The Impact of the Usage of Hypercultural Mediation in the Teaching of Special Relativity in High School in Brazil

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ABSTRACT

Background: Given the importance of working on Modern Physics in the classroom and considering the great difficulty of understanding by students, it is important to investigate efficient ways to develop the theme. **Objective:** Identify if there was learning after using a didactic material built using animated gifs and specially after using computer simulations, and to investigate if there is a difference in learning between students who interacted and did not interact with the computer simulations. **Design:** The design is based on a quantitative analysis made by comparing the results of pre-tests and post-tests of the control and experimental groups. **Setting and participants:** The research was carried out with 82 students from the third year of high school from a public school. Of these students, 62 form the experimental group, while 20 make up the control group. **Data collection and analysis:** The activities were developed during the curricular classes of the Physics discipline, with the application of questionnaires immediately before and after the activities. The activities contemplated the four types of mediations (according the CNMT referential), and the control group did not use *hypercultural* mediation. **Results:** The outcome of the analysis shows a significant difference in the results of the control and experimental groups, and the experimental group showed a statistically superior growth. **Conclusions:** Using the four types of mediations, especially *hypercultural*, students' learning is enhanced for Special Relativity concepts and problem-solving.

Keywords: Physics teaching; Special Relativity; Computer Simulations; Cognitive Networks Mediation Theory; Quantitative Analysis.

O Impacto do Uso de Mediações Hiperculturais no Ensino de Relatividade Especial no Ensino Médio

RESUMO

Contexto: Dada a importância de trabalhar a Física Moderna em sala de aula e considerando a grande dificuldade de compreensão dos alunos, é importante investigar formas eficientes de

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desenvolver o tema. **Objetivos:** Nosso principal objetivo é identificar se houve aprendizado dos alunos após o uso de um material didático especialmente construído com gifs animados e em especial após o uso de simulações computacionais e investigar se há uma diferença no aprendizado entre os alunos que interagiram e não interagiram com essas simulações. **Design:** O desenho do estudo é baseado em uma análise quantitativa feita pela comparação dos resultados dos pré-testes e pós-testes dos grupos controle e experimental. **Ambiente e participantes**: A pesquisa foi realizada com 82 alunos do terceiro ano do Ensino Médio de uma escola pública da cidade de Montenegro / RS, Brasil. Desses estudantes, 62 formam o grupo experimental, enquanto 20 compõem o grupo controle. **Ambiente e participantes**: As atividades foram desenvolvidas durante as aulas curriculares da disciplina de Física, com aplicação de questionários imediatamente antes e após as atividades. As atividades contemplaram os quatro tipos de mediações (conforme descrito no referencial da TMC), e o grupo controle não utilizou mediação *hipercultural* (simulações computacionais). **Resultados**: O resultado da análise mostra uma diferença significativa nos resultados dos grupos controle e experimental, e o grupo que interagiu com as simulações por computador apresentou um crescimento estatisticamente superior. **Conclusões:** Usando os quatro tipos de mediações, especialmente *hipercultural*, a aprendizagem dos alunos é aprimorada para conceitos de Relatividade Especial e solução de problemas.

Palavras-chave: Ensino de Física; Relatividade Especial; Simulações Computacionais; Teoria da Mediação Cognitiva em Rede; Análise Quantitativa.

INTRODUCTION

In the current classroom reality, there is an important lack of interest from most high school students in learning. In relation to the discipline of Physics, the lack of interest can be substantially higher, as it usually ends up being taught in a meaningless way, as an extension of mathematics, with calculations without real meaning and discussion of physics concepts. Gleiser (2000) points out that: "The aim of the natural sciences is to explore and understand the phenomena of Nature. Unfortunately, it is very common to believe exactly the opposite: that science, by materializing the world, takes away its beauty!" (Gleiser, 2000)

Thus, it is important to develop new approaches that bring science in the classroom closer to the reality of the modern world. It is necessary to show the student how the phenomena worked in the classroom are linked to their context. Therefore, the insertion of Modern Physics themes in the school routine becomes a viable way of making this approach.

