1000 | ,343 | ,541 | ,206 | ,088 |
| associate the graphical/ cartographic/pictorial part with theoretical concepts | 1000 | ,375 | ,424 | ,402 | ,183 |
| facilitate digital transition | 1000 | ,340 | ,574 | ,097 | ,036 |

Extraction Method: Principal Component Analysis. Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

**Table 2b**
Students' perceptions of the technical aspects of Google Earth Pro software according to grade test hierarchy.

| What do you think about the technical aspects of Google Earth Pro software? | Grade test | | | |
|---|---|---|---|---|
| | Fail (Grade below 5) % | Fail (Grade below 5) % | Fail (Grade below 5) % | Fail (Grade below 5) % |
| Total | *12* | *32* | *51* | *27* |
| It facilitates learning the fundamentals of physical and human geography | 25,0 | 65,6 | 72,5 | 70,4 |
| It is an attractively designed and user-friendly digital tool | 75,0 | 75,0 | 70,6 | 77,8 |
| It is a difficult application to use | 16,7 | 18,8 | 11,8 | 11,1 |
| It is an easy- to- use application | 66,7 | 62,5 | 58,8 | 70,4 |
| It is compatible with the study of Geography | 41,7 | 65,6 | 60,8 | 55,6 |
| It has a deeply practical and applied character | 33,3 | 46,9 | 37,3 | 63,0 |
| It is a modern and innovative digital tool | 58,3 | 46,9 | 54,9 | 63,0 |
| Due to its features is a G.I.S tool. | 8,3 | 3,1 | 2,0 | 3,7 |
| It creates learning situations that challenge the learner | 16,7 | 28,1 | 27,5 | 33,3 |
| It creates a stimulating learning environment | 41,7 | 34,4 | 35,3 | 48,1 |

**Table 3b**
Weighting of the three components extracted using the Varimax method.

| Component | Initial Eigenvalues | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 3151 | 28,649 | 28,649 | 2764 | 25,127 | 25,127 |
| 2 | 1328 | 12,070 | 40,718 | 1627 | 14,791 | 39,919 |
| 3 | 1039 | 9446 | 50,164 | 1127 | 10,246 | 50,164 |

**Table 4a**
Factor analysis between research variables: test grade and technical characteristics of Google Earth Pro.

| | Communalities | | Rotated Component Matrix | | | |
|---|---|---|---|---|---|---|
| | Initial | Extraction | Component | | | |
| | | | 1 | 2 | 3 | 4 |
| Grade Test | 1000 | ,646 | | | | |
| It facilitates learning the fundamentals of physical and human geography | 1000 | ,684 | ,744 | -,108 | ,149 | ,020 |
| It is an attractively designed and user-friendly digital tool | 1000 | ,383 | ,594 | ,089 | ,073 | -,131 |
| It is a difficult application to use | 1000 | ,696 | ,155 | ,812 | -,111 | -,012 |
| It is an easy- to- use application | 1000 | ,736 | ,084 | -,021 | ,853 | -,033 |
| It is compatible with the study of Geography | 1000 | ,377 | ,341 | ,301 | ,348 | ,222 |
| It has a deeply practical and applied character | 1000 | ,665 | ,497 | ,509 | ,074 | ,392 |
| It is a modern and innovative digital tool | 1000 | ,588 | ,744 | -,108 | ,149 | ,020 |
| Due to its features is a G.I.S tool. | 1000 | ,674 | -,062 | ,798 | ,100 | -,155 |
| It creates learning situations that challenge the learner | 1000 | ,520 | ,649 | ,237 | -,033 | ,202 |
| It creates a stimulating learning environment | 1000 | ,624 | ,549 | -,026 | ,566 | ,027 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

extracted as the main factors explaining 64% of the test score. The Varimax method (Table 4.b) also indicates a grouping of GEP characteristics into four categories of factors that explain approximately 59.94% of the test score.

The significance of the four components obtained using the Rotation Method, Varimax with Kaiser Normalisation (Table 4.a) indicates the following structure: Component 1 consists of several important variables such as: GEP is a modern and innovative digital tool (743%), GEP is an attractive digital tool due to its design and interface (59%) and it creates learning situations that challenge the student (64%); Component 2 consists of the following variables: GEP is a difficult application to use (81%), GEP is a GIS tool due to its functions (79%) and GEP has a deeply practical character (50.9%); Component 3 consists of: GEP is an easy-to-use application (85%) and GEP creates a stimulating learning environment (56%); Component 4 includes the characteristic that GEP facilitates the learning of the fundamental elements of physical and Human Geography (65%).

The way in which students perceived the technical characteristics of the GEP application had a positive impact on their test scores and their learning outcomes, as measured by their test scores. Research hypothesis no. 2 was validated.

**Working hypothesis 3:** Google Earth Pro had a significant impact on the development of the three specific Geography skills.

In validating the research hypothesis, a factor analysis was performed between the research variables represented by the scores obtained by students on the test items, which corresponded to a specific skill, and the response variables that targeted students' perceptions of the technical characteristics and benefits of the Google Earth Pro application. The tests applied to students included items associated with the formation of 3 specific Geography skills and were considered dependent variables, while the Google Earth Pro variable was considered the independent variable.

The first skill analysed in correlation with the Google Earth Pro factor was argumentation of an explanatory approach. The values of the KMO and Bartlett's indicators fell within the significance threshold, thus confirming that there are strong correlations between variables. The PCA analysis (Table 5.a) indicates that 74% of the value of the argumentation skill can be explained by the Google Earth Pro factor and some benefits of the application that have had a significant impact, such as spatial orientation (61%), real-time visualisation of the Earth's surface (67%) and assistance offered in everyday life, not only in school (59%). The Varimax method (Table 5.b) extracts as statistically significant three components that together explain 50.71% of their contribution to the formation of argumentation competence in a proportion of 74%.

