Analysis of eye tracking in inclusive mathematics video lessons in Brasilian high school

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Abstract

Large-scale assessments indicate that 68% of the Brasilians evaluated, with and without disabilities, who are at the end of basic education, have a mathematics performance below the minimum level necessary to exercise citizenship. Studies indicate that visually enriched teaching strategies are more effective than the traditional model, however, they still lack metrics to evaluate visual materials. Thus, the objective of this study was to verify the feasibility of eye tracking as an auxiliary measure in the evaluation of inclusive teaching materials in the area of mathematics. Specifically, the concepts of multiplication, greatest common divisor and distribution were covered in the inclusive video lessons. To this end, we adopted the methodology of an exploratory research, having the teaching procedure evaluated using multiple baseline experimental design between mathematical concepts. The research involved the participation of 11 people with varying biopsychosocial conditions. As main results, we obtained that eye tracking provides sufficient data to assist in the evaluation of complex teaching material, managing, together with other measures, to produce a detailed report on the individual, scoring their change in behavior and detailing the barriers faced by him during the intervention. So, gaze measurements can support decision-making about educational planning.

Keywords: eye tracking, special education, high school, mathematics.

1. Introduction

The Program for International Student Assessment (Pisa) is an international level exam that seeks to verify the knowledge and skills in reading, mathematics and science of students who are close to completing the mandatory and basic stage of local education, that is, around 15 years old (Brasil, 2020). In the 2018 program, Pisa had around 79 participating countries and more than 600 thousand students, of which 10,691 are Brasilian (Brasil, 2020). Pisa's base parameter is the ideas of literacy, defining it as the citizen's ability to identify and operate knowledge within contextualized situations (Brasil, 2020).

The program establishes an evaluation system based on seven levels (from 0 to six), with level 2 as the minimum for full exercise of citizenship. However, the 2018 results revealed low performance by Brasilian students in the exam. The report shows that 68.1% of Brasilian students are below expectations, not having the basics of what is necessary to deal with daily informal mathematics (Brasil, 2020). In this way, Brasil is placed in one of the last positions in the ranking, thus highlighting the challenges in Brasilian basic mathematics education, which requires educational strategies that guarantee the quality of teaching in the area.

It should be noted that the report does not mention the special and inclusive education group, taking us to the Carlos Chagas Filho Foundation Bulletin (2021) which highlighted the challenges related to learning for the target audience of special education during the pandemic period, generating reflections on current audience data.

One way to understand the situation in a more specific way is through the analysis of the educational trajectories of specific students. In this case, the educational trajectory analysis carried out by Moura *et al.* (2023) with two young people with intellectual disability (ID) identified pedagogical and social performance below expectations for the school year in which they were enrolled, mainly in relation to reading, writing and mathematics. It is worth stating that the students were 19 and 20 years old and both were enrolled in the second year of high school.

In addition, the study by Casagrande, Benitez, Zutião, Ribeiro, Domeniconi & Gràcia (in press) with four young people with ID and/or autism replicated the concern of Moura *et al.* (2023) in relation to the high intensity of support in the area of lifelong learning for young people enrolled in state schools in the metropolitan region of São Paulo, especially one of them who was 19 years old and enrolled in the sixth year of elementary school. In a complementary way, data from Freitas and Galvani (2021) identified and reflected on the high intensity of support from two young people with Down Syndrome, using the Support Intensity Scale (SIS Scale). As an intervention, collaborative planning of teaching objectives for the young people was carried out between the special education teacher and the researcher.

Due to the high intensity of support in the area of lifelong learning with young Brasilians, documented in previous literature (Moura *et al.*, 2023; Casagrande *et al.*, in press; Freitas & Galvani, 2021), and specifically in the basic areas access to the curriculum (e.g., reading, writing and mathematics), which practices and measures can be evaluated as a service or set of educational support strategies for the schooling process of young people with disabilities and neurodevelopmental disorders in Brasilian basic education?

Given the challenge related to teaching in the context of mathematics education, the question arises as to which educational practices and strategies have been identified as effective in teaching the process of mathematical literacy (numeracy). An alternative that has been gaining ground for contextualized teaching, that is, one considered useful for community life, is the use of methodologies consisting of video lessons and constant assessments of the young adult's performance. Video lessons are considered teaching material for individual study that uses audiovisual resources to present teaching content in an expository manner, combining sound and image simultaneously, to contribute to the teaching and learning processes (Arroio; Giordan, 2006).

Through video lessons it is also possible to carry out visual processing measures, through eye tracking. This is an important and useful characteristic for evaluating the planning outlined for teaching mathematical concepts. The eye tracking measure makes it possible to identify which region of the video lesson has the highest number of the young adult's eye fixations, allowing the creation of a heat map, and thus, evaluating the components present in the video lesson to make decisions on improving and re-planning teaching. The use of eye tracking in educational procedures has been documented in previous studies, aiming to relate learning to the path of the eyes (Barreto, 2012; Mayer, 2010).

Eye tracking then acts as an implicit and non-invasive measure to collect such data, gaining space in Special and Inclusive Education due to its evaluative potential in teaching specific behaviors. Being used in studies in the field of pedagogical behaviors, especially in the basic areas of literacy and mathematics (Christo, 2019). By understanding the measurement of gaze as a fundamental attentional process for carrying out a pedagogical activity by all sighted students, whether or not they are considered as the target audience for Special Education (Brasil, 2008). With the record in hand, programming is used to generate different data, in order to answer which, how and for how long a certain region was observed, and can also generate a map of the reading process, being limited to the type of visual resource used and what settings are adopted in the configuration, that is, how each measurement is established.

