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Learning and health analytics of different active teaching methodologies

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Abstract

This study compared conventional and active teaching methodologies (videos and comics) on knowledge acquisition among 73 Brazilian 7th-grade students. Active learning methods yielded substantially higher grade improvements (>100%) than conventional instruction (10%). We integrated learning analytics with a non-invasive health biomarker, salivary Immunoglobulin A (IgA), to assess physiological responses. A significant decrease in IgA levels was observed post-intervention, suggesting that high cognitive engagement may induce transient physiological stress. This finding highlights a critical dichotomy between academic performance and student well-being. Furthermore, a predictive model robustly associated IgA dynamics with multidimensional factors, including dietary habits, parental support, and a history of school dropout. This study pioneers a 'Learning & Health Analytics' approach, demonstrating that while active learning is highly effective, a holistic assessment including physiological well-being is crucial for sustainable educational success. This framework provides educators with actionable, data-driven insights to identify and mitigate student barriers, thereby fostering a healthier, more effective learning environment.
KEYWORDS: teaching-learning; IgA; active methodologies; learning analytics.

Highlights

1. Active Learning Paradigm Shift

Active learning methodologies (videos and comic books) demonstrate transformative efficacy, achieving 107–119% improvement in knowledge acquisition compared to 10% in conventional instruction, establishing a quantifiable benchmark for pedagogical innovation in elementary science education.

2. Learning & Health Analytics Integration

First integrated framework linking educational performance metrics with non-invasive salivary biomarkers (IgA), revealing that cognitive engagement induces transient physiological stress. This critical insight redefines educational success beyond academic grades to encompass holistic student well-being.

3. Multidimensional Predictive Model

Development of a robust predictive model associating salivary IgA dynamics with socioeconomic, nutritional, and psychoeducational variables, providing educators with granular, actionable intelligence to identify and mitigate barriers to student success in resource-limited settings.

4. Adaptive Educational Ecosystems Blueprint

Establishes a foundational framework for next-generation adaptive learning systems that dynamically personalize pedagogical approaches based on real-time cognitive and physiological state monitoring, fostering resilient, healthy learners equipped for 21st-century complexity.

BACKGROUND

The classroom is a dynamic environment in which teachers guide students through the complex interplay of personal experiences and formal knowledge to construct new meanings[1]. Globalization and the integration of technologies into education have led to changes in teaching and learning methods, requiring teachers to rethink their pedagogical practice and to work in non-traditional teaching spaces [2]. The profile of the twenty-first-century teacher requires a professional identity receptive to change, with dynamic, reflective, and interdisciplinary teaching[3]. Contextualized and thought-provoking instruction can be a precursor to student interest, since scientific and technological knowledge drives economic and social development, making science education for citizenship a means of transforming people and nations [4].

According to the National Common Curriculum Base (BNCC)[5], skill EF07CI10 should be developed in the 7th year of Elementary School, addressing the importance of vaccination for public health. The document also guides the development of skills, such as recognizing innate immune defense mechanisms and the functioning of the immune system in immunity acquired through vaccination.

Active Teaching Methodologies

The definition of learning objectives structures the educational process, enabling changes in thoughts, actions, and behaviors, and is directly related to the selection of content, procedures, activities, and resources [6]. Although expository lectures, a form of passive learning, remain widely used, active learning strategies enable deeper engagement with content and promote discussion and critical thinking [7].

Active Methodology (AM) can be defined as a set of methodologies aimed at critically and problematizing the education of reality, with a focus on the student as the protagonist of their learning [8]. Despite growing political and research interest in active learning, its definitions remain broad, and the methods used to measure its outcomes, although positive, pose problems because they rely primarily on student self-report data [9]. A meta-analysis of 225 studies found that average exam scores improved by approximately 6% in active-learning sections, and that students in classes with traditional lectures were 1.5 times more likely to fail [10]. Active methodologies, popularized in the early 1990s, are based on the premise that the student is at the center of their learning process, with the teacher acting as a facilitator[11,12].

The present study investigated the effects of traditional passive teaching and the use of comic books [13] and videos [14], with the teacher as the mediator, in science for seventh-grade elementary school students.

"Learning Analytics" and the use of "Machine Learning" in education

Digital technologies increasingly mediate education, and in this context, "Learning Analytics" assumes importance for personalizing learning by enabling the collection and analysis of data on student performance [15]. This educational tool, grounded in learning, computer science, and data science, aims to understand and improve the learning process and its context [16]. The use of video-based classes and other strategies, such as comic books, is an important component of flipped classroom approaches, which, when combined with diverse assessment and feedback strategies enhanced by Learning Analytics and machine learning tools, appear to be the future of education [17].

The use of traditional tools in data science and statistics limits the holistic and integrated assessment of data. However, integrated analysis using exploratory and unsupervised machine learning tools can yield robust and valuable insights for the teaching and learning process [18–20]. Researchers using the same database can estimate different models and obtain distinct predictions for the phenomenon under study [21]. Traditional methods for predicting academic risk have many limitations, while Learning Analytics offers advantages. However, predictive models of academic performance must include socioeconomic, health, and psychoeducational

variables to improve understanding of the phenomenon, especially in Latin America, where research on predictive models remains incipient [22].

A brief review of salivary markers and IgA

Early detection is a key factor in patient outcomes. Saliva is a noninvasive and valuable source of information, containing many of the biomarkers found in blood [23]. Saliva is considered an alternative, universal diagnostic fluid that can be collected non-invasively [24]. Comprehensive saliva analysis, or "salivaomics", has played an increasingly important role in the discovery of disease biomarkers[25]. With advances in genomic technologies and "omics" research, saliva collection has become more common, and recent proteomic platforms have analyzed the human salivary proteome, characterizing approximately 3,000 differentially expressed proteins and peptides [26].

Various diseases have been diagnosed, treated, and monitored using this bodily fluid, including different types of cancer[25,27], periodontal diseases[28], oxidative stress[29], sleep apnea[30], Diabetes Mellitus[31], psychological disorders[32], metabolic diseases[33], autoimmune diseases[34], and neurodegenerative diseases[35]. Among salivary biomarkers, Immunoglobulin A (IgA) has gained prominence in recent years[36]. IgA is the most abundant immunoglobulin in mucosal tissues, and the second most abundant immunoglobulin isotype in circulation, with IgA1 and IgA2 subclasses[37].

IgA plays a specialized role in mucosal immunity, tolerance development, and protection against infections, being the primary immunoglobulin in the respiratory and gastrointestinal tracts [38] and in human milk [39]. IgA is produced in large quantities at mucosal surfaces by IgA+ plasma cells, thereby protecting the host from pathogens [40]. Psychological stress has been negatively associated with secretory immunity, specifically IgA [41], whose levels can be modulated by factors such as hygiene, illness, nutritional status, and exercise, and can also be drastically reduced by social stress, making IgA a useful marker of well-being [42]. Cortisol, α-amylase, and IgA are indicated as the main salivary markers of stress[43].

In the present study, salivary IgA concentration was evaluated in a sample of 15 students, five from each of the three classes investigated, under pre- and post-teaching method conditions. The objective of this study was to evaluate knowledge about immunology, the socioeconomic and health profile of elementary school students (7th grade) from a public school in the state of Goiás, after the use of three different teaching methodologies.

METHODS

Participants

To conduct the research, three 7th-grade classes were selected: 7ºA (morning session) and 7ºB and 7ºC (afternoon sessions). The justification for choosing this specific series is that the content and skills for teaching Immunology are listed in the National Common Curriculum Base (BNCC) and in the Curricular Document of the State of Goiás (DC-GO) for this teaching phase.

A total of 73 students participated in the study, distributed as follows: 7ºA (n=26), 7ºB (n=24), and 7ºC (n=23), with 32 girls and 41 boys, all aged 12-14 years (12 n=58, 13 n=10, and 14 n=5).

Table 1. Subject characteristics (n = 59).

	Norm	**Position**			**Dispersion**			**Shape**	
		Me	Med	Moda	SD	SE	Var	Kur	Ske
Age (years)	<0.001	12.3	12.0	12.0	0.58	0.07	0.34	3.05	2.04
Body mass (Kg)	<0.001	56.4	52.0	38.0	17.15	2.23	294.3	2.48	1.56
Height (m)	0.191*	1.6	1.6	1.6	0.07	0.01	<0.01	-0.69	-0.18
BMI (Kg/m²)	<0.001	22.0	19.9	Am	5.96	0.77	35.5	2.02	1.53

* Normal Distribution; Norm = Normality (Shapiro-Wilk); Me = Mean; Med = Median; SD = Standard Deviation; SE = Standard Error; Var = Variance; Kur = Kurtosis; Ske = Skewness; BMI = Body Mass Index; Am = Amodal.

Ethical Aspects

Participants and their legal guardians received all information about the objectives, procedures, and risks of the study and, only after agreeing, were invited to sign an Informed Consent Form (ICF) and an Informed Assent Form (IAF), which guaranteed their rights to privacy and the freedom to withdraw from the study at any time they deemed necessary. The study was submitted to and previously approved by the Research Ethics Committee with Human Beings of the Federal University of Mato Grosso (UFMT), Araguaia campus, under opinion number 2.230.073. This committee previously approved all procedures, which were strictly in accordance with the Declaration of Helsinki.

Study Design

This is a cross-sectional, descriptive, and observational study. The present study was conducted in a state public school in Aragarças, in the interior of the state of Goiás, a city on the border between Goiás and Mato Grosso, adjacent to the cities of Pontal do Araguaia (MT) and Barra do Graças (MT). It is the “Luiz Dias Paes Leme State School”, located on the outskirts

of the city of Aragarças, which serves students in Elementary School II, divided into morning and afternoon shifts. The school's participation in the study was requested in advance by submitting a letter to the principal.

Procedures

Socioeconomic conditions

To learn more about the socioeconomic characteristics of the population studied, we administered questionnaires based on the socioeconomic questionnaire adopted by the Ministry of Education (MEC) for the SAEB 2021 assessments. According to the National Institute of Studies and Educational Research Anísio Teixeira/INEP (Brazil, 2023), the application of questionnaires of this nature, which basically combine the parents' education level with the family's possession of goods and services, makes it possible to outline an overview of the social reality of schools based on the profile of their students, producing evidence that assists in the assessment and implementation of public education policies. Such policies should aim to address potential inequalities, as the results indicate that school performance tends to increase among students from the most economically advantaged strata of society.