Using the Rotation Method, Varimax with Kaiser Normalisation (Table 5.a), we obtained three factors grouped as follows: Component 1 consists of the variables: GEP provides assistance in everyday life, not only in academic contexts (74%), GEP assists in the documentation and collection of geographical data (70%), GEP enables the analysis of geospatial data for educational purposes (69%) and GEP assists in the argumentation of phenomena (56%); Component 2 includes several significant variables such as: GEP facilitates real-time visualisation of the Earth's surface (80%) and GEP helps with spatial orientation (77%); Component 3 consists of several variables of great significance, such as: GEP assists in discovering places on the Earth's surface that one would not normally be able to see (57%).

The technical characteristics of GEP were analysed factorially in relation to the research variable represented by argumentation competence. The PCA analysis (Table 6.a) indicates that 69.9% of the value of argumentation competence can be explained by the contribution of the technical characteristics of GEP, among which the following have a

**Table 4b**
Weighting of the main components extracted using the Varimax method.

| Component | Initial Eigenvalues | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 2836 | 25,784 | 25,784 | 2036 | 18,513 | 18,513 |
| 2 | 1588 | 14,437 | 40,221 | 1744 | 15,853 | 34,366 |
| 3 | 1146 | 10,416 | 50,637 | 1485 | 13,501 | 47,867 |
| 4 | 1024 | 9310 | 59,947 | 1329 | 12,080 | 59,947 |

**Table 5a**
Factor analysis between variables: competence arguing an explanatory approach and benefits of Google Earth Pro.

| Communalities | | | Rotated Component Matrix | | |
|---|---|---|---|---|---|
| | Initial | Extraction | Component | | |
| | | | 1 | 2 | 3 |
| Competence: arguing an explanatory approach | 1000 | ,746 | | | |
| orientate yourself in space | 1000 | ,610 | ,112 | ,773 | |
| visualise the external appearance of the Earth's surface in real time | 1000 | ,675 | ,180 | ,801 | |
| discover places on the Earth's surface that you would not normally see | 1000 | ,549 | ,402 | -,248 | ,571 |
| research and collect geographic data | 1000 | ,502 | ,701 | | |
| analyse geospatial data for educational purposes | 1000 | ,512 | ,694 | | -,143 |
| help me in everyday life, not just for school purposes | 1000 | ,591 | ,747 | ,129 | ,131 |
| have control over the information that I am analyzing (the menu helps you zoom in, zoom out, see the elevation profile, the evolution over time) | 1000 | ,330 | ,506 | ,218 | ,161 |
| in the argumentation of phenomena/ relationships between man and society | 1000 | ,345 | ,560 | ,170 | |
| associate the graphical/ cartographic/pictorial part with theoretical concepts | 1000 | ,362 | ,494 | ,342 | |
| facilitate digital transition | 1000 | ,358 | ,508 | ,144 | ,282 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

significant impact: GEP facilitates the learning of fundamental elements of Geography (75%), it is a difficult application to use (69%) and it has a profound practical and applicative character (65%). Using the Rotation Method, Varimax with Kaiser Normalisation (Table 6.b), we obtained 4 factors grouped as follows: component 1 includes the variables: GEP is a digital and innovative tool (76%) and GEP creates an attractive environment through its design and interface (60%); component 2 consists of the characteristics: GEP is difficult to use (82%) and GEP is similar to GIS due to its functions (75%). Components 3 and 4 have a significantly lower contribution.

The second ability we looked at was spatial awareness. PCA (Table 7.a) analysis shows that 84% of spatial awareness can be explained by Google Earth Pro. Students think this app has many benefits, so using it has had a big impact on their spatial awareness. Some of the main benefits are spatial orientation (57%), real-time visualisation of the Earth's surface (68%) and assistance in everyday life, not only in school (61%). The Varimax method (Table 7.b) extracts as statistically significant three components which together explain 50.71% of their contribution to the formation of argumentation skills in a proportion of 87%.

Using the Rotation Method, Varimax with Kaiser Normalisation (Table 7.a), we obtained three factors grouped as follows: Component 1 consists of the variables: GEP helps in everyday life, not only in school (76%), GEP helps in documenting and collecting geographical data (66%), GEP allows the analysis of geospatial data for educational purposes (62%) and GEP helps in arguing phenomena (55%); Component 2 includes several significant variables such as: GEP facilitates real-time visualisation of the external appearance of the Earth's surface (80%) and GEP helps with spatial orientation (74%); Component 3 consists of several variables of lesser significance.

The technical characteristics of GEP were analysed factorially in relation to the research variable represented by spatial competence. PCA (Table 8.a) analysis indicates that 90% of spatial competence can be explained by the technical characteristics of GEP, among which the following have a significant impact: GEP facilitates the learning of fundamental elements of Geography (67%), it is a difficult application to use (70%) and it has a profound practical and applicative character (62%). Using the Rotation Method, Varimax with Kaiser Normalisation (Table 8.b) we obtained 4 factors which together explain the formation of competence in a proportion of 58.89%: component 1 includes the variables: GEP is a digital and innovative tool (75%), GEP creates an attractive environment through its design and interface (60%) and GEP creates a stimulating environment (60%); component 2 consists of the following characteristics: GEP is difficult to use (82%), GEP is similar to GIS due to its functions (75%) and GEP has a profound practical and applicative character (55%). Component 3 has two important variables: GEP facilitates the learning of the fundamental elements of physical and human Geography (79%) and GEP is easy to use (68%), and component

**Table 6a**
Factor analysis between variables: competence arguing an explanatory approach and technical characteristics of Google Earth Pro.