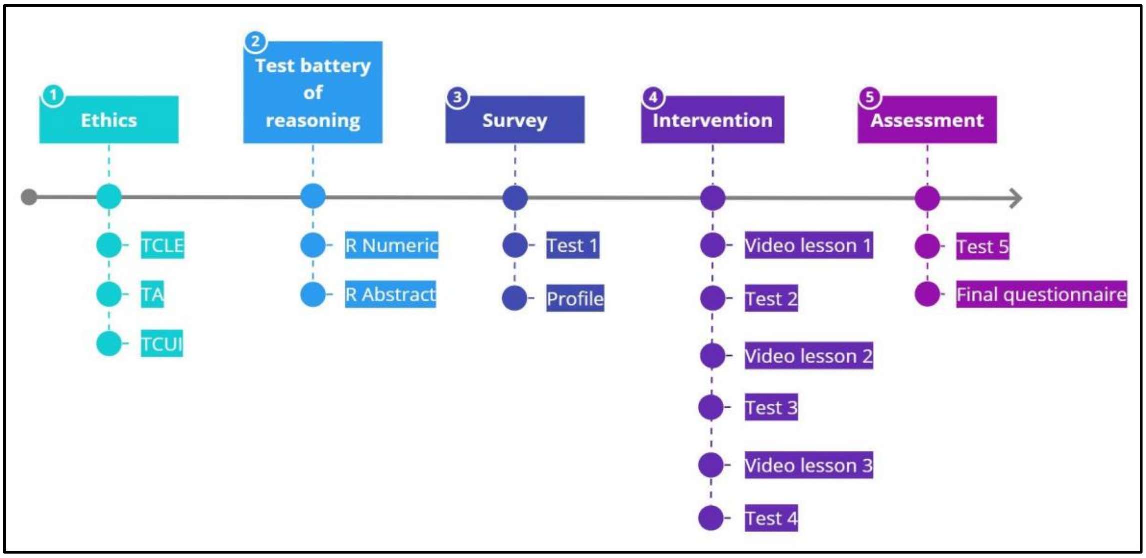
Faced with such possibilities, the question arises as to how people from a wide audience pay attention (by measuring their gaze) during a visually enriched intervention, on the topics of basic operations of integers and decimal rational numbers, circumference, calculation of the greatest common divisor (GCD), aiming to verify the feasibility of eye tracking as an auxiliary measure in the evaluation of inclusive teaching materials in the area of mathematics. We also add that this article was developed based on part of the results of a thesis.

2. Method

To satisfy the research objectives, we searched the literature for studies that worked with eye tracking within an inclusive context. In this endeavor, Batista, Kumada & Benitez (2023) carry out a review that describes and discusses how the literature has been working in the area, also proposing an initial protocol for the area, highlighting the dissemination of data. It should be said that even with such a report, the area appears to be in a state of exploration, so we follow the precepts of exploratory research, which is described by Gil (2008) as ideal for new areas of study, where the support of literature is limited.

Figure 1 shows the stages of the intervention, providing an overview of the procedures that were described below.

Figure 1. Flowchart of activities developed.



Caption: TCLE Participant consent form (PCF); TA Informed consent Term (ICT) TCUI Reproduction and Transfer of Images Agreement (RTIA).

Source: own elaboration.

2.1 Participants

We adopted a convenience sample, that is, a selection of participants according to feasibility and availability for the research, only restricting our group of participants to the age of 15 years or more due to Pisa. It should be noted that contact was made via email and/or through indication with approximately 150 people, of which around 30 agreed to participate, with only the 11 listed in Table 1 having actually scheduled and participated in all stages.

The information was collected during the intervention, which took place between March and April 2022.

Table 1. Characterization of participants.

P	A	G	EE	NR	AR	Identification	Occupation	Duration
P1	24	NB	ES	100%	96%	non-signing listener and non-blind	Researcher and student	150 m
P2	23	F	ES	85%	84%	non-signing listener and non-blind	Researcher and student	120 m
P3	24	NB	EM	80%	84%	non-signing listener, with low vision and language and thought disorders	Designer	180 m
P4	21	M	ES	45%	72%	non-signing listener and non-blind, with language and thought disorders	Student	120 m
P5	23	M	EM	30%	68%	deaf signer and non-blind	Student	180 m
P6	44	F	ES	85%	96%	non-signing listener, non-blind, with hyperactivity	Polyvalent teacher	180 m
P7	31	M	ES	0%	76%	non-signing listener, non-blind, with attention deficit disorder	Business process analyst	75 m
P8	48	M	EM	70%	52%	non-signing listener and non-blind	Merchant	90 m

P	A	G	EE	NR	AR	Identification	Occupation	Duration
P9	48	F	ES	65%	68%	non-signing listener and non-blind	Merchant and Lawyer	150 m
P10	24	M	ES	100%	92%	non-signing listener, non-blind, with language and thought disorders	Student	180 m
P11	33	M	ES	70%	68%	listener and non-blind	Telemarketing	100 m

Caption: P (Participant); A (Age); G (Gender); F (Female); M (Male); NB (Non-binary); TS (Teaching Stage completed or in progress); ES (Elementary School); HS (High School); HE (Higher Education); NR (Numerical Reasoning); AR (Abstract Reasoning);
Source: own elaboration.

2.2 Research Ethics Board

This research was submitted and approved by UFABC Research Ethics Board (CAAE: 49018021.80000.5594 - Opinion nº 5.107.152). For the development of all activities, it was strictly necessary for participants to have accepted and signed the Free and Informed Consent Form, the Reproduction and Transfer of Images Agreement of the research. Consent was given via Google Form, with capture scheduling carried out after signatures were completed.

2.3 Application of the Reasoning Test Battery

For the purposes of characterizing and quickly evaluating the general reasoning and abilities of the participants, the Reasoning Test Battery (BPR-5) was used, being a test that evaluates five reasoning factors, namely thinking: abstract; spatial; mechanic; numeric; and verbal, although for this research, it only fulfilled the parts referring to numerical and abstract reasoning (Primi; Almeida, 2000). The purpose of this stage was to generate a grouping parameter between the participants, promoting a comparison according to their mathematical reasoning.

The application was organized in an online form, which the participant was instructed to answer on their cell phone or computer, containing a description of all images and the translation into Brasilian Sign Language (BSL) of all texts.

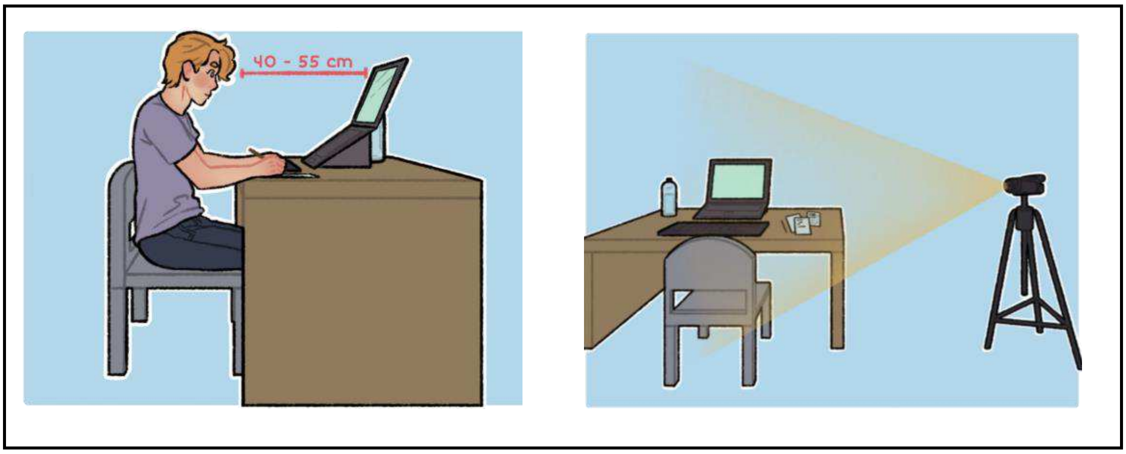
2.4 Variables and experimental delimitation

We used the teaching schedule of mathematical content as an independent variable, establishing the performance of assessments and eye tracking metrics as dependent variables. It is worth highlighting that mathematical knowledge was analyzed based on Pisa parameters. As a way to evaluate the effect of the independent variable (teaching programming) on the dependent variable (mathematical knowledge), a multiple baseline design between mathematical concepts was used (Santos; Sella; Ribeiro, 2019). Based on this type of design, the introduction of the independent variable was inserted gradually (one mathematical concept per video lesson) and mediated by tests involving the three mathematical concepts, as illustrated in Figure 2.