Health conditions

To understand the health status of our population, we developed, together with primary health care professionals from the Family Health Unit, PSF 303 in the city of Aragarças-GO, a questionnaire with objective multiple-choice questions, containing five questions that addressed topics such as the number of meals eaten per day, cases of vomiting and diarrhea observed in the last year, number of visits to health facilities (health centers, PSFs, CAPS, hospitals, clinics) in the last year, as well as questions about the student's vaccination status. The questionnaires on students' health conditions were administered in February, along with the socioeconomic questionnaires.

Immunological Knowledge Quiz.

The questionnaires on immunological knowledge were created based on the work of [44] Botelho and Andrade (2018). They were constructed with 10 objective, multiple-choice questions covering basic immunology, including the antigen-antibody relationship, definitions of pathogens, concepts related to immunity, and the distinction between vaccines and therapeutic serum.

To administer the questionnaire, the teacher welcomed the students into the classroom as usual. After they were seated, the first instructions for completing the questionnaire were provided. First, the questionnaires were distributed, and participants were instructed to complete the name and grade fields for future verification during reapplication and subsequent data entry. After the initial instructions, students were allowed to begin answering their questions; however, no content-specific instructions were provided to assess their prior knowledge. After they began answering, a 25-minute time limit was imposed for students to complete the questionnaires. By the end of the time, all students had completed their answers, with most finishing well before the deadline. The methodological intervention was conducted in October 2023 (4th semester) to align the distribution of Immunology content with the Curricular Document of the State of Goiás (DC-GO). To this end, we used a total of five 50-minute classes (Supplementary Table 4). In class 7ºA, theoretical classes and traditional consolidation exercises (control) were applied; in class 7ºB, in addition to the theoretical classes, videos from the Ozzy and Drix series, suggested by [45] Dias et al., (2023), were also used; finally, in class 7ºC, in addition to the same theoretical classes mentioned above, specific chapters of comic books were also used.

The control class, 7th A, consisted of theoretical lectures delivered via slides and projectors, totaling three 50-minute sessions. Afterwards, the students performed consolidation exercises with free-response and objective questions, covering the same content as in the other grades (7th B and 7ºC) and using diverse resources (videos and comic books).

In the 7th B class, lectures were delivered using slides and projectors, and students then watched 4 episodes of Ozzy and Drix (Supplementary Figure 1). This series aired between 2002 and 2004 on Cartoon Network's closed channel. It was based on the film Osmose Jones – Uma Aventura Radical pelo Corpo Humano (2001), produced by Warner Bros. [45] (Dias et al., 2023). The animated series follows police officer Ozzy (Osmose Jones), a leukocyte from Frank Detorre's body, and his partner, an anti-flu pill, Drix (Drixenol). Both are transported from Frank's body to the body of Hector Cruz, a 13-year-old boy, by a hematophagous mosquito. After reaching the teenager's body, Ozzy and Drix begin to act as "private detectives," chasing and fighting numerous pathogens that try to infect Hector's body.

In the 7th-grade class, the same theoretical classes taught in 7th-grade A and 7th-grade B were replicated, using the same teaching methods and tools. However, as a differentiating element, we included reading comic books (Supplementary Figure 2). To this end, we used

materials published by Stricto Senso, [46-48] namely The Actives, vol. 2 (2020), The Actives, vol. 3 (2022), and The Immunes, vol. 4 (2020).

This material was organized in such a way as to allow the approach of concepts and curiosities involving the theme of immunology in a playful way through the use of comic books, bringing complex concepts that are often distant from the reality of these students closer to the reality of the general population, and in this specific case, of elementary school students. In this regard, this material is an important pedagogical tool for teaching Immunology, as it facilitates the understanding of complex concepts.

The comic book chapters were printed and distributed to students at stations, each containing a different story. The students were divided into pairs, and after finishing the first comic book, they proceeded to the next station to read another. In this way, the rotation between stations continued until all pairs had read the four comic book chapters that were made available to the class.

Although, in an ideal scenario, students would read the comic books individually, we chose to pair them to mitigate the marked difficulties in reading and interpreting text observed among students. Such difficulties would make it impossible for them to understand and assimilate the content covered in the comic books. According to [49] Souza et al., (2023), functional illiteracy resulting from failures in the literacy process reveals the social inequalities observed in Brazilian society and was intensified during the COVID-19 pandemic, in which access to remote classes did not occur equally, further exacerbating the difficulties observed in the literacy process, as well as the difficulties in accessing and remaining in education.

In November 2023, after the methodological interventions were completed in the three classes, the immunological knowledge questionnaires were re-administered to the students, using the same guidelines as for the first administration. Subsequently, the questionnaires were corrected, and the number of correct answers was converted into a grade for scoring in the Science subject.

Saliva collection for IgA measurement

To include an immunological parameter in this research, saliva IgA was collected. The motivation for choosing this parameter was that it is a non-invasive, painless method, thereby making it easily accepted by students and their guardians.

In total, two collection sessions were conducted. One before the methodological intervention, carried out in September 2023, and another after the methodological intervention, carried out in December 2023. Before the first saliva collection, the students were familiarized with the procedure they would undergo. Basic concepts of saliva were examined, such as: What is it? What is it for? What is the IgA present in this fluid? To this end, a brief expository lecture was delivered, followed by an explanatory video (https://www.youtube.com/watch?v=wQXh8AdwK14).

Five students from each class were randomly selected to conduct the collections, for a total of 15 collections. The collection was carried out during each class period. Students in grade 7A participated in the morning collection period, while students in grades 7B and 7C participated in the afternoon collection period. Before the collection period, students were instructed to refrain from eating or drinking for the next 30 minutes. We then removed the selected students from the classroom to collect. After receiving appropriate instructions, the students rinsed their mouths lightly with water. Then, the students were given the Salivette devices. Each student removed the cotton from the Salivette and chewed it for approximately two minutes to saturate it with saliva. After the stipulated period, the cotton was reinserted into the Salivette device, which was then identified and refrigerated until the afternoon collection period. After the collection period in the afternoon, the Salivettes were sent to the laboratory for analysis.

IgA Measurement in Saliva

Salivary IgA levels were measured in a laboratory using the Nephelometry method. This method involves measuring turbidity to quantify the intensity of light scattered by insoluble particles in the sample [50] (Marin-Hinojosa et al., 2024).

Statistical Analysis

The generated data were subjected to analysis of variance (ANOVA), followed by Bonferroni's post hoc test, Spearman's rank correlation analysis, and other procedures described below, and were considered statistically significant at $p<0.05$.

To compare data across time and classes, because the variance of the biomarker values in this population is unknown, we use comparison tests at the 5% significance level ($p < \alpha$). To this end, the Shapiro-Wilk test was initially applied (due to $n<30$ individuals in each class) to verify the normality between the data, which could result in two possibilities:

1) If the value obtained were $p<0.05$, the “Kruskal-Wallis One-Way Analysis of Variance on Ranks” would be applied.

2) If the value obtained was $p\geq0.05$, the “Equal Variance Test (Brown-Forsythe)” would be applied, and if this test failed ($p<0.050$), it would be “Kruskal-Wallis One Way Analysis of Variance on Ranks”, but if this test passed ($p\geq0.050$), the “ANOVA” Test would be applied.

For data analysis, SigmaPlot 14.5 (Academic Perpetual License, Single User, ESD), Past 4.03 (a free statistical analysis application for Windows), and AcaStat 10.0 (Data Analysis Simplified: inexpensive, easy-to-use data analysis tools) were used. designed for Mac and Windows), in addition to the programming languages R 4.3.1 (integrated with R Studio) and Python 3.8.10 (Integrated with Spyder).

To assess the reliability of the questionnaires used, we employed Cronbach's alpha, a widely used measure of internal consistency [51] (Roco-Videla et al., 2024).

Procedure method in machine learning (Δ% IgA)

To investigate the predictive value of the percentage change in salivary Immunoglobulin A (%ΔIgA), a multifaceted analytical pipeline was implemented. This process began with rigorous data preprocessing, including the creation of additive ordinal scores and binarization-based scores from questionnaire variables, as well as the transformation of continuous IgA measures into ordinal categories. Subsequently, an exploratory analysis was conducted in two stages: the first focused on the associations between the ordinal attributes (original and synthetic) and the IgA measures using nonparametric correlations (Spearman and Kendall) and median comparison tests (Wilcoxon, Kruskal-Wallis); the second stage expanded the analysis to include original nominal attributes, investigating their association with the ordinal IgA categories using Fisher's Exact Test. This design aimed to maximize the detection of potential predictors in a limited-sample context, using methods that were robust to the data's characteristics. Pre-processing of predictor data was conducted using three distinct strategies to optimize the information contained in the questionnaire variables. First, original attributes with ordinal scale responses (e.g., meal frequency, symptom episodes, parental support, school history) were converted to ordinal numeric values, which were subsequently aggregated by summation to generate additive ordinal scores, such as the Health_General_Index_Score; in certain instances, such as for symptomatology, the values were inverted so that higher scores reflected more favorable conditions. In a second approach, indicators related to the possession of assets and infrastructure were initially binarized (0 for absence, 1 for presence) and then summed to form aggregated scores, such as the Material_Resources_Score and the Stress_Lack_Infrastructure_Score, where, for the latter, the absence of an infrastructure item

contributed positively to the stress score. Finally, intrinsically ordinal variables, such as meal_num, were derived directly from the numerical mapping of the original responses.

In parallel, the continuous outcome variables for salivary IgA (IgA_pre, IgA_pos, and the calculated Var_IgA) were transformed to accommodate nonparametric analyses and to address the small-sample distribution. Initially, these variables were standardized into Z-scores. Subsequently, the Z-scores were discretized into five ordinal categories (IgA_pre_Ord, IgA_pos_Ord, Var_IgA_Ord). For Var_IgA_Ord specifically, the category '0' was defined to represent the largest percentage increase in IgA, the category '2' to indicate stability or minimal fluctuations, and the category '4' to denote the largest percentage decrease in IgA. This categorization approach was intended to enhance the robustness of subsequent statistical analyses and facilitate the interpretation of clinically relevant changes.

Calculations

Cohen's equation [52,53] (Cohen, 1988; 1992) was used to calculate the effect size (Cohen's d):

$$d = \frac{(M1 - M2)}{\sqrt{(SD1^2 - SD2^2 \div 2)}}$$

Where M represents the means of the observations and SD their respective standard deviation.

Table 2. Values for interpreting effect size.

Effect	Small	Medium	Large
Cohen d	0.20	0.50	0.80

Source: [52,53] (Cohen, 1988; 1992).