The themes of Modern and Contemporary Physics are of great relevance, as they can bring new perspectives on science and the world to students. However, they often end up being left out of the high school classroom. According to Terrazan (1992), there is a growing influence of Modern and Contemporary Physics for the understanding of the current world. After all, most of the emerging technologies are explained by the science of the 20th and 21st century. This highlights the importance and need for these themes to be addressed, as this way the students will be able to develop a conscious, participative and modifying insertion in the current society, which is fundamental for their formation as critical citizens.

Furthermore, by addressing these phenomena in physics classes, it is possible to "arouse the curiosity of students and help them recognize physics as a human endeavor and, therefore, closer to them". Among these phenomena, Einstein's Theory of Relativity stands out, as it gives students a glimpse of the most current science. In addition to solving problems that arose at the time, it enabled the emergence of numerous technologies of wide use, such as the Global Positioning System (GPS).

By understanding the role of Physics in the development of these technologies, which students use in their daily lives, it is possible to arouse a great interest in them for what is worked in the classroom, which contributes to their learning. In addition, these topics are usually of interest to students, who generally only have contact with them through the media.

However, it should be noted that, when talking about Modern and Contemporary Physics (MCP), these are more complex subjects, which require a high degree of abstraction from students, which makes their understanding difficult. In the case of the Relativity Theory (RT), its effects are imperceptible directly in everyday situations, and it is not possible to easily notice the Lorentz Transformations. On the other hand, Galileo's Transformations are easily observed in the students' daily lives. Therefore, it becomes important to develop means that enable students to visualize the Lorentz Transformations so that they can effectively understand the RT.

In this scenario, the use of digital technologies in the classroom is effective to facilitate this process. In the teaching of Physics, the use of computer simulations that allow the student to directly visualize what was studied is an efficient solution in different situations (Trevisan & Serrano, 2014; Freitas & Serrano, 2019). These simulations used for didactic purposes function as external mediation mechanisms (Souza, 2014) and will assist in the process of understanding the phenomena.

It is worth noting that, as pointed out by Pereira and Ostermann (2009) in their bibliographic review, most of the production of works related to the teaching of MCP is concentrated in bibliography for consultation or scientific dissemination, with few reports and results of application in the classroom. The number of works that bring evaluation of the application and the students' conceptions is even smaller, having represented only 15.69% of the total sample of 102 analyzed articles. As they highlight:

> Although development work is extremely relevant to science teaching, as it is a source of information and resources for teachers and students, it is necessary that the material resulting from these works be subjected to a critical evaluation to verify to what extent they actually facilitate the processes teaching-learning. (Pereira & Ostermann, 2009, our translation)

In a more recent bibliographic review, Kikuchi, Ortiz and Batista (2013) found results similar to those of Pereira and Ostermann (2009). Thus, it is evident the importance

of developing works that bring the application of CMF in the classroom, as well as an analysis of it. In this context, this research is inserted. We bring an account of an application made with third-year high school classes from a state school. Questionnaires were applied before and after activities with students; these data are analyzed here quantitatively.

THE COGNITIVE NETWORKS MEDIATION THEORY

The theoretical framework used in the present research consists of the Cognitive Networks Mediation Theory (CNMT) (Souza, 2012). According to the author, the human brain has the ability to complement information processing using organized external physical systems and this is among its best features. Therefore, when dealing with more complex situations, individuals need to use these mechanisms to assist in the processing of information. This complementation also occurs with digital technologies.

Thus, according to the theory, the use of Information and Communication Technologies (ICT) has caused and continues to cause changes in the cognitive structure of individuals. The human being will acquire knowledge of something by using these mechanisms, or, to be more specific, he will understand some object or situation through the interaction with it through these structures. This interaction can occur through four different mediations (Souza, 2004): psychophysical, social, cultural and *hypercultural*.

Psychophysical mediation is understood as any interaction with objects that stimulate sensory-motor schemes. It can occur through experimental activities or interactive models, for example. Social mediation occurs through the interaction between individuals, which can occur directly or indirectly. This mediation can be present through other mediations, as in an experimental activity, where students interact with each other and with the teacher.