2.5 Teaching schedule

The didactic intervention environment followed the representation in Figure 2, in person. Participants were in an environment that allowed a diversity of means of expression, being able to speak, sign, write, draw or diagram their responses.

Figure 2. Arrangement of instruments in the collection environment.

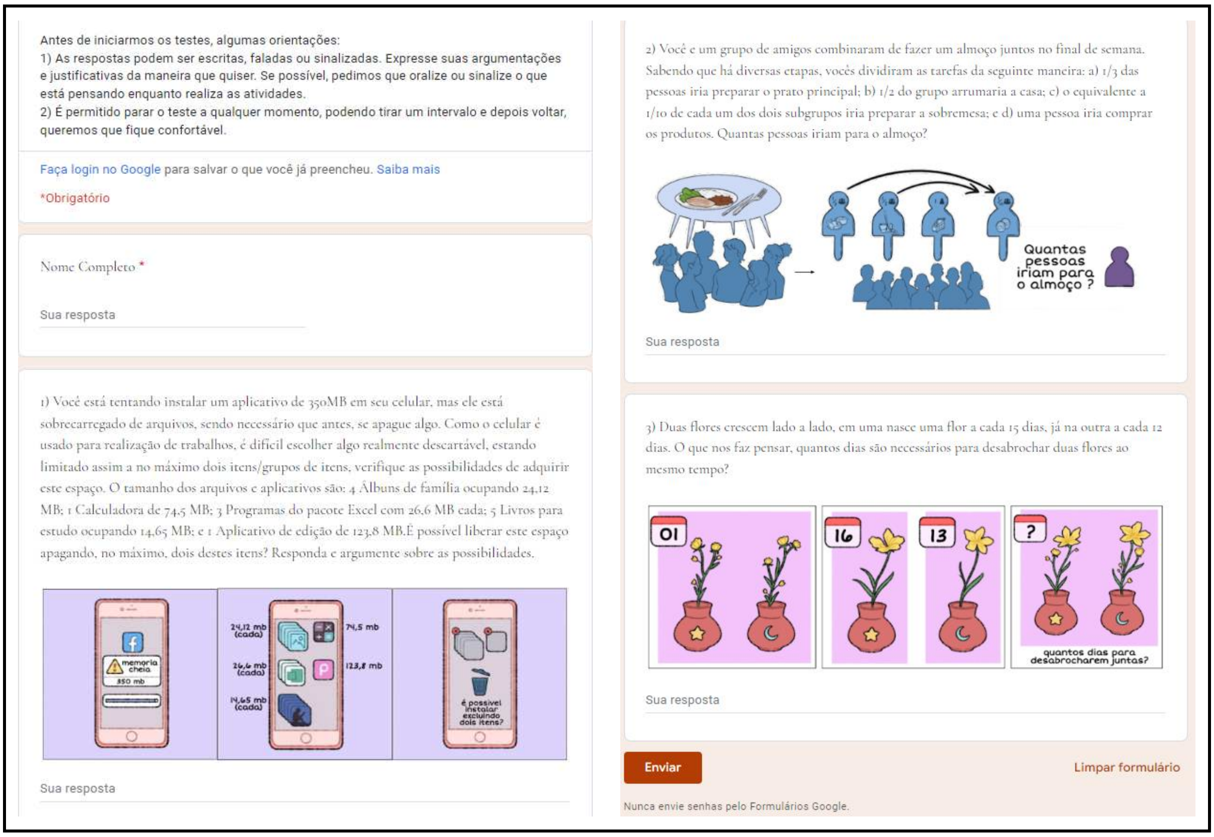


Source: Batista (2023, p.64).

For the teaching program, a set of five tests were proposed that assessed the three mathematical concepts worked on in the video lessons at different times. The tests always contained three exercises, each mainly focused on one of the topics in the video lessons, evaluating what was known at that point. They were developed based on the numeracy precepts adopted by Pisa, containing different levels of difficulty and resolution.

Specifically, tests 1 and 5 had great similarity, seeking to provide an entry and exit profile, working only with contextualized and more difficult exercises. Tests 2, 3 and 4 contained fixation exercises and contextualized problems, of different difficulties, used to check development at each moment, helping the participant's understanding process. Figure 3 displays one of the tests used, illustrating its structure.

Figure 3. Test 1 applied to participants.


Antes de iniciarmos os testes, algumas orientações:
1) As respostas podem ser escritas, faladas ou sinalizadas. Expresse suas argumentações e justificativas da maneira que quiser. Se possível, pedimos que oralize ou sinalize o que está pensando enquanto realiza as atividades.
2) É permitido parar o teste a qualquer momento, podendo tirar um intervalo e depois voltar, queremos que fique confortável.

Faça login no Google para salvar o que você já preencheu. Saiba mais

*Obrigatório

Nome Completo *

Sua resposta

1) Você está tentando instalar um aplicativo de 350MB em seu celular, mas ele está sobrecarregado de arquivos, sendo necessário que antes, se apague algo. Como o celular é usado para realização de trabalhos, é difícil escolher algo realmente descartável, estando limitado assim a no máximo dois itens/grupos de itens, verifique as possibilidades de adquirir este espaço. O tamanho dos arquivos e aplicativos são: 4 Álbuns de família ocupando 24,12 MB; 1 Calculadora de 74,5 MB; 3 Programas do pacote Excel com 26,6 MB cada; 5 Livros para estudo ocupando 14,65 MB; e 1 Aplicativo de edição de 123,8 MB.É possível liberar este espaço apagando, no máximo, dois destes itens? Responda e argumente sobre as possibilidades.

Sua resposta

2) Você e um grupo de amigos combinaram de fazer um almoço juntos no final de semana. Sabendo que há diversas etapas, vocês dividiram as tarefas da seguinte maneira: a) 1/3 das pessoas iria preparar o prato principal; b) 1/2 do grupo arrumaria a casa; c) o equivalente a 1/10 de cada um dos dois subgrupos iria preparar a sobremesa; e d) uma pessoa iria comprar os produtos. Quantas pessoas iriam para o almoço?