Next, for better interpretation of the data, the percentage variation calculation was applied:

$$\Delta\% = \frac{(Final\ value - Initial\ Value)}{Initial\ Value}\ x\ 100$$

To calculate the class's performance, the following formula was used:

$$P = \frac{CA\ x\ 100}{TC}$$

P = Performance; CA = Correct answers; TC = Total Chance.

RESULTS

Table 4, which presents the frequency distribution of the sample's socioeconomic profile, indicates a balanced sex distribution. Still, age was predominant for 12 years, in skin color or race for brown and white, without special needs, living with a mother or stepmother and having siblings, with variable reading habits of the parents, but with the guardians always or almost always talking about what happens at school, encouraging them to do homework,

encouraging the student to attend school, going to parent-teacher meetings and encouraging the student to study, all of which are positive data.

Notably, 38% of the sample were unable to report their mother's education level, and 59% were unable to report their father's. Even in the 21st century, approximately 15% of the population lacks paved streets, 20% lacks treated water, 74% lacks a sewage system, 14% lacks garbage collection, and 12% lacks lighting. And that 4% do not have a refrigerator, 82% do not have a tablet, 52% do not have a computer, 5% do not have a room to sleep in, 8% do not have a television, 3% do not have a bathroom, 40% do not have a car, 4% do not have a cell phone with internet, 25% do not have a TV with internet, 10% do not have access to Wi-Fi, 44% do not have a desk to study at.

The majority of the sample (77%) takes 30 minutes or more to get to school, with most (68%) traveling on foot or by bicycle. The majority began studying between ages 4 and 5 (49%) and continued their studies in public schools for their entire lives (79%). Regarding approval, 4% have failed once, and 7% have failed two or more times. Regarding attendance, 10% have dropped out of school once, and 5% have done so two or more times. Outside of school and on school days, 49% spend less than one hour a day studying, 79% do not take courses, 88% work from home, 31% work outside the home, 62% spend more than two hours a day watching TV, the Internet, etc. and 16% still do not know what they will do when they finish elementary school, 56% will continue studying and working at the same time, 5% will only work and only 22% will continue only studying. These data reveal the sample's profile and indicate what the student profile in Brazil remains.

Supplementary Table 6, which shows the distribution of frequencies by the sample's health profile, indicates that 1% of students do not eat any meals outside of school, 11% eat only one meal, 19% eat two meals, 33% eat three meals, and 36% eat four or more meals. Of these students, 30% had at least one episode of diarrhea in the past year, and 53% had at least one episode of vomiting; however, 19% did not seek care at any health service, including primary care, specialty care, emergency care, or other services. Another concerning finding was that 27% of the sample were unaware of the location of their vaccination card.

Regarding the teaching methods studied, Figure 1 showed that class 7A, which received conventional instruction using theoretical classes and traditional consolidation exercises, showed a 10% variation in grades, which was not statistically significant ($p = 0.12$). Class 7B, in which, in addition to theoretical classes, videos from the Ozzy and Drix series were also used

(Figure 1), presented a percentage variation in grades of 107%, which was considered to have a large effect (1.84). Class 7C, in which, in addition to the same theoretical classes mentioned above, specific chapters of comic books were also used (Figure 2), presented a percentage variation in grades of 119%, which was also considered to have a large effect (1.28).

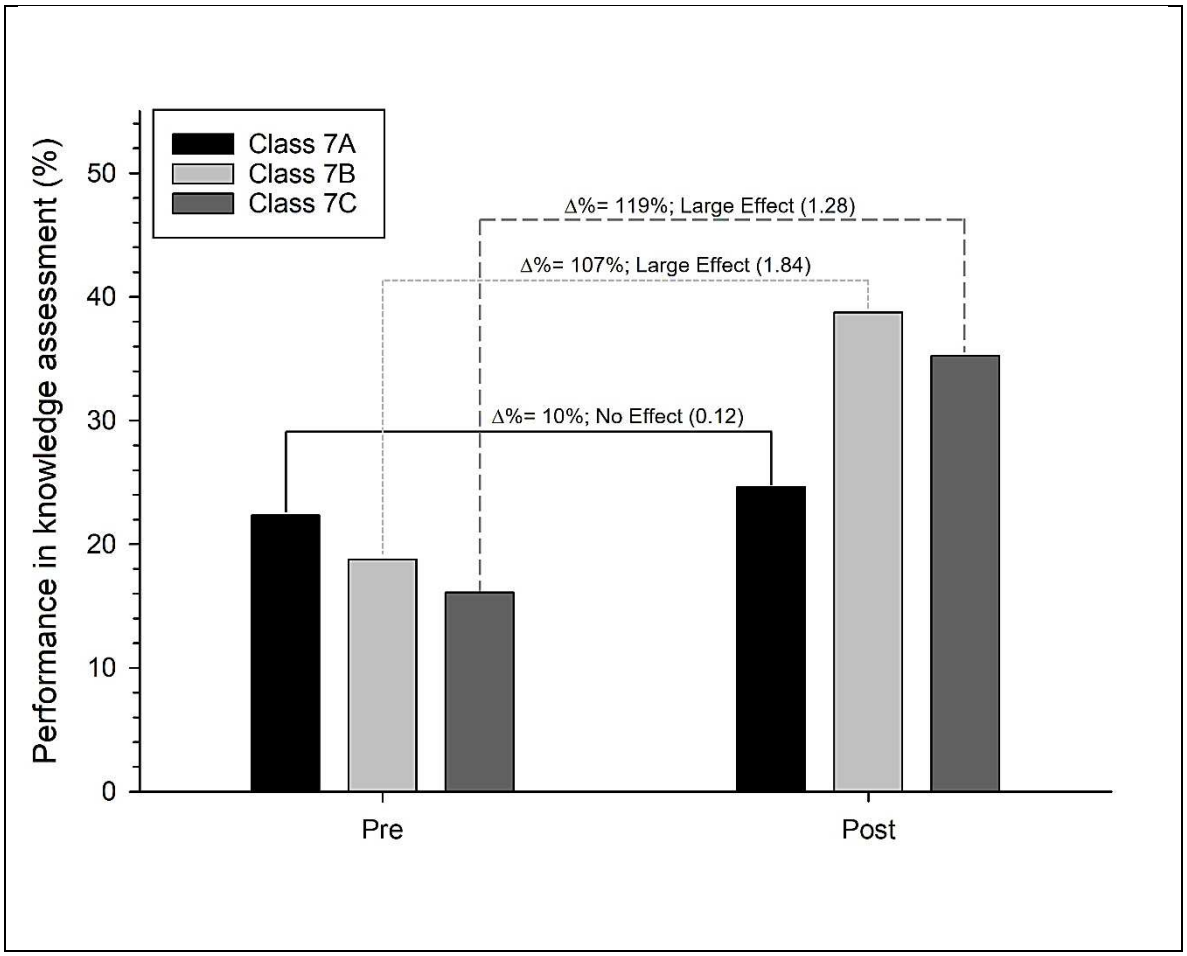


Figure 1. Percentage variation in grades and effect size of each teaching method.

The collection of salivary IgA performed before and after the intervention period indicated a behavior antagonistic to that of the knowledge generated, so that class 7A, which received conventional education, in which theoretical classes and traditional consolidation exercises were applied, presented a percentage variation of -42% in concentration, this effect being considered large (0.84). Class 7B, in which in addition to theoretical classes, videos from the Ozzy and Drix series were also used presented a percentage variation of -20% and a medium effect (0.56); and class 7C, in which in addition to the same theoretical classes previously mentioned, specific chapters of comic books were also used presented a percentage variation of -33%, with an effect also considered medium (0.70).