Cultural mediation will take place using language, writing and images. It covers the means of communication and understanding and can occur using books or presentation of videos. Finally, *hypercultural* mediation is based on the use of technological tools that enable external information processing. In this way, changes in the individual's internal structures occur. It can occur using computer simulators, as they allow students to process information about phenomena that, many times, they would not be able to do alone.

> . . . in the current Digital Revolution, the emergence of a Hyperculture is witnessed, where the external mediation mechanisms start to include the computational devices and their cultural impacts, while the internal mechanisms include the necessary competences for the effective use of such external mechanisms. (Souza, 2004, p.85, our translation)

Computer simulators are, therefore, a viable alternative that allows the visualization of certain effects and phenomena through the interaction of students with them. They

become efficient tools in facilitating the comprehension and processing of the subjects worked, enhancing the student's intellectual activities. However, this interaction with different external mechanisms requires the development of internal mechanisms as well.

Thus, with the use of external mediation mechanisms, individuals develop drivers that make it possible to understand the functioning of these resources as well as the information provided by them. Thus, these drivers are internal mechanisms that will enable interaction with external mechanisms. They will enable the student to access information about new situations and problems.

In order to enhance the teaching of the Theory of Relativity, we seek to contemplate the four types of mediations mentioned above. In the present research, a greater focus was given to the use of hypercultural mediation through computer simulations used by students.

LITERATURE REVIEW

Searching for a general teaching parameter of the Theory of Special Relativity, a bibliographic review was carried out during February 2020. The search started through the Education Resources Information Center (ERIC) platform using the terms "special relativity", restricting itself to the last ten years, that is, starting in 2011. The search presented 58 results, among which 8 papers were selected. The selection was based on reading the abstracts of the articles. Only articles that brought results and/or application analyzes were selected.

Following the search, the Scopus platform was used, with the terms and operators "special relativity" AND ("teaching" OR "learning"), to search both in the title, in the summary and keywords. The search was also restricted to the last ten years, resulting in 60 papers, among which 10 articles were chosen by reading their abstracts, articles already selected by ERIC were not considered. Only articles with results and / or application analyzes were also selected here.

Finally, a search was made on Google Scholar looking for works that were not covered in the two previous platforms. The terms and operators "special relativity" AND ("teaching" OR "learning") were used and the search was restricted to the last ten years. The search resulted in 12,600 articles, with 14 articles selected on the first 20 pages. The articles were selected by reading their abstracts, articles that did not bring results and / or analysis of applications were not selected.

Through the literature review, it can be seen that, in general, students have several difficulties in relation to the Theory of Relativity. This was found by Alias and Ibrahim (2013), in their study with 206 university students through a questionnaire. The main difficulties pointed out by the researched students were in relation to the interpretation of the questions and, mainly, the difficulty of visualizing the proposed situations.

Kizilcik and Ünlü Yavas (2016) obtained a similar result through interviews with 25 students. Respondents reported difficulty with RT because they are abstract concepts, which they cannot imagine or associate with everyday life. They also had difficulties with mental experiments.

In another subsequent study (Ünlü Yavas & Kizilcik, 2017), carried out with 245 high school students and 446 higher education students, based on the results obtained, the researchers sought to detect the levels of these difficulties. Through a questionnaire on a Likert scale, it was found that the main difficulties of students in relation to RT are the difficult interpretation and the fact that events are not experienced and observed in daily life, with non-intuitive results, which was in agreement with previous studies.

It was also possible to assess that the use of Information and Communication Technologies (ICT) is very efficient in teaching the Theory of Relativity. In the work of Carr and Bossomaier (2011), 67 participants used a game about asteroids, among them some had already studied RT and others had not. Through the application of pre and post-tests, they noticed a significant growth by the Wilcoxon test for participants who had not yet studied RT. They realized then that the software had a positive impact on the construction of these students' concepts. Like Hosson, Kermen and Maisch (2011), who, using virtual reality (VR) on the relativistic effects on objects at high speeds, realized that students were able to develop an intuitive sense about them.

Chu, Humer and Eckhard (2019) also observed a positive impact on the use of ICT. They developed a virtual reality (VR) about the Solar System that was applied with 34 participants. They answered questionnaires on a Likert scale before and after activities and watched an introductory video before using VR. They perceived a significant gain in the participants' understanding of spatial contraction and a not so significant gain for temporal dilation. They found that VR was efficient to help students understand, but that a greater visual appeal in relation to temporal dilation can be worked.