Sua resposta

3) Duas flores crescem lado a lado, em uma nasce uma flor a cada 15 dias, já na outra a cada 12 dias. O que nos faz pensar, quantos dias são necessários para desabrochar duas flores ao mesmo tempo?

Sua resposta

Enviar

Limpar formulário

Nunca envie senhas pelo Formulários Google.

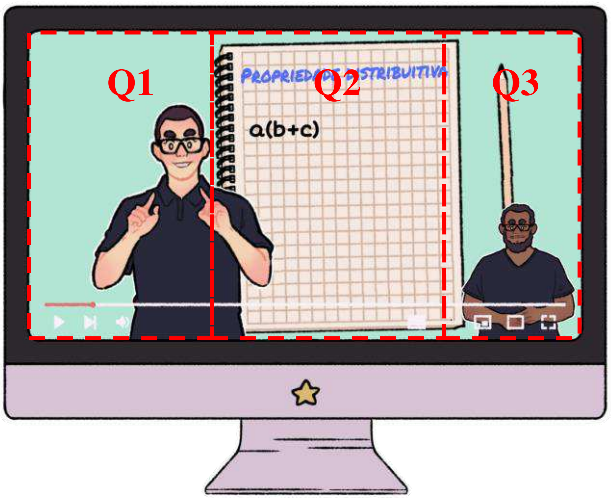
Source: Batista (2023, p. 61).

The three video lessons used in the teaching program were developed by SueLi research group and were passed through the Unity platform, being regulated to have images from the laptop[1] camera. Being a complex visual resource built based on visual pedagogy that combines the Portuguese Brasilian Sign Language Translator and Interpreter (Tilsp) highlighted on the left, visual elements in the center and a small square in the lower right part of the listening teacher, which can be considered as a screen with three vertical divisions (Kumada *et al*., 2022).

The structure of the video lessons (Figure 4) allows the division into three quadrants (mostly separated in the Tilsp region, the visual resources and the teacher), which can be used to trace with certain distinction which direction is being set by the participants, for example, verifying which of these elements had the greatest focus and facilitating the isolation of the factors involved during the analysis.

Figure 4. Structure of the video lessons.

[1] Lenovo 81FE laptop, with 1920 x 1080 screen resolution, Intel Core i7-8550U Processor, 1.80GHz CPU, 1992 Mhz, 4 Cores and 8 Logic Processors.



Source: own elaboration.

The contents covered in the video lessons are part of a didactic sequence, respectively: 1) Multiplication and Division of Integers and Decimal Rational Numbers[2] lasting 727 seconds; 2) Distributive Property of Multiplication and Notable Products [3]lasting 483 seconds; and 3) Calculation of the Greatest Common Divisor[4] lasting 404 seconds.

As for eye tracking, the equipment used was a Tobii 4C, a device that uses cameras and infrared lighting to track the x and y coordinates (in pixels) where the user is looking on the screen. Using these coordinates, it is possible to calculate fixations and saccades, being calibrated by six points individually at the beginning of each intervention carried out. The metrics and configurations adopted for analysis are presented in Table 2.

Table 2. Settings used in eye tracking programming

Device	Tobii 4C
Vertical and horizontal variation	Both eyes are simultaneously within the capture zone
Variation of monitor distance	Participants were 45 to 60 centimeters apart
Number of calibration points	Calibration was done with four points
Device Frequency	60 frames per second
Latency	The interval between captures was 11.1 milliseconds
Fixation Time	Accounting for fixations of at least 100 milliseconds
Reaction Time	It was not accounted
Deflection Time	It was not accounted
Saccadic Movements	Movements exceeding a speed of 40 pixels per second, acceleration

[2] Available on https://youtu.be/Y5DEnBW6xLw
[3] Available on https://youtu.be/6sAeApRKOD8
[4] Available on https://youtu.be/WuWr5cv1iv8

	of 340 pixels per second squared and duration of at least 5 milliseconds.

Source: Elaborated based on Batista, Kumada and Benitez (2023).

At the end of the intervention, a questionnaire was used to collect opinions, recording the participant's perspective on the material, specifically: 1) What did you think of the video lesson's interpreter?; 2) Was the space allocated to the teacher sufficient?; 3) What did you think of the images and illustrations in the middle of the screen present in the video lessons?; 4) Do colors act as a guide during operations? Comment on; 5) Did you feel that assistive technologies (Interpreters, image description, etc.) got in the way at any point?; 6) Did you feel that the video lesson contributed to your learning?; 7) Were your expectations met? Comment; 8) During the evaluations, when possible, did you like and focus more on the text, images or interpretation?; 9) When taking a test, which source of information do you like the most?; 10) When taking a test, which source of information do you feel more confident with?; 11) As for the images present in the evaluations, what were they for?

2.6 Data analysis

For the analysis of eye tracking, we followed the precepts described in Table 3, based on the literature in the area, articulating eye metrics with other information for inferences.

Table 3. Eye tracking data reading.

Metrics	Description	Examples of uses in the research
Fixation	It is the fixation made by the user, that is, when there are several repeated and consecutive records of the user's focus, which can be interpreted as when their eyes stop at a certain point in the visual resource. Within this measurement, it is still possible to make specific cuts related to fixation, namely: Time of each fixation; Total fixation time performed; Number of fixations; Heat map.	Used to check which points received the attention (or absence) of users' eyes. So, researchers can also analyze: The time of each fixation, where the users' behavior pattern is verified, or even how they maintain their attention. The total time of fixations, where you can measure how long attention is captured. The number of fixations, another aspect to better understand users' visual behavior. The heat map can help evaluate points of attention and inattention within a visual resource.
Saccadic Movements	These are rapid eye movements that occur between fixations, that is, the movement of the gaze path to the next focus.	Being able to check the paths that are taken when reading a visual resource.

Source: Elaborated based on Mayer (2010), Barreto (2012), Plochl, Ossandón & Konig (2012), Vieira, Teixeira and Chaves (2017), Balam and Osório (2018), Feller *et al*. (2021) and Batista (2023).