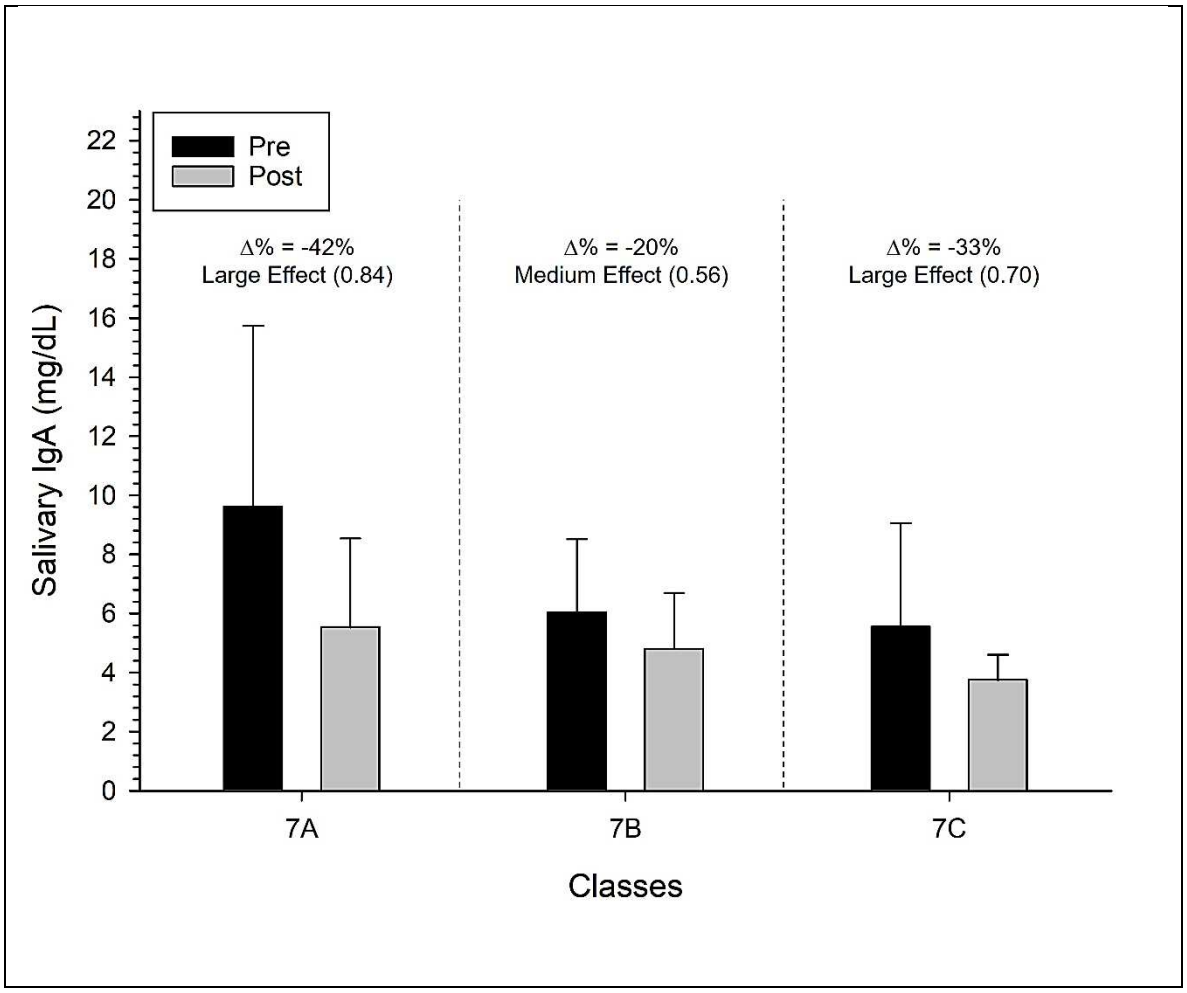
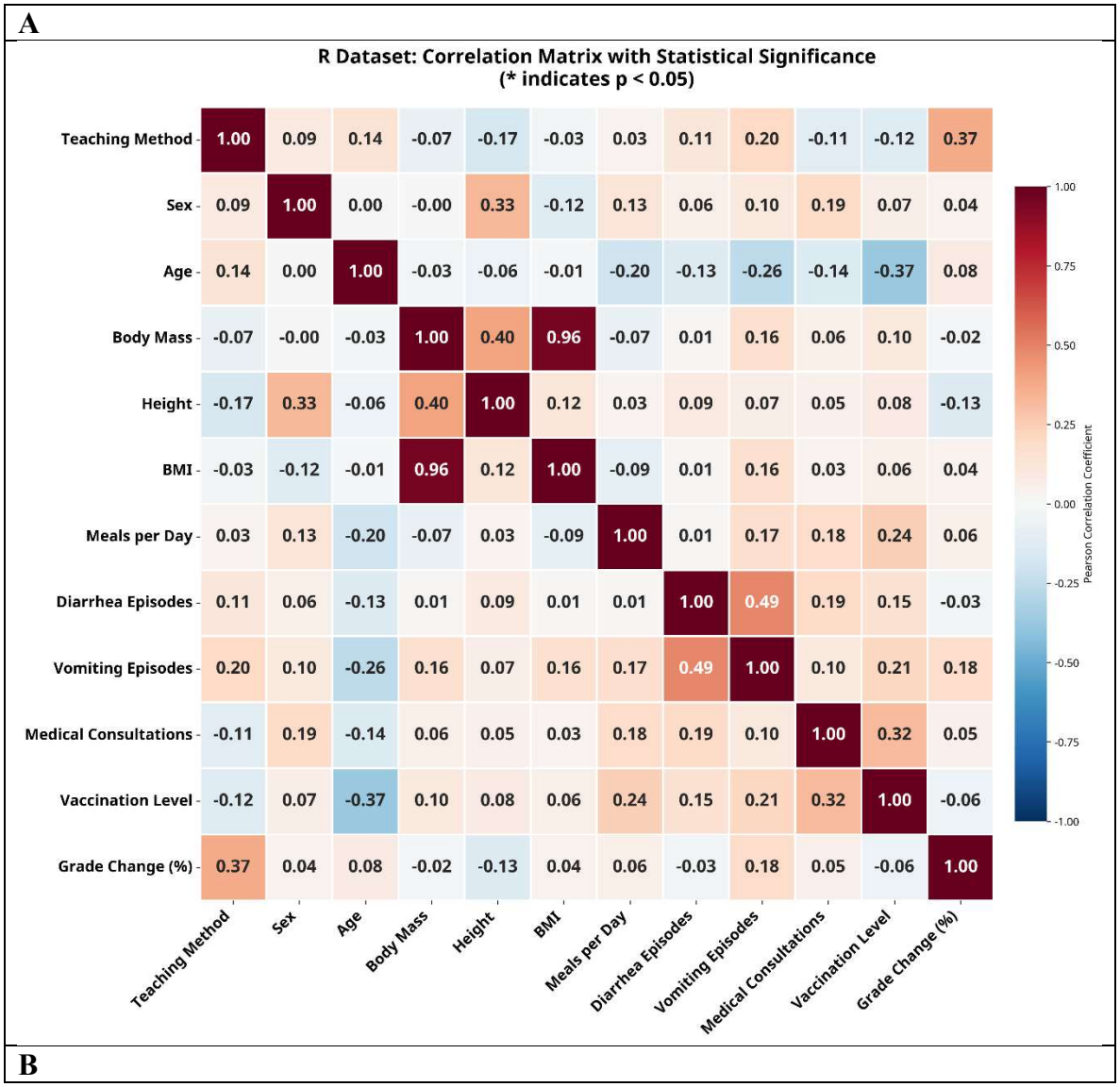


Figure 2. Percentage variation in salivary IgA concentration and the effect size of each teaching method on this variable.

Analysis of the main predictive attributes for Δthe % of Grades

In an analysis focusing on health variables, physical characteristics and teaching method, the Data Structure indicated for the teaching method (balanced distribution: 26, 24, 23 cases), Demographics: Sex: Binary (33 male, 40 female); Age: ((mostly 12 years (58 cases), some 13 (10) and 14 (5)); physical characteristics ((Body mass: 36.5-115.0 kg (mean: 56.44 kg, n=59); Height: 1.41-1.75 m (mean: 1.60 m, n=59); BMI: 15.68-42.24 (mean: 22.00, n=59); BMI categories (Normal: 25 cases (34.2%); Underweight: 21 cases (28.8%); Unknown: 14 cases (19.2% - missing data); Obese: 8 cases (11.0%); Overweight: 5 cases (6.8%)); Health and Nutrition (Meals/day: Scale 0-4 (mostly 4 meals: 26 cases, 3 meals: 24 cases); Diarrhea Episodes (Scale 0-4 (51 without episodes, 13 with 1 episode)); Vomiting Episodes (Scale 0-4 (34 without episodes, varied distribution)); Number of Consultations (Scale 0-4 (24 with 4 consultations, balanced distribution)); Vaccine (Scale 0-4 (38 with level 4, 20 with level 1). Significant Correlation Found (Teaching Method: r = 0.373* (p = 0.001)); Method 1: mean

21.15%; Method 2: mean 153.47%; Method 3: mean 166.67%; Analysis by Teaching Method Groups ((Method 1: 21.15% (n = 26) - lowest performance; Method 2: 153.47% (n = 24) - high performance; Method 3: 166.67% (n = 23) - higher performance)) (Figure 3).



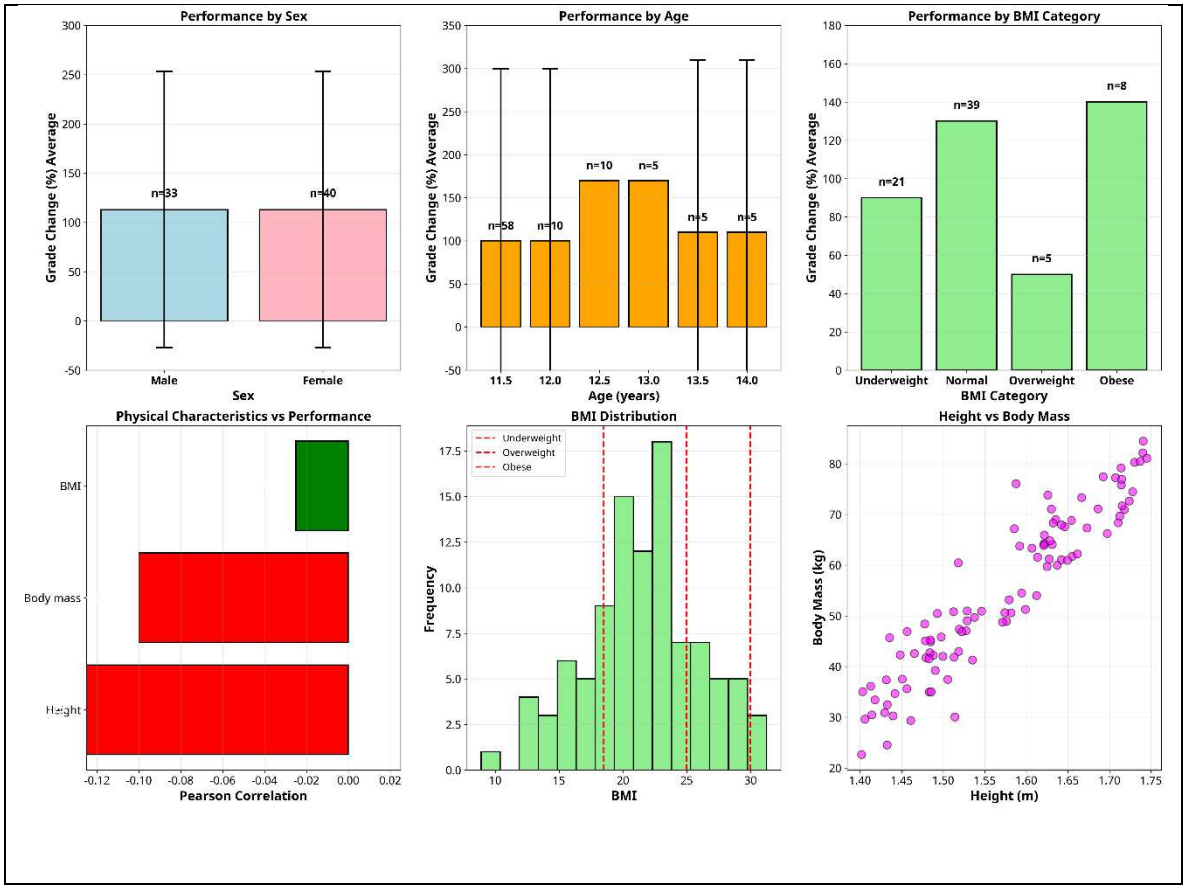
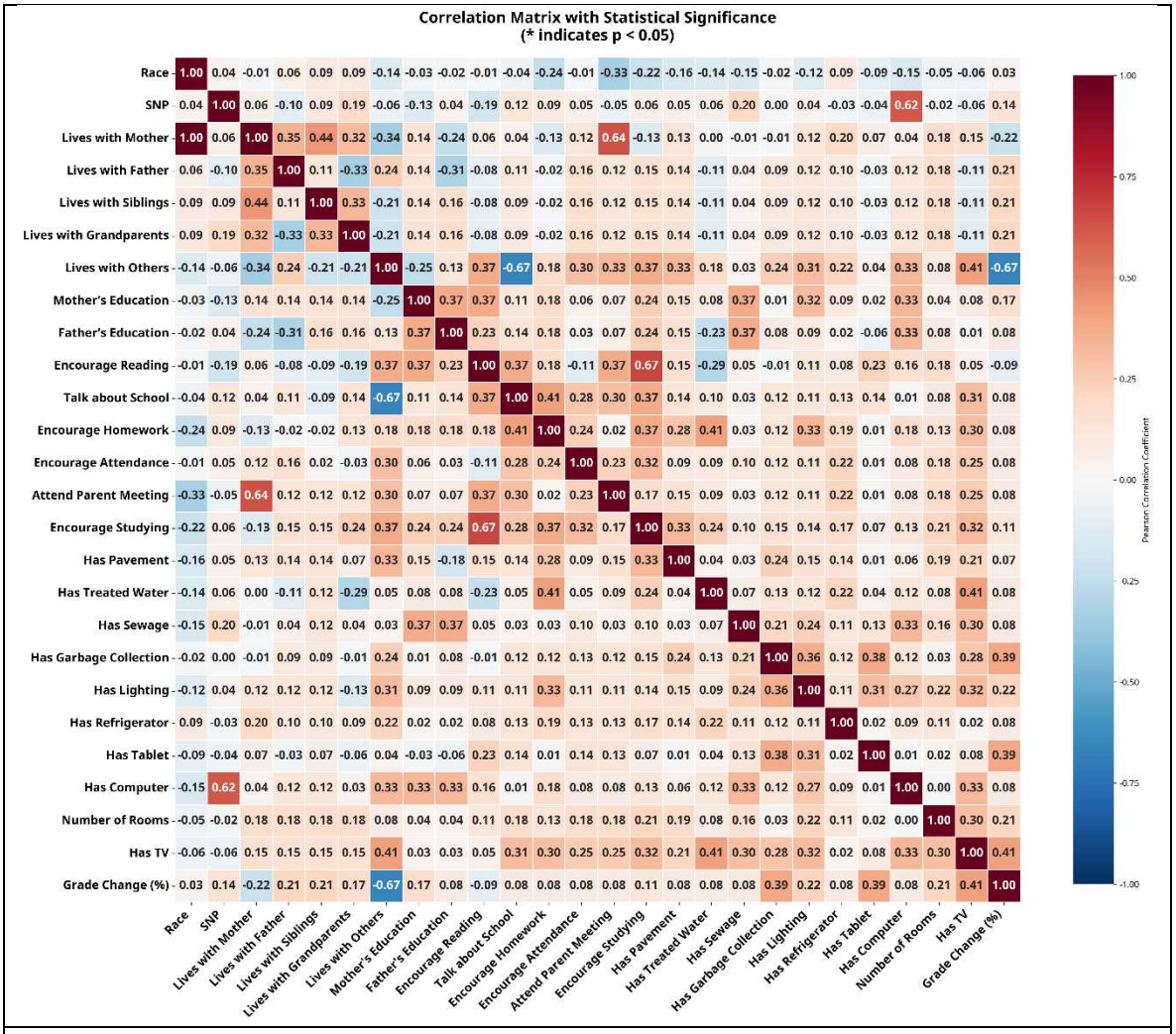