| Communalities | | | Rotated Component Matrix | | | |
|---|---|---|---|---|---|---|
| | Initial | Extraction | Component | | | |
| | | | 1 | 2 | 3 | 4 |
| Competence: arguing an explanatory approach | 1000 | ,699 | | | | |
| It facilitates learning the fundamentals of physical and human geography | 1000 | ,753 | -,140 | | ,739 | ,429 |
| It is an attractively designed and user-friendly digital tool | 1000 | ,395 | ,602 | ,120 | | -,132 |
| It is a difficult application to use | 1000 | ,695 | | ,823 | | |
| It is an easy- to- use application | 1000 | ,608 | ,184 | -,111 | ,719 | -,211 |
| It is compatible with the study of Geography | 1000 | ,425 | ,287 | ,321 | ,486 | |
| It has a deeply practical and applied character | 1000 | ,653 | ,397 | ,577 | ,258 | ,308 |
| It is a modern and innovative digital tool | 1000 | ,599 | ,761 | | ,104 | |
| Due to its features is a G. I.S tool. | 1000 | ,659 | | ,750 | | -,302 |
| It creates learning situations that challenge the learner | 1000 | ,540 | ,586 | ,316 | | ,308 |
| It creates a stimulating learning environment | 1000 | ,602 | ,603 | | ,486 | |

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

**Table 5b**
Proportion of the three components extracted using the Varimax method.

| Component | Initial Eigenvalues | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 3150 | 28,635 | 28,635 | 2824 | 25,670 | 25,670 |
| 2 | 1349 | 12,266 | 40,901 | 1554 | 14,124 | 39,794 |
| 3 | 1079 | 9813 | 50,714 | 1201 | 10,920 | 50,714 |

**Table 6b**
Weighting of the four components extracted using the Varimax method.

| Component | Initial Eigenvalues | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 2823 | 25,660 | 25,660 | 1955 | 17,772 | 17,772 |
| 2 | 1574 | 14,312 | 39,972 | 1821 | 16,551 | 34,323 |
| 3 | 1168 | 10,614 | 50,586 | 1627 | 14,792 | 49,115 |
| 4 | 1064 | 9669 | 60,254 | 1225 | 11,139 | 60,254 |

**Table 7a**
Principal component analysis between variables: spatial skills and Google Earth Pro benefits.

| Communalities | | | Rotated Component Matrix | | |
|---|---|---|---|---|---|
| | Initial | Extraction | Component | | |
| | | | 1 | 2 | 3 |
| Spatial skills | 1000 | ,874 | | | |
| orientate yourself in space | 1000 | ,574 | ,124 | ,744 | |
| visualise the external appearance of the Earth's surface in real time | 1000 | ,680 | ,169 | ,802 | |
| discover places on the Earth's surface that you would not normally see | 1000 | ,474 | ,528 | -,358 | -,260 |
| research and collect geographic data | 1000 | ,492 | ,668 | ,138 | ,165 |
| analyse geospatial data for educational purposes | 1000 | ,437 | ,622 | | -,224 |
| help me in everyday life, not just for school purposes | 1000 | ,618 | ,763 | ,126 | ,144 |
| have control over the information that I am analyzing (the menu helps you zoom in, zoom out, see the elevation profile, the evolution over time) | 1000 | ,331 | ,530 | ,201 | |
| in the argumentation of phenomena/ relationships between man and society | 1000 | ,343 | ,551 | ,192 | |
| associate the graphical/ cartographic/pictorial part with theoretical concepts | 1000 | ,375 | ,469 | ,370 | -,133 |
| facilitate digital transition | 1000 | ,380 | ,581 | | ,195 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

4 has a significantly lower contribution.

The third competence analysed in correlation with the GEP factor was the establishment of correlations between elements and phenomena in reality (nature and society). The PCA (Table 9.a) analysis indicates that 69% of the value of the competence can be explained by the Google Earth Pro factor, as students' perception that this application has numerous benefits has had a significant impact on its formation, such as spatial orientation (60%), real-time visualisation of the Earth's surface (66%) and analysis of geospatial data for educational purposes (60%). The Varimax method (Table 9.b) extracts as statistically significant 3 components which together explain 50.95% of their contribution to the formation of argumentation competence in a proportion of 69%.

Using the Rotation Method, Varimax with Kaiser Normalisation (Table 9.a), we obtained three factors grouped as follows: Component 1 consists of the variables: GEP helps in everyday life, not only in school (76%), GEP helps with documentation and collection of geographical data (65%), GEP allows the analysis of geospatial data for educational purposes (60%), GEP helps in arguing certain phenomena (55%), GEP facilitates digital transition (56%) and GEP ensures control over the analysed information (56%); component 2 includes several significant variables such as: GEP facilitates real-time visualisation of the Earth's surface (78%) and GEP helps with spatial orientation (74%); component 3 consists of several variables of lesser significance.

The technical characteristics of GEP were analysed factorially in relation to the research variable represented by the ability to establish correlations between elements and phenomena in the real world (nature and society). The PCA (Table 10.a) analysis indicates that 55% of the value of the competence can be explained by the contribution of the technical characteristics of GEP, among which the following have a

**Table 8a**
Principal component analysis between variables: Spatial skills and technical characteristics of Google Earth Pro.

| Communalities | | | Rotated Component Matrix | | | |
|---|---|---|---|---|---|---|
| | Initial | Extraction | Component | | | |
| | | | 1 | 2 | 3 | 4 |
| Spatial skills | 1000 | ,908 | | | | |
| It facilitates learning the fundamentals of physical and human geography | 1000 | ,670 | -,107 | | ,794 | ,162 |
| It is an attractively designed and user-friendly digital tool | 1000 | ,397 | ,609 | ,109 | | -,117 |
| It is a difficult application to use | 1000 | ,705 | ,121 | ,824 | | |
| It is an easy- to- use application | 1000 | ,547 | ,204 | -,111 | ,687 | -,146 |
| It is compatible with the study of Geography | 1000 | ,401 | | | | |
| It has a deeply practical and applied character | 1000 | ,625 | ,421 | ,555 | ,270 | ,259 |
| It is a modern and innovative digital tool | 1000 | ,604 | ,757 | | | ,140 |
| Due to its features is a G. I.S tool. | 1000 | ,577 | | ,759 | | |
| It creates learning situations that challenge the learner | 1000 | ,462 | ,607 | ,293 | | |
| It creates a stimulating learning environment | 1000 | ,582 | ,612 | | ,448 | |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