To analyze the tests, we grouped the records of each participant, and then allocated them according to Pisa levels, considering reasoning, identification of numerical values, elaborated logical sequences, the use of mathematical tools and the end result. According to the participants' performance, they are classified among seven cumulative levels (Brasil, 2020), namely, the students: Level 0) do not present the skills assessed; Level 1) answer questions about the family context, identify information and carry out routine procedures. Level 2) can interpret and recognize problem situations within contexts with direct inferences, extracting information from a single mode of representation. They employ basic algorithms, formulas and procedures involving integers. Level 3) perform clearly described procedures, with interpretations safe enough to serve as a basis for building a simple model or selecting and applying simple problem-solving strategies. Level 4) able to work effectively with explicit models in complex concrete situations, which may involve restrictions or require formulation of hypotheses. They integrate and articulate different representations, being able to construct and communicate explanations and arguments based on their ideas. Level 5) develop and work with models for complex situations, identifying restrictions and specifying hypotheses, in addition to comparing and evaluating which would be the most appropriate strategy in each situation. Level 6) can conceptualize, generalize and use information based on their investigations and modeling of complex problems, in addition, they can articulate different information, mastering mathematical tools and symbols.

3. Results and Discussions

Based on the data obtained from the 11 research participants, we divided this section into: group analyses; individual analyses; analyzes from the participant's perspective; evaluation of teaching programming; and reflections arising from exploratory research.

3.1 Participant performance and eye tracking

Based on the results obtained in the reasoning tests, it was possible to develop three groups, namely: Group A (n=5), being the group of those who performed close to the maximum (>80%) in numerical reasoning activities and abstract, composed of participants 1, 2, 3, 6 and 10; Group B (n=3), consisting of participants 8, 9 and 11, characterized by those who had a regular performance (50%-80%) in numerical and abstract reasoning activities; Group C (n=3), referring to participants with scores below 50% in numerical reasoning and regular abstract reasoning (50%-80%), consisting of participants 4, 5 and 7.

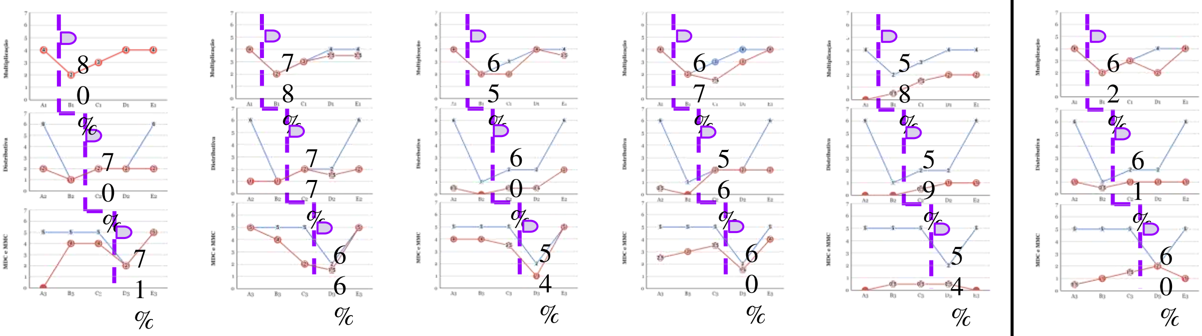
To display the performance of the participants, we show in Table 4 the trajectory throughout the didactic intervention. To facilitate and guide reading, we use a system of acronyms, in which Test 1 is A, Test 2 is B, Test 3 is C, Test 4 is D and Test 5 is E. For the exercises we use 1 for multiplication, 2 for distributive and notable products and 3 for GCD, being used after the initial notation. For example, the Multiplication exercise in Test 2 was coded A1.

As already mentioned, we chose to use exercises and problems of different natures and difficulties, therefore, we used the blue line in the graph to indicate the **Maximum Score** that could be obtained in that exercise/assessment, while the red line shows the participant's performance, overlaying in blue, the maximum score has been reached.

Another element added to the graph, dotted in purple, was the moment in which each video lesson was inserted during the intervention, highlighting the impact of the video lessons. We also display the percentage[5] of time of the participants' fixation, calculated from the total fixation time compared to the video lesson time, being a particular aspect of each individual. Finally, we put in orange, also as a percentage, the duration of the gaze of the participant on each quadrant, thus highlighting where the most proportional time was dedicated.

Table 4. Performance by content of each participant.

P1 (A)	P2 (A)	P3 (A)	P4 (C)	P5 (C)	P6 (A)



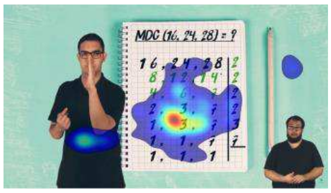
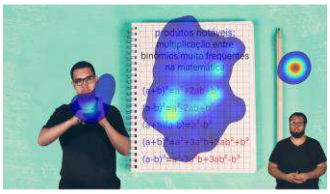
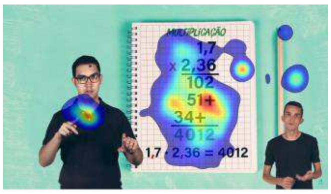
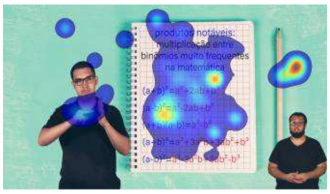
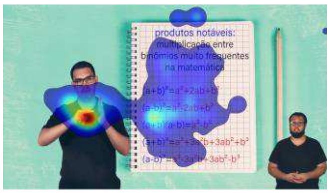
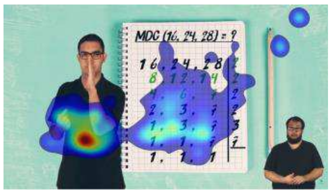
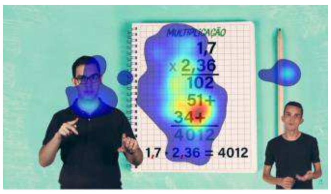
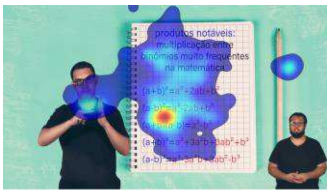
P7 (C)	P8 (B)	P9 (B)	P10 (A)	P11 (B)
Multiplicação	Multiplicação	Multiplicação	Multiplicação	Multiplicação
Distributiva	Distributiva	Distributiva	Distributiva	Distributiva
MDC e MMC	MDC e MMC	MDC e MMC	MDC e MMC	MDC e MMC