Figure 3. Correlation coefficient (Pearson) of the variation in grades with health variables (A), and mean analysis (B).

Figure 4, which was divided into 4 A and B due to the number of variables studied, presented the correlation coefficient (Pearson) of the variation in grades with the socioeconomic variables. Although there was no correlation between grade variation and socioeconomic variables, the positive correlations between having garbage collection and having lighting are striking, indicating the socioeconomic profile and how strongly this profile correlates with the incentive to attend school, as shown in Figure 4A. In relation to figure 4B, the correlation between working outside the home and dropping out of school and the type of school with dropping out of school indicate two serious social problems, the need to work to support the family at an increasingly younger age and that alternating between studying in public and private schools generates worse results than students who studied only in public schools.

A


Correlation Matrix with Statistical Significance
(* indicates p < 0.05)
Race 1.00 0.04 -0.01 0.06 0.09 0.09 -0.14 -0.03 -0.02 -0.01 -0.04 -0.24 -0.01 -0.33 -0.22 -0.16 -0.14 -0.15 -0.02 -0.12 0.09 -0.09 -0.15 -0.05 -0.06 0.03
SNP 0.04 1.00 0.06 -0.10 0.09 0.19 -0.06 -0.13 0.04 -0.19 0.12 0.09 0.05 -0.05 0.06 0.05 0.06 0.20 0.00 0.04 -0.03 -0.04 0.62 -0.02 -0.06 0.14
Lives with Mother 1.00 0.06 1.00 0.35 0.44 0.32 -0.34 0.14 -0.24 0.06 0.04 -0.13 0.12 0.64 -0.13 0.13 0.00 -0.01 -0.01 0.12 0.20 0.07 0.04 0.18 0.15 -0.22
Lives with Father 0.06 -0.10 0.35 1.00 0.11 -0.33 0.24 0.14 -0.31 -0.08 0.11 -0.02 0.16 0.12 0.15 0.14 -0.11 0.04 0.09 0.12 0.10 -0.03 0.12 0.18 -0.11 0.21
Lives with Siblings 0.09 0.09 0.44 0.11 1.00 0.33 -0.21 0.14 0.16 -0.08 0.09 -0.02 0.16 0.12 0.15 0.14 -0.11 0.04 0.09 0.12 0.10 -0.03 0.12 0.18 -0.11 0.21
Lives with Grandparents 0.09 0.19 0.32 -0.33 0.33 1.00 -0.21 0.14 0.16 -0.08 0.09 -0.02 0.16 0.12 0.15 0.14 -0.11 0.04 0.09 0.12 0.10 -0.03 0.12 0.18 -0.11 0.21
Lives with Others -0.14 -0.06 -0.34 0.24 -0.21 -0.21 1.00 -0.25 0.13 0.37 -0.67 0.18 0.30 0.33 0.37 0.33 0.18 0.03 0.24 0.31 0.22 0.04 0.33 0.08 0.41 -0.67
Mother's Education -0.03 -0.13 0.14 0.14 0.14 0.14 -0.25 1.00 0.37 0.37 0.11 0.18 0.06 0.07 0.24 0.15 0.08 0.37 0.01 0.32 0.09 0.02 0.33 0.04 0.08 0.17
Father's Education -0.02 0.04 -0.24 -0.31 0.16 0.16 0.13 0.37 1.00 0.23 0.14 0.18 0.03 0.07 0.24 0.15 -0.23 0.37 0.08 0.09 0.02 -0.06 0.33 0.08 0.01 0.08
Encourage Reading -0.01 -0.19 0.06 -0.08 -0.09 -0.19 0.37 0.37 0.23 1.00 0.37 0.18 -0.11 0.37 0.67 0.15 -0.29 0.05 -0.01 0.11 0.08 0.23 0.16 0.18 0.05 -0.09
Talk about School -0.04 0.12 0.04 0.11 -0.09 0.14 -0.67 0.11 0.14 0.37 1.00 0.41 0.28 0.30 0.37 0.14 0.10 0.03 0.12 0.11 0.13 0.14 0.01 0.08 0.31 0.08
Encourage Homework -0.24 0.09 -0.13 -0.02 -0.02 0.13 0.18 0.18 0.18 0.18 0.41 1.00 0.24 0.02 0.37 0.28 0.41 0.03 0.12 0.33 0.19 0.01 0.18 0.13 0.30 0.08
Encourage Attendance -0.01 0.05 0.12 0.16 0.02 -0.03 0.30 0.06 0.03 -0.11 0.28 0.24 1.00 0.23 0.32 0.09 0.09 0.10 0.12 0.11 0.22 0.01 0.08 0.18 0.25 0.08
Attend Parent Meeting -0.33 -0.05 0.64 0.12 0.12 0.12 0.30 0.07 0.07 0.37 0.30 0.02 0.23 1.00 0.17 0.15 0.09 0.03 0.12 0.11 0.22 0.01 0.08 0.18 0.25 0.08
Encourage Studying -0.22 0.06 -0.13 0.15 0.15 0.24 0.37 0.24 0.24 0.67 0.28 0.37 0.32 0.17 1.00 0.33 0.24 0.10 0.15 0.14 0.17 0.07 0.13 0.21 0.32 0.11
Has Pavement -0.16 0.05 0.13 0.14 0.14 0.07 0.33 0.15 -0.18 0.15 0.14 0.28 0.09 0.15 0.33 1.00 0.04 0.03 0.24 0.15 0.14 0.01 0.06 0.19 0.21 0.07
Has Treated Water -0.14 0.06 0.00 -0.11 0.12 -0.29 0.05 0.08 0.08 -0.23 0.05 0.41 0.05 0.09 0.24 0.04 1.00 0.07 0.13 0.12 0.22 0.04 0.12 0.08 0.41 0.08
Has Sewage -0.15 0.20 -0.01 0.04 0.12 0.04 0.03 0.37 0.37 0.05 0.03 0.03 0.10 0.03 0.10 0.03 0.07 1.00 0.21 0.24 0.11 0.13 0.33 0.16 0.30 0.08
Has Garbage Collection -0.02 0.00 -0.01 0.09 0.09 -0.01 0.24 0.01 0.08 -0.01 0.12 0.12 0.13 0.12 0.15 0.24 0.13 0.21 1.00 0.36 0.12 0.38 0.12 0.03 0.28 0.39
Has Lighting -0.12 0.04 0.12 0.12 0.12 -0.13 0.31 0.09 0.09 0.11 0.11 0.33 0.11 0.11 0.14 0.15 0.09 0.24 0.36 1.00 0.11 0.31 0.27 0.22 0.32 0.22
Has Refrigerator 0.09 -0.03 0.20 0.10 0.10 0.09 0.22 0.02 0.02 0.08 0.13 0.19 0.13 0.13 0.17 0.14 0.22 0.11 0.12 0.11 1.00 0.02 0.09 0.11 0.02 0.08
Has Tablet -0.09 -0.04 0.07 -0.03 0.07 -0.06 0.04 -0.03 -0.06 0.23 0.14 0.01 0.14 0.13 0.07 0.01 0.04 0.13 0.38 0.31 0.02 1.00 0.01 0.02 0.08 0.39
Has Computer -0.15 0.62 0.04 0.12 0.12 0.03 0.33 0.33 0.33 0.16 0.01 0.18 0.08 0.08 0.13 0.06 0.12 0.33 0.12 0.27 0.09 0.01 1.00 0.00 0.33 0.08
Number of Rooms -0.05 -0.02 0.18 0.18 0.18 0.18 0.08 0.04 0.04 0.11 0.18 0.13 0.18 0.18 0.21 0.19 0.08 0.16 0.03 0.22 0.11 0.02 0.00 1.00 0.30 0.21
Has TV -0.06 -0.06 0.15 0.15 0.15 0.15 0.41 0.03 0.03 0.05 0.31 0.30 0.25 0.25 0.32 0.21 0.41 0.30 0.28 0.32 0.02 0.08 0.33 0.30 1.00 0.41
Grade Change (%) 0.03 0.14 -0.22 0.21 0.21 0.17 -0.67 0.17 0.08 -0.09 0.08 0.08 0.08 0.08 0.11 0.08 0.08 0.08 0.39 0.22 0.08 0.39 0.08 0.21 0.41 1.00
Race
SNP
Lives with Mother
Lives with Father
Lives with Siblings
Lives with Grandparents
Lives with Others
Mother's Education
Father's Education
Encourage Reading
Talk about School
Encourage Homework
Encourage Attendance
Attend Parent Meeting
Encourage Studying
Has Pavement
Has Treated Water
Has Sewage
Has Garbage Collection
Has Lighting
Has Refrigerator
Has Tablet
Has Computer
Number of Rooms
Has TV
Grade Change (%)
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
Pearson Correlation Coefficient