**Table 7b**
Proportion of the three main components extracted using the Varimax method.

| Component | Initial Eigenvalues | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 3149 | 28,628 | 28,628 | 2882 | 26,199 | 26,199 |
| 2 | 1318 | 11,985 | 40,613 | 1580 | 14,368 | 40,567 |
| 3 | 1111 | 10,099 | 50,712 | 1116 | 10,144 | 50,712 |

**Table 8b**
Weighting of the four components extracted using the Varimax method.

| Component | Initial Eigenvalues | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 2847 | 25,877 | 25,877 | 2033 | 18,479 | 18,479 |
| 2 | 1559 | 14,175 | 40,052 | 1776 | 16,145 | 34,624 |
| 3 | 1070 | 9727 | 49,779 | 1600 | 14,546 | 49,170 |
| 4 | 1003 | 9117 | 58,896 | 1070 | 9727 | 58,896 |

**Table 9a**
Principal component analysis between variables: competence establishing correlations between elements and phenomena in the real world (nature and society) and Google Earth Pro benefits.

| Communalities | | | Rotated Component Matrix | | |
|---|---|---|---|---|---|
| | Initial | Extraction | Component | | |
| | | | 1 | 2 | 3 |
| Competence: establishing correlations between elements and phenomena in the real world (nature and society) | 1000 | ,691 | | | |
| orientate yourself in space | 1000 | ,603 | ,123 | ,744 | ,184 |
| visualise the external appearance of the Earth's surface in real time | 1000 | ,662 | ,194 | ,788 | |
| discover places on the Earth's surface that you would not normally see | 1000 | ,437 | ,536 | -,386 | |
| research and collect geographic data | 1000 | ,457 | ,657 | ,135 | |
| analyse geospatial data for educational purposes | 1000 | ,607 | ,601 | | ,495 |
| help me in everyday life, not just for school purposes | 1000 | ,593 | ,760 | ,123 | |
| have control over the information that I am analyzing (the menu helps you zoom in, zoom out, see the elevation profile, the evolution over time) | 1000 | ,462 | ,561 | ,187 | -,335 |
| in the argumentation of phenomena/ relationships between man and society | 1000 | ,341 | ,556 | ,176 | |
| associate the graphical/ cartographic/pictorial part with theoretical concepts | 1000 | ,416 | | | |
| facilitate digital transition | 1000 | ,337 | ,566 | | ,107 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

significant impact: GEP facilitates the learning of the fundamental elements of Geography (63%), it is a difficult application to use (68%), it has a profound practical and applicative character (59%) and GEP is a GIS tool due to its functions (50%). Using the Rotation Method, Varimax with Kaiser Normalisation (Table 10.b), we obtained 3 factors which together explain 50.9% of the formation of competence: component 1 includes the variables: GEP creates a stimulating environment (76%) and GEP is a digital and innovative tool (70%); component 2 consists of the characteristics: GEP is difficult to use (82%), GEP, due to its functions, is similar to GIS (73%) and GEP has a profound practical and applicative character (58%). Component 3 has two important variables in terms of impact, such as GEP facilitates the learning of the fundamental elements of physical and Human Geography (76%).

## Discussion

To what extent did Google Earth Pro facilitate learning and impact students' results on the summative test?

The use of Google Earth Pro software impacted students' results on the summative test, as shown by the results of the statistical analysis. The proportion of students with marks below 5 (which is considered a fail) is lower in the experimental group and almost double in the control group, while the proportion of average marks (7–8.9) is also higher in the experimental group. Google Earth Pro influenced test results differently for each year of study. Thus, the 9th grade experimental class obtained higher results in all categories of values from averages,

**Table 10a**
Principal component analysis between the variables of competence establishing correlations between elements and phenomena in the real world (nature and society) and the technical characteristics of Google Earth Pro.

| Communalities | | | Roteted Component Matrix | | |
|---|---|---|---|---|---|
| | Initial | Extraction | Component | | |
| | | | 1 | 2 | 3 |
| Competence: establishing correlations between elements and phenomena in the real world (nature and society) | 1000 | ,552 | | | |
| It facilitates learning the fundamentals of physical and human geography | 1000 | ,631 | ,222 | | ,762 |
| It is an attractively designed and user-friendly digital tool | 1000 | ,294 | ,493 | ,191 | -,122 |
| It is a difficult application to use | 1000 | ,686 | | ,823 | |
| It is an easy- to- use application | 1000 | ,369 | ,532 | -,175 | ,235 |
| It is compatible with the study of Geography | 1000 | ,414 | ,428 | ,305 | ,370 |
| It has a deeply practical and applied character | 1000 | ,599 | ,464 | ,585 | ,204 |
| It is a modern and innovative digital tool | 1000 | ,505 | ,705 | | |
| Due to its features is a G.I.S tool. | 1000 | ,545 | | ,735 | |
| It creates learning situations that challenge the learner | 1000 | ,410 | ,524 | ,367 | |
| It creates a stimulating learning environment | 1000 | ,596 | ,764 | | ,110 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

**Table 9b**
The three components extracted using the Varimax method.

| Component | Initial Eigenvalues | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 3156 | 28,694 | 28,694 | 2901 | 26,373 | 26,373 |
| 2 | 1323 | 12,024 | 40,718 | 1567 | 14,244 | 40,617 |
| 3 | 1126 | 10,236 | 50,954 | 1137 | 10,337 | 50,954 |

**Table 10b**
The three main components extracted using the Varimax method.

| Component | Initial Eigenvalues | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 2821 | 25,643 | 25,643 | 2378 | 21,620 | 21,620 |
| 2 | 1561 | 14,188 | 39,832 | 1857 | 16,884 | 38,504 |
| 3 | 1221 | 11,099 | 50,930 | 1367 | 12,426 | 50,930 |

minimums and maximums, a higher frequency of students with high grades and a lower frequency of those with grades below 5. GEP seems to have had a maximum impact on all categories of students with different levels of preparation. It also seems to have helped those with learning difficulties to learn more easily, as their proportion is much smaller than in the control group.