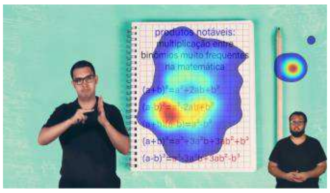
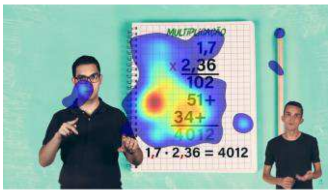
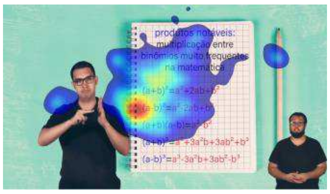
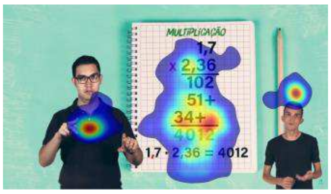
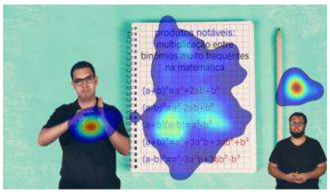
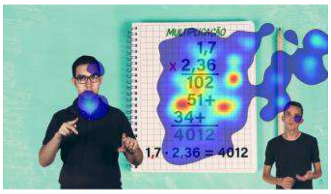
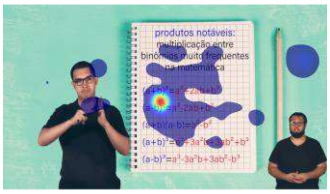
Caption. A (Test 1); B (Test 2); C (Test 3); D (Test 4); E (Test 5); 1 (Multiplication); 2 (Distribution and Notable Products); 3(GCD); Q1 (first quadrant); Q2 (second quadrant); Q3 (Third quadrant).
Source: own elaboration.

We provide the data obtained from eye tracking in Table 5, containing the heat maps corresponding to each video lesson and participant, in addition to inserting the total fixation time and the number of saccadic movements performed.

[5] This representation was chosen to promote the comparison among the video lessons, as they have different durations.

Table 5. Heat map of each participant.

Participant	Video lesson 1		Video lesson 2		Video lesson 3	
	Saccadic Numbers	Fixation Time	Saccadic Numbers	Fixation Time	Saccadic Numbers	Fixation Time
Participant 1 Group A						
	696	581 (79,9%)	449	340 (70,4%)	388	287 (71%)
Participant 2 Group A						
	591	565 (77,7%)	383	371 (76,8%)	312	266 (65,8%)
Participant 3 Group A						
	563	473 (65,1%)	332	289 (59,8%)	259	217 (53,7%)
Participant 4 Group C						
	581	491 (67,5%)	326	271 (56%)	312	240 (59,4%)
Participant 5 Group C						
	387	419 (57,6%)	307	284 (58,8%)	257	219 (54,2%)
Participant 6 Group A						
	472	451 (62%)	318	294 (60,9%)	301	241 (59,7%)

Participant	Video lesson 1		Video lesson 2		Video lesson 3	
	Saccadic Numbers	Fixation Time	Saccadic Numbers	Fixation Time	Saccadic Numbers	Fixation Time
Participant 7 Group C						
	696	509 (70%)	442	328 (67,9%)	303	242 (59,9%)
Participant 8 Group B						
	662	402 (55,3%)	353	282 (58,4%)	351	195 (48,3%)
Participant 9 Group B						
	551	430 (59,1%)	399	270 (55,9%)	355	189 (46,8%)
Participant 10 Group A						
	400	389 (53,5%)	216	259 (53,6%)	247	234 (57,9%)
Participante 11 Group B						
	282	300 (41,2%)	174	129 (26,7%)	147	121 (29,9%)

Source: Elaborated based on Batista (2023).

The members of Group A showed a certain internal similarity, achieving higher scores when compared to the other groups, showing a mastery of mathematical tools. It is also possible to observe a predisposition (that is, they present high scores in the pre-test assessment) in the multiplication and development of GCD in the group is also observable. In the case of the distributive, even if the only participant (P10) who solved the problem was from this group, the intervention was empirically shown to be insufficient to change expressive behavior on the topic, even if only momentarily. As for eye tracking, as it is possible to see, there is a greater focus on the central and neutral[6] region. A curious fact is that when compared to the other groups, this one has less total screen viewing, that is, their gaze is more fixed in the region, which can be interpreted as a gaze concentrated in a smaller area.

In relation to Group B, they also achieved a good performance in the multiplication activity and few advances in distribution. However, unlike Group A, there is no significant development in the GCD content, indicating that the third video lesson is better enjoyed by those with a greater mathematical predisposition. Furthermore, their performances are very similar, with the exception of P8. The progress made within the group was satisfactory, managing to identify the elements and develop them to a certain extent. Moving on to their fixations, it is possible to observe that their fixations covered most of the screen, with larger regions and less focus on the neutral region, presenting a more dispersed look than Group A. Within Group C, it was not possible to establish internal relationships with three different eye tracking and performance metrics.

At this point, it is appropriate to mention that in Credidio (2012) a relationship is made between the complexity of an image and the search patterns, so that the simplest ones are more systematic, while the complex ones are more random. Even though the material was different, since one is a static image and the one in this research is a video, we can make two points: a) such data are replicated in this research, where the simpler class presented a more centralized and contained coverage of fixations , while the more complex classes presented a more dispersed and random look; b) numerical and abstract reasoning tests allow us to establish that Group A has greater mathematics skills than Group B; based on this information and the heat maps, our study aligns with the phenomenon described by Credidio (2012), where Group A presents a more systematized view than Group B, so that we can infer that the level of complexity is built with the individual and material relationship, with eye tracking being a tool that can help in the assessment of such a phenomenon.

We highlight that the differences between the groups are discrete, so we suggest that future studies work with greater collection moments, being able to formulate new inferences within the groups.

At the same time, considering the group of participants as a whole, it was possible to observe that the listening teacher in 64% of cases (P1, P2, P4, P5, P6, P8, and P9) did not have records of a single fixation, not even for one recognition of the person. Such data may suggest not looking at the teacher, or even that this moment was faster than configured by the programming. Another phenomenon observed was fixation in the neutral region, where seven participants (P1, P2, P3, P4, P6, P8 and P10) showed a slight concentration of focus in this region, without showing fixations around it. This event draws attention, as there is no direct explanation for this behavior. So, we hypothesize that it is a neutral place that is comfortable to focus on while listening, since P5 (the only deaf participant) did not show this tendency. Despite this, we recognize the need for other studies that analyze such behavior for more assertive considerations in this regard.

3.2 Assessment of the participants' perspective on the teaching program

[6] Region located in the third quadrant, a little above the teacher, with a pencil that remains there during the three video lessons. In other words, it is not a region of visual stimuli.

In addition to the results previously raised, this section is dedicated to data obtained from some reports during the intervention and the final feedback carried out, taking some participants as an example.

Starting with Participant 3, where we identified that there was constant progress. However, at the end of the intervention, he reported a problem with the video lessons, especially in the second one, as explained in Excerpt 1.