B

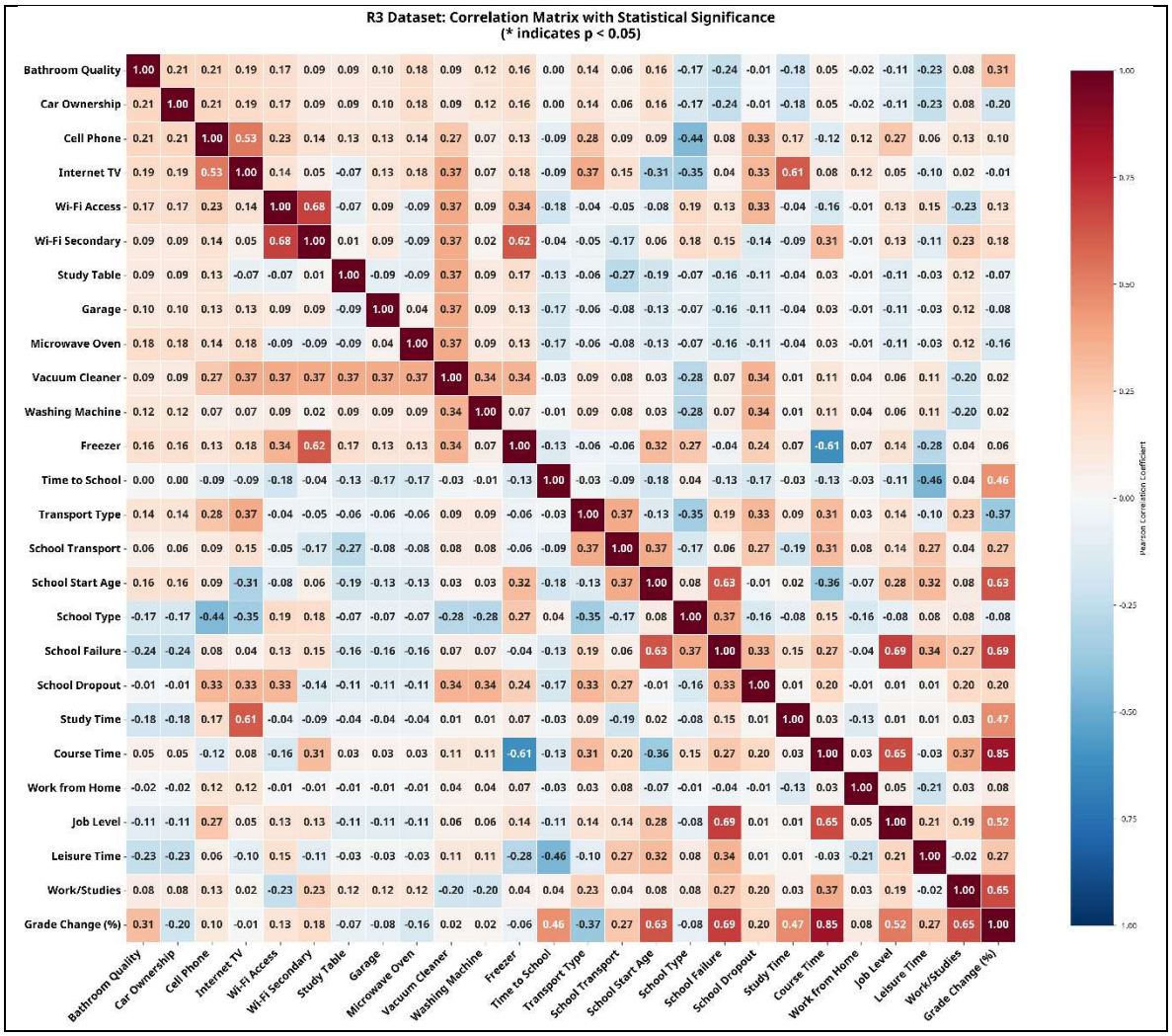
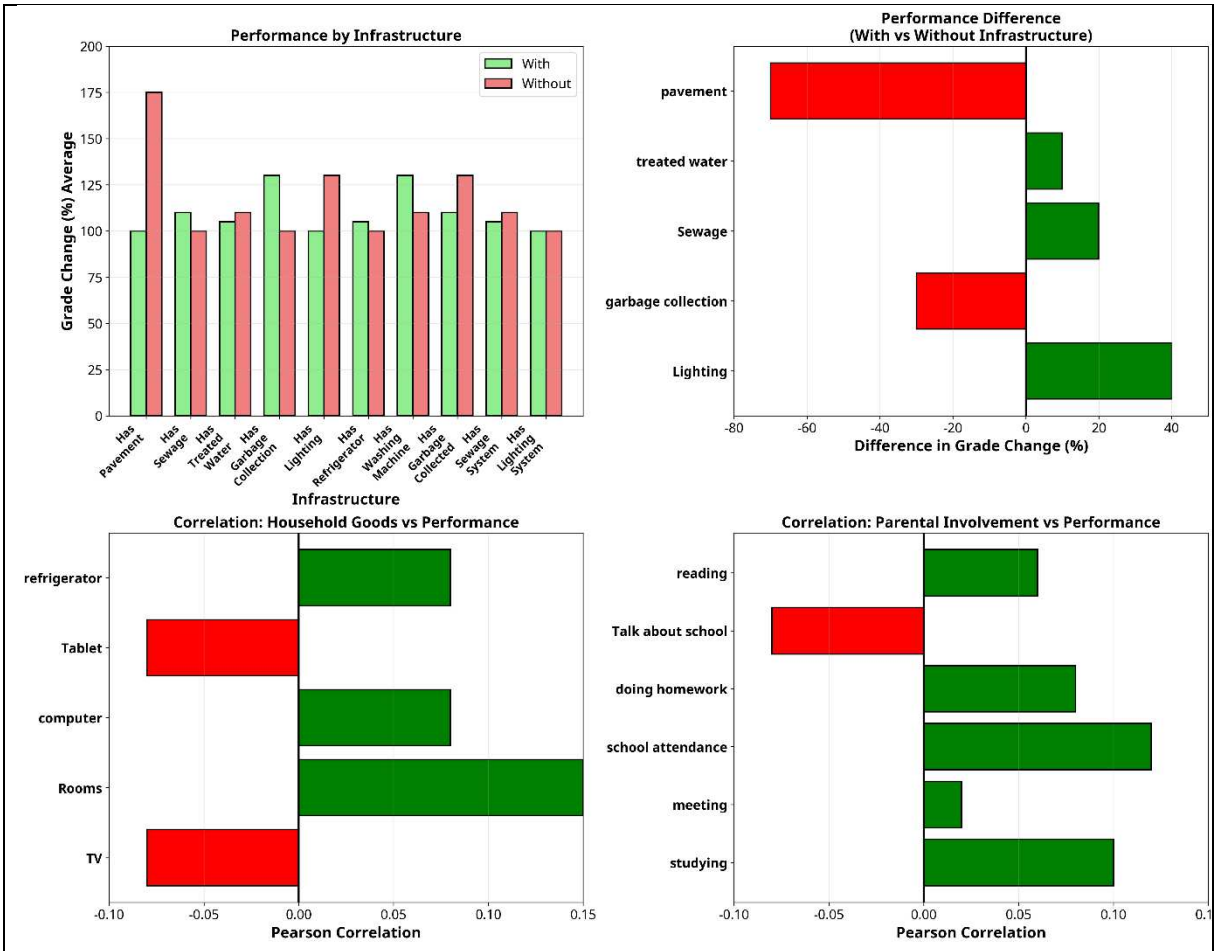


Figure 4. Correlation coefficient (Pearson) of the variation of grades with socioeconomic variables, divided into (A) and (B) due to the number of variables.

Some Intriguing highlights about <u>Δ% of Grades</u> were presented below (Figure 5).