Although the use of Google Earth Pro was a challenge, as students had to learn the menu and use the application to complete specific tasks and learning activities, the proportion of students who failed is low, so the digital tool was not an obstacle to learning. During the five weeks of experimenting with learning Geography using GEP, students were able to simultaneously develop both their digital skills and those specific to Geography, quickly learning the skills to study Geography with the help of GEP. GEP had a positive impact on the category of students who achieved high grades (9–10), their share being 8 times higher than that of the control group. Practically, GEP becomes a particularly useful digital tool in teaching Geography, capable of helping students both to perform well and to pass. This could be observed in 10th grade students, where although the average of the experimental group is lower than that of the control group, GEP still had a positive influence on test results because all students passed the summative test, with no student obtaining a grade below 5, which is an achievement.

The main concern of a teacher is to increase the pass rate in the class and to help students learn effectively so that they make progress. It is worth noting that the introduction of the GEP application in teaching Geography also had a positive impact in terms of perception, as students had a very good opinion of Google Earth Pro as a digital technical application and its benefits for learning. Regardless of their test scores, students were not influenced by the grades they received and greatly appreciated GEP. Paradoxically, students with grades below 5 appreciated some benefits more than their colleagues with high/average grades, such as spatial orientation, documentation and collection of geographical data, control over the information they analyse and the reasoning behind certain phenomena. The very high percentage values of perception may indicate the students' openness to using this digital application, overcoming the difficulties of learning the menu, willingness to learn Geography with a new, complex tool which could also create learning and manipulation problems, confidence in experimenting with new learning methods than those they were used to and a desire to adapt to a new, modern educational context that ensures the digital transition.

Due to time constraints, teachers sometimes avoid introducing GIS tools into high school Geography teaching for fear that students will not be able to use the application or that they will reject modern digital tools that require them to think more, pay attention and show interest. Understanding students' perceptions of the technical characteristics of GEP is particularly useful. It helps teachers understand students' concerns, learn how to introduce this tool into their teaching and learning strategy, identify students who encounter technical difficulties and create tasks of varying difficulty levels so that students can better learn Geography with GEP. We thus found that students with grades below 5, unlike their peers, did not have a high perception of the GEP's ability to 'facilitate the learning of the fundamental elements of physical and Human Geography.' The reason for this was not related to the degree of difficulty of the application but rather to the pleasure of learning in general, the motivation to learn and their relationship with school.

The fact that the students' results in the summative test were influenced by Google Earth Pro is also demonstrated by factor analysis. 76% of the test score is explained by the GEP factor, by three categories of benefits that account for 50%. The first factor groups characteristics related to the usefulness and applicability of the application focused on the formation of specific Geography skills that are useful in everyday life. The second factor consists of benefits related to the formation of geo-visualisation skills and spatial abilities. The third factor groups characteristics that can have an educational impact, also related to school performance. 64% of the score is explained by four components with a significant contribution (59.94%), which group the technical characteristics of GEP by factors: technological (modern, innovative, stimulating, practical applicability, design), technical functionality (degree of difficulty, GIS), utility and accessibility (integration into the study of Geography) and educational efficiency (impact on learning, link to school performance).

The results of this research challenge the view that there are no significant differences between students who learn using GIS and those who do not [55]. Furthermore, the educational context has changed significantly since the pandemic. Educational institutions are now much better equipped with technology than they were before the pandemic and the importance of technological barriers [56] has also diminished considerably, as have the problems arising from the lack of teacher training [57] and user spatial literacy [58] because the pandemic forced teachers to improve their digital skills, introduce modern digital methods into the teaching-learning-assessment process of Geography and test new software from Kahoot, Google Forms and Wordwall in the classroom [59]. After the pandemic, students' attitudes towards digital tools and educational software/applications improved, appreciating their use in teaching, learning and assessing Geography [60]. Favier [61] suggests various means of integrating GIS into Geography by varying the emphasis on the processes of learning Geography but also on technology, as well as making the teacher or student responsible for this tool [62].

The results of this study support the effectiveness of GIS use in secondary education and support the results obtained also by [63–65]. Even though GEP has some limitations, it is a GIS tool that can currently be used successfully in teaching Geography in secondary education. As Kerski emphasised, the value of GIS in specific aspects of learning, such as visualisation and territory-centred spatial thinking [66] or critical spatial thinking [67], these advantages can also be achieved with the help of GEP. Fig. 1 shows the correspondence analysis between student test grades and Google Earth Pro.

Correspondence analysis indicates an association between student test grades and the Google Earth Pro application. This differentiated performance is associated with the benefits of Google Earth Pro as a learning tool and its technical and functional characteristics. We observe that very good performance/students with very good results (grades of 9–10) is associated with the following variables: GEP creates a stimulating learning environment, is an attractive digital tool in terms of design and interface, is an easy-to-use application, is a modern and innovative tool and helps in everyday life, not only in school but also in spatial orientation. The outstanding performance of students with grades of 9–10 is associated with the four technical characteristics of the software, which indicates a visual-spatial but also kinaesthetic learning style. This segment consists mainly of students from urban areas, from the 10th grade, specialising in mathematics and computer science.