Excerpt 1

> P.3: It was enlightening at first, but then I got lost as he talked... a, x and b started to appear a lot, all together and I got lost, so I didn't really understand what he was saying. The information didn't reach my head. I know it wasn't the focus, I don't know, but there were a lot of pauses in the video. I understand that there is the issue of the interpreter, there is this pause, he is explaining and I understood, but sometimes, after he finished the video lesson there are transitions and pauses that didn't make sense, he would start to explain the line of a new example and it opened, closed and started again... and I found it a little bad because I was starting to concentrate and then the transition came and messed up the information I was gathering. This was in the distributive, when he started to explain, there was the example in full, he started to explain, but then he would finish an example he could take a break there, but he would amend the second example and start to narrate the second example but he would finish the first line, and then the pause with transition would come and start again with the second example and it got messy.

Given this report, we retrieved the eye tracking data and compared it with the video lesson, where we identified that he had a constant fixation pattern, however, in the transition moments there was an interruption, leaving a few seconds without any fixation. Thus, it was possible to empirically link that a participant's complaint is actually confirmed in the eye tracking data, so that the intensity and moment of the transition ended up being a negative factor, destabilizing the focus.

This fact is found in a similar way in the literature by Vieira, Teixeira and Chaves (2017) who carry out studies with subtitles, so that discontinuous texts or texts with many breaks were negative for the understanding of sentences. In this way, when we transpose the visual issue but as image information and not text, we can identify this same phenomenon.

Participant 6 also has an interesting report (Excerpt 2), where she states that she did not show real attention to the screen, although she looked at it.

Excerpt 2

> P.6: I tried hard to pay attention, but even so I ended up dispersing in the middle, the teachers' voices were very neutral, especially in the second video class... So the classes were boring, like those math formulas, you know? That seriousness brought that zen sensation, too neutral... In the second class I really dozed off.

When visiting her records, it appears that she is even able to apply some new algorithms during the intervention, but she still has many difficulties in developing them, especially within complex problems. Thus, this failure to look closely may justify her lack of significant behavioral change during the intervention, even with their relatively high and constant fixation rates.

Finally, a participant worth highlighting is Participant 8, who, although he also maintained the same level of mathematical knowledge, these were the first video lessons he witnessed, so this change in format may have been an impactful factor, since he is still visually literate for the video class while undergoing the intervention (Reily, 2003). This effect is based on the observation of eye tracking data, since in each video lesson there is a different gaze configuration, making it not possible to determine a profile, which is coherent for this literacy process, in addition to making small comments during the intervention where he stated he needed more time or "review the lesson calmly" to "learn everything".

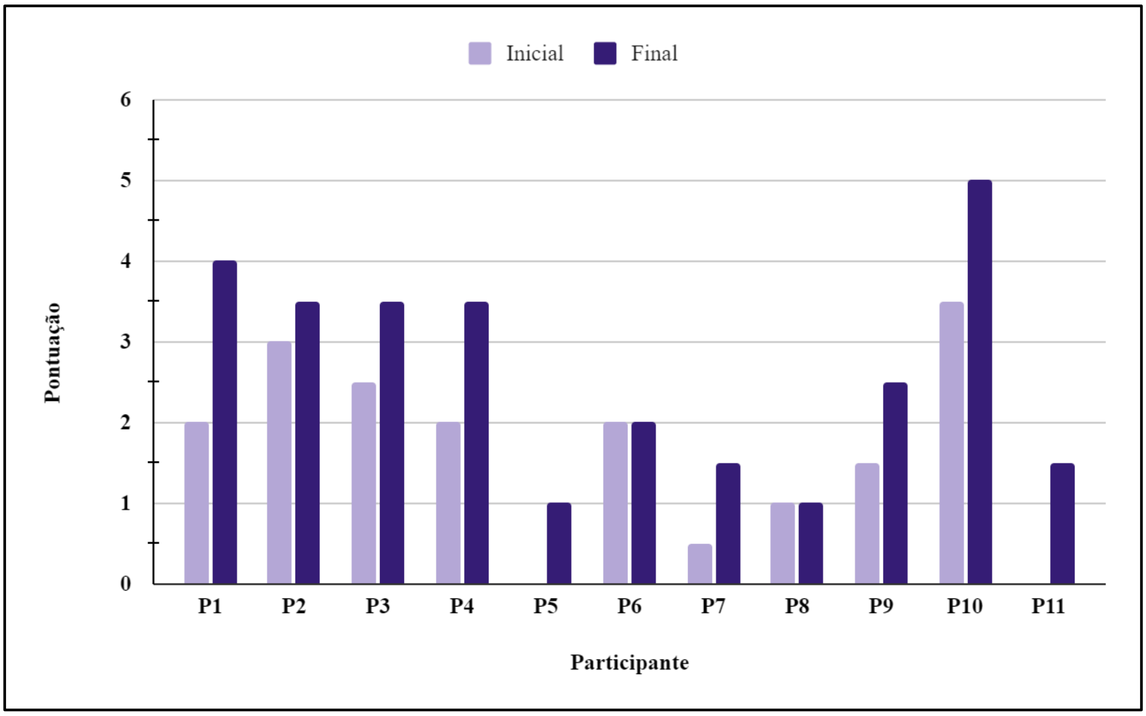
Given this situation, we then complement Covre *et al.* (2005), so that the visual profile is constructed through the visual literacy that the individual encounters with a certain type of material. It is recommended that future studies verify the visual literacy process of new materials.

3.3Assessment of teaching programming

If we initially discussed the data about the participants, for this subsection we highlight the teaching program itself, checking the performance of the activity developed.

Overall, the teaching program generated positive[7] feedback, participants went from an average score of 1.63 to 2.68, managing to progress approximately one level in Pisa parameters within the proposed contents. Individually, this growth varied from half to two points (Graph 1), with only two cases where there was no progression after the intervention. We then have, empirically, evidence of behavioral change under the content after an intervention that lasted a maximum of three hours.

Graph 1. Graph showing the difference between the results of Test 1 and Test 5.



Source: Batista (2023).

[7] Around 81.8% reported that the intervention was positive, remembering and/or learning the content, while the other 18.2% stated that they had partial use.

It is worth highlighting that such results were achieved with a single application of video lessons, which lasted for up to 180 minutes, which means around 4 lessons of 45 minutes. It is also noteworthy that the participants did not pause or return to the video, therefore, we can infer that their use outside the research context can be much more positive. Specifically, there are still some points to talk about video lessons and eye tracking, as Woloszyn, Gonçalves and Merino (2020) denote how such a resource is capable of highlighting positive and negative elements, where:

I) Multiplication: Although it presents simpler content, it was generally the one that retained the biggest attention in relation to the others, generating two hypotheses, the first due to the participants being rested and the second due to the novelty of the format, causing it to be explored. A feature of this video lesson is that it presented little information at a time in the area of visual resources, always containing large and small elements, which could be an indication of how to use these elements within the video lesson, due to the positive feedback.