A


Performance by Infrastructure
With
Without
Grade Change (%) Average
Has Pavement
Has Sewage
Has Treated Water
Has Garbage Collection
Has Lighting
Has Refrigerator
Has Washing Machine
Has Garbage Collected
Has Sewage System
Has Lighting System
Infrastructure
Performance Difference
(With vs Without Infrastructure)
pavement
treated water
Sewage
garbage collection
Lighting
Difference in Grade Change (%)
Correlation: Household Goods vs Performance
refrigerator
Tablet
computer
Rooms
TV
Pearson Correlation
Correlation: Parental Involvement vs Performance
reading
Talk about school
doing homework
school attendance
meeting
studying
Pearson Correlation

B

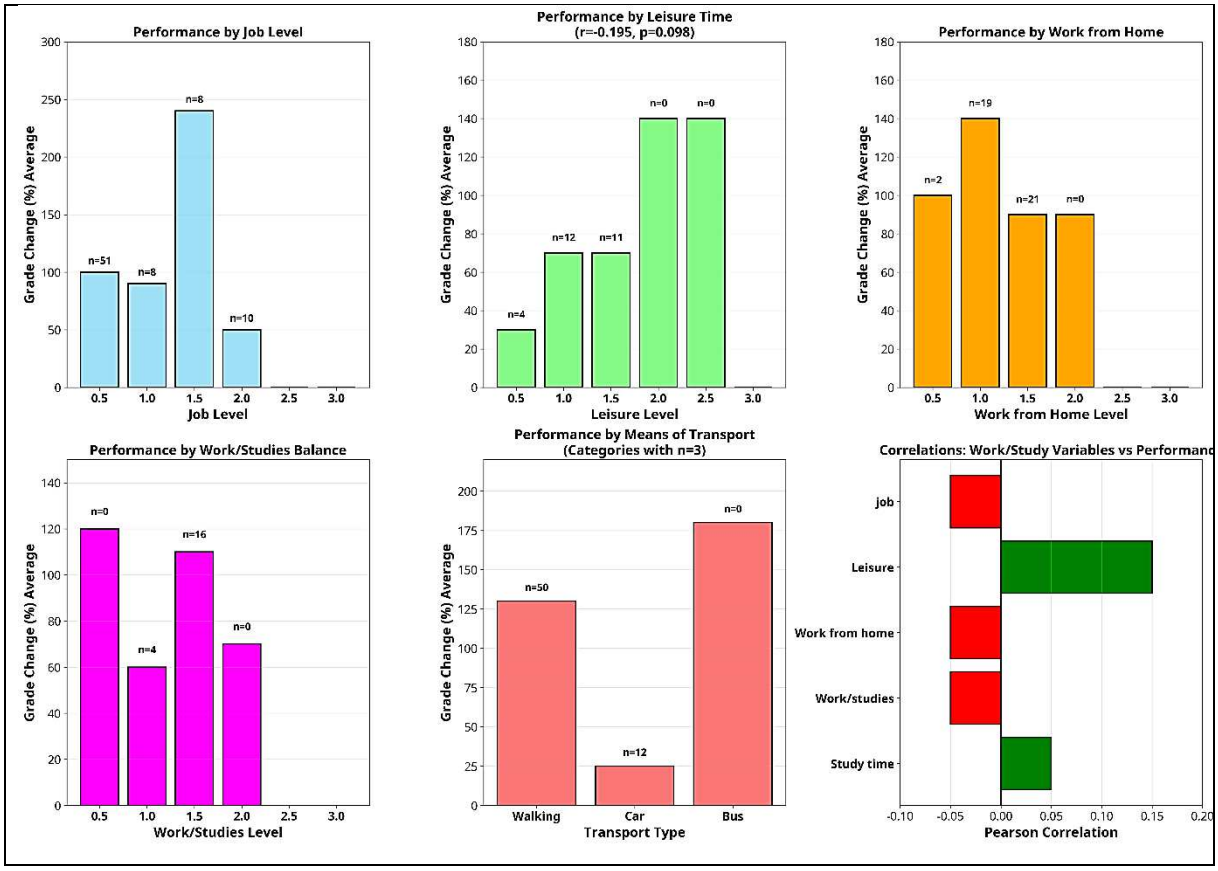


Figure 5. Intriguing highlights.

The reliability coefficients for the questionnaires used, computed using Cronbach's alpha, are shown in Table 3.

Table 3. Result of the reliability of the questionnaires applied by Cronbach's Alpha (95% confidence interval).

	Lower	Alpha	Upper
Socioeconomic aspects			
Feldt	0.41	0.58	0.72
Duhachek	0.43	0.58	0.73
Health aspects			
Feldt	0.39	0.55	0.68
Duhachek	0.40	0.55	0.69
Knowledge in immunology			
Feldt	0.50	0.63	0.75
Duhachek	0.51	0.63	0.76

According to Landis and Koch (1977), the values of (α) to verify internal consistency can be evaluated as: 0 to 0.21 - low reliability, 0.21 to 0.40 - reasonable, 0.41 to 0.60 - moderate, 0.61 to 0.80 - substantial, and 0.81 to 1.0 - almost perfect. Thus, based on the calculation of Cronbach's Alpha (α), values of 0.58 were found for the socioeconomic aspects questionnaire and 0.55 for the health aspects questionnaire, indicating moderate internal consistency for both tools. For the immunology knowledge questionnaire, the value found was 0.63, considered

substantial reliability. Based on the sample size and the number of items in the questionnaires, the result was considered satisfactory.

Analysis of the main predictive attributes for Δ% IgA

Analysis of Global IgA Variation

The analysis of salivary IgA dynamics throughout the study period revealed a significant change. The Wilcoxon Signed-Rank Test indicated a statistically significant decrease in IgA levels between the pre- and post-intervention time points (Median IgA_pre = 5.64 ml/dL vs. Median IgA_post = 4.22 ml/dL; W = 20.0, p = 0.042, N=14). This result suggests a general downward modulation of this immunoglobulin secretion in the oral mucosa of participants during the observed period.

Predictors with Convergent Evidence of Association with Salivary IgA Dynamics

The association of several predictors with IgA measurements was investigated, with consistency across analytical approaches (nonparametric correlations, Fisher's Exact Test, and median comparison tests) used to identify the most robustly associated factors.

Number of Daily Meals:

The number of daily meals was a consistently predictive factor for salivary IgA dynamics. The analysis of the ordinal numerical representation (meals_num) revealed a positive and moderate correlation with Var_IgA_Ord (Spearman $\rho = 0.50$, p=0.066; Kendall $\tau = 0.48$, p=0.057). Considering that numerically higher categories of Var_IgA_Ord denote a smaller increase or greater decrease in IgA, this correlation suggests a general trend where an increase in the number of meals could be associated with a smaller propensity for an increase in IgA, favoring stability or even a decrease.

The investigation of continuous Var_IgA through the Kruskal-Wallis test corroborated the existence of a significant overall association with meals_num ($H = 6.19$, $p = 0.045$). The medians of Var_IgA for two, three, and four or more meals were, respectively, -62.06 ml/dL, -11.63 ml/dL, and -27.16 ml/dL. This pattern in medians suggests a non-linear relationship, with the group that consumed three meals per day showing the smallest median decrease in IgA, indicating a potentially greater stabilizing effect in this group than in the others.

Analysis of the original categorical variable (cd_q1) using Fisher's Exact Test provided greater granularity to this complex relationship, indicating significant associations with IgA_pre_Ord (p=0.033), IgA_pos_Ord (p=0.059), and, crucially, with Var_IgA_Ord (p=0.024). Notably, a lower number of meals (two, cd_q1 category 'C') was associated with higher initial IgA levels and a moderately increasing IgA variation (Var_IgA_Ord category '1'). In contrast, the consumption of three meals per day (cd_q1 category 'D') tended to be associated

with lower initial IgA levels but with a subsequent stability in IgA variation (Var_IgA_Ord category '2'). This convergence of evidence, pointing to a non-monotonic relationship that depends on the number of meals, underscores the importance of dietary patterns in modulating salivary IgA.

History of School Dropout:

The history of school dropout also stood out as a factor consistently associated with IgA variation. The variable dropout_frequency_ordinal (where higher values indicate more dropout episodes, derived from question cse_q18) showed positive and moderate correlations with the IgA variation measures. The association with continuous Var_IgA (where positive values indicate an increase and negative values indicate a decrease) was Spearman $\rho = 0.53$ ($p=0.051$) and Kendall $\tau = 0.41$ ($p=0.051$), suggesting that a greater history of school dropout tends to be associated with a more positive or less negative percentage variation in IgA. Convergently, the correlation of dropout_frequency_ordinal with Var_IgA_Ord (discrete, where '0' represents the largest increase and '4' the largest decrease) was Spearman $\rho = 0.47$ ($p=0.088$) and Kendall $\tau = 0.43$ ($p=0.095$). This positive correlation indicates that higher ordinal dropout frequencies are associated with higher ordinal categories of Var_IgA_Ord, suggesting a tendency toward smaller increases, stability, or even decreases in IgA.

This relationship was corroborated by Fisher's exact test applied to the original categorical variable cse_q18 (frequency of school dropout). An association was observed between cse_q18 and Var_IgA_Ord ($p=0.078$, this p-value refers to the analysis of the ordinal numerical form ordinal dropout frequency vs Var_IgA_Ord, which mirrors the test with cse_q18), where a higher dropout frequency (category 'C' of cse_q18, corresponding to ordinal dropout frequency = 2) was exclusively associated with categories '3' and '4' of Var_IgA_Ord, indicating a decrease in IgA.

In contrast, individuals without a history of dropout (cse_q18 category 'A', ordinal_dropout_frequency = 0) predominantly presented categories '1' or '2' in Var_IgA_Ord (moderate increase or stability). The test showed no significant associations of cse_q18 (or its ordinal form) with IgA_pre_Ord ($p=0.173$) or IgA_pos_Ord ($p=0.614$). The consistency between the correlational analysis of the ordinal variable and the categorical analysis of the original variable suggests that a greater history of school dropout is associated with a lower propensity for salivary IgA levels to increase or a greater tendency for them to decrease over time.

Perceived Parental Support and Initial IgA Levels:

The Parental_Support_Score, an additive index of parental involvement, correlated positively and moderately with initial IgA levels. An association was observed with IgA_pre (Spearman ρ=0.48, p=0.071; Kendall τ=0.37, p=0.067) and, more robustly, with IgA_pre_Ord (Spearman ρ=0.59, p=0.021; Kendall τ=0.48, p=0.031). These results suggest that greater perceived parental support may be associated with higher baseline salivary IgA levels. No significant associations were detected between this score and IgA variation.

Diarrhea Symptomatology and Initial IgA Levels:

The frequency of diarrhea episodes, represented by the ordinal variable diarrhea_num, showed a moderate and significant negative correlation exclusively with the ordinal category of initial IgA (IgA_pre_Ord: Spearman ρ = -0.57, p=0.028; Kendall τ = -0.52, p=0.036). This finding suggests that a higher incidence of diarrhea may be associated with an ordinal lower initial IgA level. However, this association was not confirmed by Fisher's Exact Test when analyzing the original categorical variable (cd_q2).

Factors Modulating IgA Variation (Var_IgA_Ord) – Fisher's Exact Test:

Fisher's Exact Test, applied to the original categorical variables, revealed significant associations with Var_IgA_Ord for the following predictors:

Vomiting Frequency (cd_q3): Showed an association with Var_IgA_Ord (p=0.048), where a moderate frequency of vomiting (2-3 episodes) was concentrated in the IgA stability category, while absence or low frequency tended to be associated with an increase, suggesting a non-linear relationship.

Parental Encouragement to Do Tasks (cse_q8C): Showed an association with Var_IgA_Ord (p=0.063). The absence of encouragement was associated with a decrease in IgA, constant encouragement with stability, and occasional encouragement with a moderate increase in IgA.