The students' positive perception of the geography learning

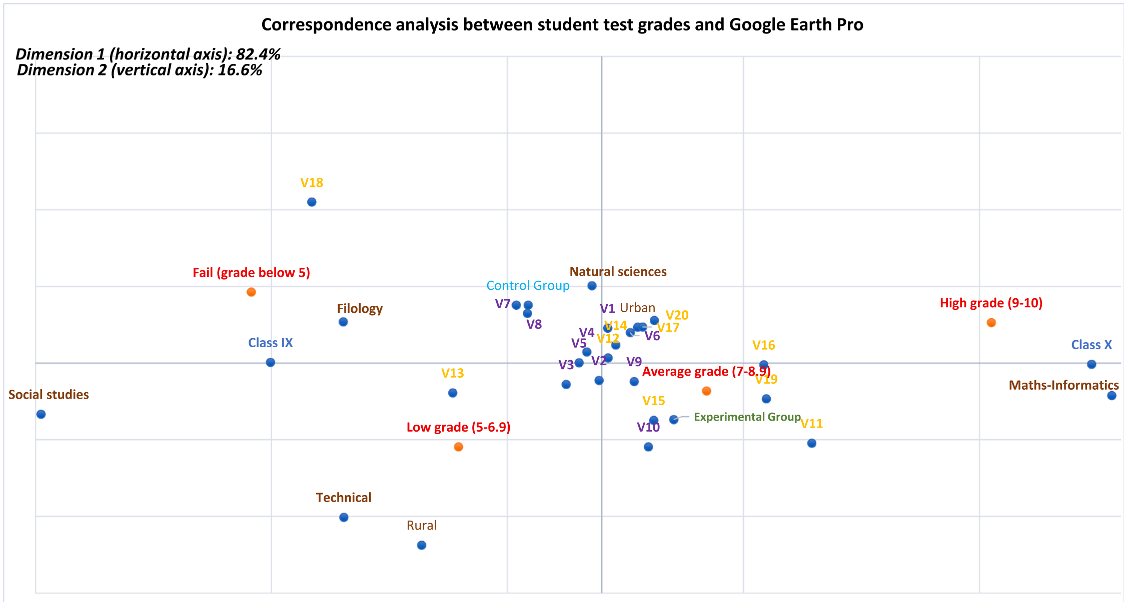


**Fig. 1.** Correspondence analysis between student test grades and Google Earth Pro.
**Benefits of using Google Earth Pro: V1-** orientate yourself in space **V2-** visualise the external appearance of the Earth's surface in real time **V3-** discover places on the Earth's surface that you would not normally see **V4-** research and collect geographic data **V5-** analyse geospatial data for educational purposes **V6-** help me in everyday life, not just for school purposes **V7-** have control over the information that I am analyzing (the menu helps you zoom in, zoom out, see the elevation profile, the evolution over time) **V8-** in the argumentation of phenomena/ relationships between man and society **V9-** associate the graphical/cartographic/pictorial part with theoretical concepts **V10** - facilitate digital transition
Technical functionality bebefits of Google Earth Pro:
**V11**- It facilitates learning the fundamentals of physical and human geography **V12**- It is an attractively designed and user-friendly digital tool **V13**- It is a difficult application to use **V14**- It is an easy- to- use application **V15**- It is compatible with the study of Geography **V16**- It has a deeply practical and applied character **V17**- It is a modern and innovative digital tool **V18**- Due to its features is a G.I.S tool. **V19**- It creates learning situations that challenge the learner **V20**- It creates a stimulating learning environment.

experiment with Google Earth Pro software and the analysis of the correspondence between the digital tool and school performance highlight several characteristics of the students: Students who achieve high performance in this context exhibit a visual-spatial learning style supported by the graphic and interactive elements of the application; increased intrinsic motivation due to the attractiveness and real usefulness of the digital tool; greater autonomy in learning, as GEP is easy to explore without constant assistance; and a transferability of knowledge, in the sense that what they learn can also be applied in everyday life (e. g., geographical orientation, route planning, understanding global geographical space).

Good student test grades (7–8.9) are associated with research variables that target both the technical and functional characteristics of the software and the benefits of the application on learning. Among the technical characteristics of the software, the practical and applicative nature of GEP stands out, as does the fact that it creates learning situations that challenge the student and its compatibility with the study of geography. A positive perception by students of the benefits of GEP for learning geography, due to the association between the graphic/cartographic/image part and the theoretical concepts, the aspects that facilitate the learning of the fundamental elements of physical and human geography and the digital transition, contributed to good results (grades between 7–8.99). Therefore, the good test grades of students reflect a positive relationship between the effective use of GEP and the increase in the quality of learning in geography. This segment of students with good performance consists of 10th grade students studying mathematics and computer science. The statistical association highlights the fact that students have a visual-spatial, kinaesthetic/applied learning style and are more predisposed to learning through experience with a great openness to learning with digital tools. The good and very good results of the students are supported by GEP on a segment of students who have multiple learning styles. Practically, GEP meets the need to train students with various learning styles.

We also find a positive correlation between school performance and the GEP digital tool in the segment of students with test grades between 5 and 6.9 who believe that the application helped them learn thanks to the real-time visualisation of the Earth's surface and the discovery of places on the Earth's surface that they would not normally be able to see, yet for them GEP is a difficult application to use. This segment of students consists of ninth-grade students from rural areas specialising in social sciences and humanities and technical fields such as food and tourism.