II) Distributive: The metrics reveal a similarity with the first video lesson, however, in this one the participants demonstrated to be more dispersed, covering a larger region with their fixations. Reanalyzing the video lesson, we see that it has the highest density of visual information, with small print and many operations, which could be interpreted as visual pollution. Therefore, it may be necessary to adjust the sizes, focusing on the elements on the screen so as not to become confusing, in addition to having slower transitions so that the change in topic is understood, given that of the three video lessons, it was the one that provided the least progress, with only a person being able to completely carry out the contextualized exercise at the end of the intervention.

III) GCD: In the last video lesson, an interesting phenomenon was, in general, that the area viewed expanded horizontally. Revisiting the video lesson, the visual elements were large and scattered. Another factor to be pointed out is that many showed signs of tiredness, with a reduction in the fixation rate.

Thus, based on the results and statements from the participants, the video lessons had the following positive points: a) they provoked learning; b) attractive; c) fulfilled their role as a video lesson; d) helped to resolve related problems; e) well done; f) managed to work on concepts that they have difficulty with, even initially; g) objective; h) met expectations; i) summarized content.

As points to improve, we found that: a) the third video lesson did not take advantage of the visual aspect; b) the size of the Tilsp professional was exaggerated and may undergo small adjustments to make room for visual resources. An alternative would be a user-adjustable screen; c) the teachers' voices were monotonous; d) the second video lesson showed signs of being visually polluted in addition to not providing good progress on the topic. These are all aspects that need to be improved in the next construction of the project. Regarding the visualization of the elements, we found that the following were most observed: a) the visual resources arranged in the center of the screen; b) the Tilsp professional, specifically, the region of his hands and chest; c) the neutral region located above the listening teacher. As for the areas with shorter fixation time: a) the listening teacher, it is not even possible to capture fixations to recognize identity in many cases; b) the regions close to the edge of the video lesson; c) the neutral regions that are to the left and on Tilsp; d) Tilsp's face.

Going specifically into the components of the video lesson evaluated by the screening and the participants, the Tilsp professional was a key point in our evaluation, given that in Kumada *et al.* (2022) it was known that the unusual size could be a point of conflict. Considering that, reversing the roles, or even highlighting Tilsp in an inclusive material, for more logical it may be due to the need to visualize the Brasilian Sign Language, it still represents a cultural clash.

Thus, our study found that 45.4% (n=5) of the participants judged the interpreter window to be positive, 36.4% (n=4) were indifferent towards Tilsp, even stating that it did not get in the way during the video class, while 18.2% (n=2) felt that it ended up hindering their concentration in the video class. Participant 7 was one of the people who reported the discomfort, but, when we evaluate his fixations (Table 5, P7), it appears that he practically did not fix his gaze on the professional, making us question whether the discomfort was didactic or if there is some cultural conflict, since the structure provided inverts the “hierarchy” of the social imaginary. As for the other participant, P6, we actually have an indication that there was interference, so that approximately 11% of her fixation was concentrated on the professional, while she was one of the people whose intervention did not cause a change in behavior, with evidence that the choice was harmed her.

As for the figure of the listening teacher in the bottom right corner of the video lesson, 90.9% of participants classified it as sufficient, with only 9.1% (Participant 8) asking for its expansion, specifically, equivalent to the Tilsp, reinforcing again the suggested hierarchical aspect previously, as shown in Table 5, there are practically no fixations on this element of the screen by the participant in question.

Another element used and evaluated in the video lessons (Kumada *et al*., 2022) were the colors used to guide and highlight elements of mathematical operations, being well evaluated, unanimously, so that all participants made comments on how they successfully performed in conducting operations, what aligns with Oliveira, Locatelli and Sato (2021), who guided the implementation of this functionality. Excerpt 3 was translated from a speech in the Brasilian Sign Language and acts as an example of the comments made by the participants.

Excerpt 3

P.5 Yes, it helps to understand which part was working, green, red and blue were well used.

Finally, the visual elements at the center of the video lesson, so that Kumada *et al.* (2022) followed the assumptions of Leffa and Irala (2012) and favored the center of the video lessons with visual elements and obtained a positive return, since most of the fixations were concentrated in this sector, as illustrated in Table 5. A neutral region, in the third quadrant, which we hypothesize acted as a rest region, may indicate the need for this type of space within teaching materials with listeners, both to avoid overloading the screen and for rest. It is recommended that future studies investigate whether listening participants, faced with multimodal material, which combines visual and sound, look for a neutral region to focus on while listening to what is being said.

3.4 Contribution of the area from the exploratory research

As previously described, Gil (2008) denotes that exploratory research is destined to explore an environment with little discussion. Therefore, in addition to the results already discussed, we take the opportunity to report on some experiences of this type of research, contributing to future work. This way we have to:

1) Eye tracking requires a lot of machine processing, so that research ends up being shaped around this problem, making use of external equipment or simplifying collections.

2) Reconciling participants' schedules was a problem, so the experiments were often carried out outside business hours, which can be a problem when research is limited to these hours.

3) The polishing of eye tracking data goes through a complex programming process, where minimal errors can result in data being discarded. In this research, for example, the first batch of data had to be entirely redone due to the screen resolution that was not properly configured, generating an erroneous first report. We take this moment to emphasize that the findings and recommendations of this research were made based on the limitations of the programming carried out, so, even if the specifications were checked, future studies can validate its indications.

4. Conclusions

The present study, using an exploratory methodology, aimed to verify the feasibility of eye tracking as an auxiliary measure in the evaluation of inclusive teaching materials in the area of mathematics. To achieve this objective, we proposed a mathematics teaching program, using the advent of eye tracking in conjunction with tests and opinion questionnaires to evaluate the material.

Based on this, we can indicate that eye tracking provided sufficient data to assist in the evaluation of complex teaching material, managing, together with other measures, to produce a detailed report on the individual, scoring their change in behavior and detailing the barriers faced by them during the intervention.

It is worth mentioning that, just like Moraes *et al*. (2018), it is possible to associate educational performance together with eye tracking metrics to indicate significant differences within video lessons, highlighting the positive points and those that can be improved, in addition to linking such points with specific behavior. Thus, gaze measurements can support decision-making regarding educational planning, however, the data found in the research leads us to support that such metrics need input from other measures, such as performance and opinion assessments, since only fixation on the screen is not related to learning, acting as justifications and validation of materials, strategies, etc.

Furthermore, the programming discussed can be understood as an Assistive Technology, since it involved a methodology composed of educational strategies that guaranteed a change in the behavior of a heterogeneous group of students in relation to the curricular components of the secondary education area of mathematics, after an intervention that lasted approximately three hours. During this time, it was possible to link screening data with fatigue, which is an important issue in education, given that we submit our students to more than five hours of classes a day, leaving us questioning how an intervention lasting a maximum of three hours, with breaks it was a problem.

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