Public Lighting (cse_q9E): Demonstrated association with Var_IgA_Ord (p=0.035), where the absence of lighting was related to a greater dispersion in the variation of IgA (increase or decrease), while its presence tended towards stability.

For the other scores and variables analyzed by Spearman or Kendall correlations, no other statistically significant associations ($p \geq 0.10$) were found with the IgA measurements (continuous or ordinal), and the Mann-Whitney U or Kruskal-Wallis tests for comparing the medians of Var_IgA did not reveal any other significant differences besides that already mentioned for refeicoes_num.

The results presented above were discussed cautiously, drawing on the limited literature on the relationships studied in this chapter.

DISCUSSION

The fact that guardians always or almost always talk about what happens at school, encouraging them to do their homework, encouraging the student to attend school, going to parent meetings and encouraging the student to study are presented as positive data detected in the present study, since as already observed in the literature, parents' eating habits have a strong influence on eating habits during childhood and adulthood [54] (Mahmood et al., 2021), the habit of practicing regular exercise by parents influences their children's habits in combating sedentary lifestyle and obesity [55] (Xu et al., 2015) and, even more, habits and incentives for education generate responsible individuals, with autonomy and unlimited possibilities for adult life and for promoting changes in the society in which they are inserted [56,57] (Goldstein, 2013; Goshin et al., 2021).

Notably, 38% of the sample did not know how to answer the question on the mother's education level, and 59% did not know how to answer the question on the father's education level. Even in the 21st century, approximately 15% of people lack paved streets, 20% lack treated water, 74% lack a sewage system, 14% lack garbage collection, and 12% lack lighting. And 4% do not have a refrigerator, 82% do not have a tablet, 52% do not have a computer, 5% do not have a room to sleep in, 8% do not have a television, 3% do not have a bathroom, 40% do not have a car, 4% do not have a cell phone with internet, 25% do not have a TV with internet, 10% do not have access to Wi-Fi, 44% do not have a desk to study at. The lack of training, and even more so the lack of conversations about its necessity and importance, represents a major social problem for developing countries [58] (Brito et al., 2021). This, combined with the lack of adequate sanitary conditions, knowledge about hygiene, rights and duties in public health, and guaranteed access to education and health, still represent problems in many countries around the world [59,60] (Huttly, 1990; Zemer et al., 2023), facts that were highlighted during the COVID-19 pandemic [61] (Bilavych et al., 2021). In the present study, most of the sample (77%) takes up to 30 minutes to get to school, the majority (68%) on foot or by bicycle, which is positive data, since the mobility of children when traveling to school can represent a negative factor in school attendance and in the teaching-learning process [62] (Miiler et al., 2018). Most of them began studying between the ages of 4 and 5 (49%). Regarding attendance, 10% have already dropped out of school once, and 5% have done so two or more times. This is concerning, as attendance at high-quality preschool and children's age have a

significant influence on student performance, as shown in Provinha Brasil [63](Campos et al., 2011).

Research indicates that more than 16 million people in Brazil are illiterate, and the International Student Assessment Program reports that the quality of Brazilian education remains a major concern [64] (Santos et al., 2017). In the present study, outside of school and on school days, 49% spend less than one hour a day studying, 79% do not take courses, 88% work at home, 31% work outside the home, 62% spend more than two hours a day watching TV, the Internet, etc. and 16% still do not know what they will do when they finish elementary school, 56% will continue studying and working at the same time, 5% will only work and only 22% will continue only studying. Santos and collaborators also found that, in a municipality in the central-west region, close to the region of the present study, extracurricular study and Internet access were essential factors in students' performance. These issues, combined with the need to work to supplement family income, can limit the trajectories of children and adolescents [65] (Abramo et al., 2020).

Brazilian society is shaped by economic, social, and cultural factors that can influence learning in schools. Malnourished children or those with nutritional deficiencies have difficulty assimilating food, and hunger hinders their ability to concentrate, compromising their academic performance [66] (Frota et al., 2009). Currently, 1% of students do not eat any meals outside of school, 11% eat only one meal, 19% eat two meals, 33% eat three meals, and 36% eat four or more meals. Of these students, 30% had at least one episode of diarrhea in the past year, and 53% had at least one episode of vomiting; however, 19% did not seek care in any health service, whether primary care, specialty, emergency, or other. Another concerning finding was that 27% of the sample were unaware of the location of their vaccination card. In relation to the teaching-learning process, expository classes, a form of passive learning, still represent the most widely used teaching method. However, active learning strategies enable students and teachers to engage more deeply with the subject, fostering discussion, critical thinking, and advanced critical reasoning skills [7] (Torralba & Doo, 2020). Digital technologies increasingly mediate education in the 21st century. In this context, “Learning Analytics” assumes particular importance for the personalization of learning. The set of techniques and processes that enable the collection, processing, and analysis of data on student performance in their learning activities, with the aim of better understanding their behaviors, preferences, and difficulties, is defined as Learning Analytics. To this end, key factors for this practice include assessment, use of whiteboards, social learning networks, intelligent tutoring, monitoring, feedback, and

support [15] (Gonzales & Chiappe, 2024). In the present study, the class that received conventional teaching showed a 10% variation in grades, which was considered not statistically significant ($p = 0.12$). The class that received videos in addition to theoretical classes showed a 107% change in grade percentage, which was considered a large effect (1.84). The class that received specific chapters of comic books in addition to the aforementioned theoretical classes showed a 119% change in grade, which was also considered a large effect (1.28). The use of videos and comic books as a complementary strategy to the traditional passive teaching process had already shown positive results from elementary school [67,68] (Trevisan et al., 2020; Júnior & Soares, 2023) to graduate school [69] (Rosado et al., 1998), corroborating the findings, as there was a significant correlation between grades and active teaching methods (0.4 ($p = 0.0011552$).

Regarding salivary IgA concentration, the observed reduction across the three groups appears to be multifactorial, as psychological stress has been negatively associated with secretory immunity, specifically IgA [41] (Engeland et al., 2016). This immunoglobulin, which plays an important role in immunity, may have its values modulated not only by issues involving poor hygiene, illness, nutritional status or exercise, but its concentrations may also be drastically reduced by social stress, being an extremely useful marker for measuring well-being [42] (Guhad & Hau, 1996), indicating cortisol, α-amylase and immunoglobulin A (IgA) as the main salivary markers of stress [43] (Obayashi, 2013). There was also a positive correlation between episodes of diarrhea and vomiting, 0.5 ($p = 0.000009$), a positive correlation between the number of meals per day and the number of vaccines taken, 0.5 ($p = 0.043$), and an inverse correlation between the same number of vaccines received and age, -0.4 ($p = 0.0012819$). These data seem to indicate a correlation between episodes of diarrhea and vomiting as compatible with gastroenteritis, which added to the percentages of lack of treated water (20%), lack of sewage collection and treatment (74%) and lack of garbage collection (14%), in addition to the 19% who never went to health services and the lack of information about hygiene and health care, indicate a public health problem and a fundamental role of the science teacher in acquiring knowledge about health care. The positive correlations between having garbage collection and having lighting 0.7 ($p = 0.000000000006$) indicating the socioeconomic profile and how much this profile correlates with the incentive to attend school 0.5 ($p = 0.000001$), added to the correlation between working outside and dropping out of school 0.5 ($p = 0.0000032216$) and the type of school with dropping out of school 0.4 ($p = 0.002$) indicate serious social problems that require further studies and broad discussions for

their analysis [58, 59, 60, 61, 65, 66] (Huttly, 1990; Frota et al., 2009; Abramo et al., 2020; Brito et al., 2021; Bilavych et al., 2021; Zemer et al., 2023).

Conclusion

This study identified that in the sample studied, 38% do not know their mother's level of education and 59% do not know their father's level of education; 15% do not have pavement on their streets, 20% do not have treated water, 74% do not have a sewage system, 14% do not have garbage collection and 12% do not have lighting; 77% take up to 30 minutes to get to school, most of them (68%) on foot or by bicycle; 49% started studying between four and five years of age. Outside of school and on school days, 49% spend less than one hour a day studying; 79% do not take courses; 88% work at home; 31% work outside the home; 62% spend more than two hours a day watching TV, the Internet, etc.; 16% still do not know what they will do after finishing elementary school; 56% will continue studying and working at the same time; 5% will only work; and only 22% will continue studying only. Although 1% of students do not eat any meals outside of school, 11% eat only one meal, 19% two meals, 33% three meals, and 36% four or more meals. Of these students, 30% had at least one episode of diarrhea in the last year; 53% had at least one episode of vomiting; yet 19% had never been to a health service, whether primary care, specialty, emergency, or other. Another concerning finding was that 27% of the sample were unaware of their vaccination card.

In relation to the teaching-learning process, the class that received conventional teaching showed a percentage variation in grades of only 10%, which was considered to have no effect (0.12). The class that received videos in addition to theoretical classes showed a 107% change in grades, which was considered a large effect (1.84). The class, which, in addition to the aforementioned theoretical classes, used specific chapters of comic books, showed a percentage change in grades of 119%, with an effect considered large (1.28).

CONCLUSION

This study establishes a new paradigm by integrating learning analytics with non-invasive health biomarkers, demonstrating that active learning methodologies yield transformative improvements in knowledge acquisition (>100% increase) while revealing a critical dichotomy: the observed decrease in salivary IgA suggests that cognitive engagement may induce transient physiological stress, highlighting that academic performance alone cannot measure educational success. By developing a predictive model linking salivary IgA dynamics to multidimensional variables—nutritional habits, parental support, and school dropout history—we provide educators and policymakers with actionable insights into student barriers and facilitators. Future research must pursue longitudinal biomarker tracking, expanded stress

and cognitive indicators, and real-time adaptive educational ecosystems that personalize both content and pedagogy, ultimately fostering resilient, healthy, and engaged learners prepared for the 21st century.

Data availability
The main results have been included in the manuscript. Supplementary data can be accessed via the link (https://doi.org/10.6084/m9.figshare.31338988). For further information, please contact the corresponding author by email.

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Author contributions
P.F.M., L.C.O.G., and A.M.M.N. conceived of and designed the study. P.F.M., L.C.O.G., R.S.S., L.F.L.N., and A.M.M.N. collected the data. P.F.M., L.C.O.G., T.P.LM., R.P.M.S, J.RM., M.V.A.V., A.S.G, C.M.B.A., N.R.D.M.M., and A.M.M.N. analyzed the data and wrote the manuscript. All authors read and provided critical feedback on the manuscript before approval.

Competing interests
The authors declare no competing interests.

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