The segment of students who did not achieve academic success consists mainly of ninth-grade students specialising in natural sciences and philology. The relationship between academic performance and the GEP application indicates a strong correlation between student results and the application's ability to develop certain skills, such as analyzing geospatial data for educational purposes, documenting and collecting geographic data, arguing geographic phenomena and controlling information and menus. In practice, students are unable to solve certain tasks involving argumentation, geospatial data analysis, documentation and data collection. Students with more gaps in their skills are much more at risk of academic failure. Clustering these variables in the same quadrant highlights the fact that the lack or low level of specialised skills training justifies students' poor results and low performance. Correspondence analysis indicates a direct relationship between school performance and learning geography with GEP software, but simply using the application is not enough to produce positive effects on all students; it is necessary to implement differentiated pedagogical interventions depending on the students' skill level. We note that 10th grade students in the Mathematics-Computer Science profile achieved very good and good performance after the experiment. The study shows that students in rural areas have poorer results, among the causes of which could be students' access to technology and their digital skills. For this segment, additional digital training is necessary so that GEP does not become a tool for accentuating educational inequalities.

**How effective was Google Earth Pro as a teaching, learning and assessment tool for developing Geography-specific skills?**

The summative assessment aimed to evaluate the level of training in three specific Geography skills: arguing an explanatory approach, spatial skills and establishing correlations between elements and phenomena in the real world (nature and society). These skills are included in the schools' Geography curriculum. Viewed globally, the mark obtained by the student in the summative assessment indicates his or her level of preparation, but the skills training grid provides much clearer information on those skills that have not been sufficiently developed and on which the teacher must insist in order to improve them and increase their level of training. Knowing the level of training of the three skills allows the teacher to adapt their teaching strategy and introduce new tools into the Geography teaching-learning process, allocate more time to remedial activities, combine several innovative teaching tools and methods and propose more personalised learning activities differentiated for all categories of students.

The study highlighted the impact that Google Earth Pro had on the development of each skill. Google Earth Pro was very significant in explaining 74% of the final value of the skill 'argumentation of an explanatory approach'. Students felt that the application provided them with sufficient visual (geovisualization) and spatial (geolocation and spatial orientation) data to improve their argumentation skills. The research showed that students considered that GEP facilitated the learning of the fundamental elements of physical and Human Geography, contributing 75% to the development of the argumentation competence and that the software, through its practical and applicative interface, helped 65% in the development of this competence. This argumentation skill in an explanatory approach draws on a range of previously acquired knowledge, concepts and terminology, which are often easily forgotten if they have been memorised mechanically or not sufficiently understood, but GEP, with its GIS-like features, stimulates students' visual memory and helps those with a visual and kinaesthetic learning style. It can help students search for answers and arguments thanks to its attractive, modern and innovative menu. Questioning thematic layers stimulates learning through discovery. Students search for answers and explanations on their own. They can argue their opinions and answers using concrete geospatial data retrieved and analysed in real time directly from this software. They can document their arguments with images retrieved and saved from the application. They can perform calculations, measurements, draw polygons, terrain profiles and compare historical images.

There is broad consensus among specialists in teaching disciplines regarding the essential role of argumentation and various studies in different fields have shown that many students, including those at the undergraduate level, encounter difficulties in formulating solid arguments [68–71]. At the same time, there is evidence that many of them face challenges in integrating counterarguments and objections into their own reasoning [72–74], in using valid evidence to support conclusions [75–77] and in formulating arguments based on source material [78]. There is also a frequent lack of the language skills needed to write clear and convincing arguments [79,80]. One possible factor explaining these difficulties, identified in several countries, could be the limited attention paid to the development of this skill in Geography lessons. For example, research in Germany indicates that only a small percentage (6.7%) of the tasks proposed in Geography textbooks involve argumentation activities [81]. This factor identified by Budke does not apply because argumentation skills are included in the national curriculum starting in the 7th grade and the tasks and learning activities that require the development of this skill are found in Geography textbooks starting in the 7th grade. Argumentation skills are currently one of the most difficult to develop because students no longer have the habit of spending much time at home preparing individually for Geography. They have a low level of specialised language because they no longer have the habit of reading extensively. They have a low level of general knowledge that would allow them to work with data, think critically and search for interdisciplinary arguments. In addition, traditional education is widely practiced, which emphasises content rather than the development of skills. The students in the experimental group were asked how much time they had spent preparing at home during the five weeks they had been piloting the Google Earth Pro-based teaching scenario and the average was 1.9 h. Although the students were informed at the beginning of the module that they would take a summative test at the end of module II, the average score obtained by the students is 2.82 (from a maximum of 4.50) which means that the level of performance and training in argumentation skills is of the medium level. This competence remains a challenge for both teachers and students. The research results showed that GEP has a significant positive impact on the development of argumentation skills in Geography, but this digital tool must be used frequently, not just in short-term experimental research.

Google Earth Pro also had a significant impact on the development of spatial competence, with 84% of the value of this competence being explained by this tool, which acted as a determining factor thanks to its benefits related to geovisualization, geospatial data analysis, spatial orientation and applicability in everyday life, not only in school. In contrast, the technical features (the menu and its functions) contributed 90% to the development of spatial competence. The impact being very significant, as it is a very effective tool.

The Geography curriculum aims to progressively develop spatial skills starting in the fifth grade, with an emphasis on reading cartographic representations, visualisation, map orientation/cardinal points, scale and distance measurement. In the sixth grade, the spatial skills previously acquired on a smaller scale are extended to a larger scale at the level of the European continent, with an emphasis on the spatial distribution of fundamental elements of Physical and Human Geography. In the seventh grade, the school curriculum requires the development of spatial skills through a more complex series of applications in a broader context at the level of non-European continents. Alongside reading cartographic material, locating and visualizing fundamental elements of Geography, the interpretation and analysis of geographical phenomena and processes is introduced. In the 7th grade, the development of spatial thinking as a specific competence is more clearly outlined through the introduction of components such as correlating given geographical elements and phenomena by referring to graphic and cartographic supports, making connections and associations between natural and human elements, comparing real-life geographical elements and phenomena by referring to graphic and cartographic supports and analyzing and interpreting geographical phenomena and processes based on cartographic supports. In the 8th grade, spatial skills and spatial thinking are contextualised at national level, with pupils studying the Geography of their country. The novelty lies in the introduction of ICT and GIS tools in the development of these competences. The results of this research demonstrate the effectiveness of GEP in developing Geography skills and GIS tools could be widely used in the teaching-learning-assessment process of Geography.

GEP also had a significant impact on the development of the skill of establishing correlations between elements and phenomena in reality (nature and society). The GEP factor contributed 69% to explaining the level of development of this skill. The technical characteristics of GEP had a smaller impact on the development of this competence, perhaps due to the fact that students used this application for the first time and were forced to quickly learn its menu and functionalities, as they were not used to solving learning activities during Geography lessons with GIS tools.

Google Earth Pro offers new pedagogical possibilities for teaching and learning Geography at the pre-university level with the free provision of the software by Google. Until recently, GIS software was only used in academic courses, but with the free provision of GEP, it can now be introduced as a support tool in the teaching of Geography to high school students. For Generation Z students, this is no longer such a big challenge. On the one hand, students have ICT lessons included in the compulsory school curriculum, two hours per week starting in the 5th grade (ages 10–11), so students' digital skills are progressively developed throughout middle and high school in the national education system. The free availability and capabilities of Google Earth Pro software to import thematic files from GIS increase its compatibility for use in teaching Geography in high school and connecting students with the GIS industry [82] from an early age. GEP allows students to overlay and make visible any type of map or image on the Google Earth layer [83], facilitating the association of geographically specific content. In practice, some of the obstacles of the past, such as access to GIS software and data, have been resolved or significantly reduced [84]. While these difficulties included the lack of reusable learning objects (RLOs) that are ready for use in lessons [85], this difficulty has now disappeared. In our research, we reused thematic layers found within the ESRI/ArcGIS online communities, *eduterre* website or the specialised websites of European agencies.

Among the difficulties that teachers may encounter in adopting GEP in the teaching process are those of a technical nature, access to the internet and access to computer labs. West [86] also warned that the time gap between training and teaching with GIS can lead to a loss of enthusiasm and skills. Short lesson times (50 min), which limit sustained engagement, can be another obstacle [87]. However, it is necessary to use the software for a longer period of time so that students have the opportunity to explore all the features it offers. The use of a digital tool such as Google Earth Pro requires careful supervision by the teacher. Students seated in front of the tool tend to act freely, sometimes ignoring the teacher's instructions, wasting valuable time exploring Google Street View, or searching for answers on Wikipedia or ChatGPT instead of investigating the virtual globe. This risk increases, especially if students are not accustomed to analyzing, observing, locating, and working with cartographic supports in general. However, using Google Earth Pro to teach Geography requires a bit more time for students to adapt, especially those who are stepping out of their usual learning environment. They are tasked with more than just observing—they must analyze and conduct a geographical investigation using a new digital tool. Some students feel a bit overwhelmed when facing the thematic layers of Google Earth Pro, particularly when they have to interpret historical imagery, analyze topographic profiles, and other similar tasks. Among the difficulties that teachers may encounter in adopting GEP in the teaching process are those of a technical nature, access to the internet, and access to computer labs.

For this reason, the COLABTEACH research project is interdisciplinary and Geography teachers collaborated with ICT teachers or the school's computer scientist to help students navigate the GEP menu so that they would not lose their enthusiasm and improve their skills. For the same reason, students worked in teams during Geography lessons.

## Conclusions

Statistical tests comparing proportions and averages showed that the experimental group consisting of 9th graders achieved better results in the summative test, both in terms of the overall average of the sample and in terms of maximum and minimum values, compared to the control group. In the 10th grade, the minimum score of the experimental group (5.10) is higher than the score of the control group (3.80), which indicates that it has a 100% pass rate on the summative test. Significant differences were also found in the four performance categories: in the 9th grade, considerable differences were noted in favor of the experimental group, which recorded a much higher frequency of students with high grades (16.7%), a lower frequency of low grades (29.2%) and those below 5 (16.7%).

Factor analysis validated the hypothesis that students' results on the summative test are dependent on the use of Google Earth Pro in the teaching and learning of Geography. GEP becomes a particularly useful digital tool in teaching Geography, capable of helping students to successfully excel in tests.

The study highlighted the impact that Google Earth Pro had on the development of three specific Geography abilities: arguing an explanatory approach, spatial skills and establishing correlations between elements and phenomena in the real world (nature and society). Google Earth Pro was significant in explaining 74% of the final value of the skill 'arguing an explanatory approach'. Students considered that the application provided them with sufficient visual (geovisualization) and spatial (geolocation and spatial orientation) data to improve their argumentation skills.

Google Earth Pro also had a significant impact on the development of spatial competence, with 84% of the value of this competence being explained by this tool, which acted as a pivotal factor attributed to its benefits related to geovisualization, geospatial data analysis, spatial orientation and applicability in everyday life, not only in school. In contrast, the technical features (the menu and its functions) contributed 90% to the development of spatial competence. The impact being very significant, as it is a very effective tool.

GEP contributed to the development of a particular competence—establishing correlations between elements and phenomena in the real world (nature and society). The GEP element contributed 69% to explaining the level of its development.

The results of this research challenge the opinions that there are no significant differences between students who learn using GIS and those who do not [55]. The results of this study support the effectiveness of using GIS in secondary education [63–65]. In spite of GEP having some limitations, it is a GIS tool that can currently be used successfully in teaching Geography in secondary education.

The benefits of Google Earth Pro for learning Geography and developing fundamental skills, as highlighted by the results of this research carried out with a target group of lower secondary school students (aged 14–16), introduces new perspectives on the need to introduce GIS tools into Geography teaching in secondary education at an earlier age, given that today's students are capable of meeting this challenge.

## CRediT authorship contribution statement

**Marioara Pascu:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Pascu, Marioara reports financial support was provided by University of Mons. Pascu, Marioara reports a relationship with University of Mons that includes: funding grants. it is not the case If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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