Finally, Kusumawati, Kahar, Khoiri and Mursidi (2019) investigated how different types of representation in the theory of relativity affect students' understanding. The research was carried out with university students from three different islands (Java, Kalimantan and Papua) through a descriptive test. They realized that the different types of teaching influence the representations used by students; in addition, students able to use a greater number of representations had a better understanding of the phenomena. Therefore, it is possible to realize the importance of using different types of representations in teaching the Theory of Relativity.

METHODOLOGY

The main research question pursued in this paper is: "Is there evidence of learning of the Galileo's and Lorentz's Transformations after using a didactic material that particularly includes computer simulations?", In addition, we also want to answer the auxiliary research

question "Is there a difference in learning between students who interacted and did not interact with computer simulations? ".

The activities were carried out with 82 students from four different classes of the third year of high school in a state school in Brazil. The application took place during the Physics classes, which had two weekly classes of 50 min each (the usual chronogram of physics teaching for high school students in the country). The activities were carried out during ten classes, with the researcher being the full professor of the classes. Before the research was carried out, the project was submitted to the Ethics Committee, being approved through Review no. 3,625,879, issued by the Ethics and Research Committee of the Lutheran University of Brazil - ULBRA, on October 7th, 2019.

Of the four classes, three are part of the experimental group, which performed all activities – that includes both the didactic material and the computer simulations. At the same time, one is the control group, which did not perform only the activities with computer simulations but used the didactic material. The activities were applied in the third quarter of the year, when students had already studied the contents of Electromagnetism.

Development of Materials and Instruments

Essentially, the didactic material consists of a 63-slide presentation[1] that was developed, using images, videos, gifs and animations. Four simulations were also developed using the Modellus 4 software. Of these, two were used to teach Galileo's Transformations, called "Bolinha no Trem" and "Carros e Avião"[2], figures 1 and 2, the latter being developed based on the one used by Monaghan and Clement (1999). The other two were to work on the Lorentz Transformations, called "Dilatação Temporal" and "Contração Espacial"[3], figures 3 and 4. Roadmaps for use for each simulation were developed using the POE strategy (predict-observe-explain). Thus, students imagined how some proposed situation would occur, observed that situation in the simulation and then compared what they had imagined as what they had observed.

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[1] Available in: http://ppgecim.ulbra.br/ciencias/index.php/2020/04/14/apresentacao-de-slides-sobre-a-teoria-da-relatividade-especial/

[2] Available with script in: http://ppgecim.ulbra.br/ciencias/index.php/2020/04/14/simuladores-sobre-velocidade-relativa/

[3] Available with script in: http://ppgecim.ulbra.br/ciencias/index.php/2020/04/14/simuladores-sobre-transformacoes-de-lorentz/
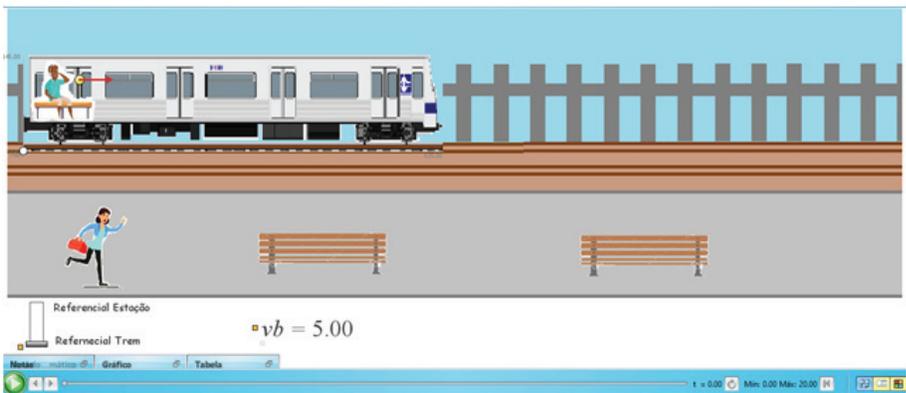
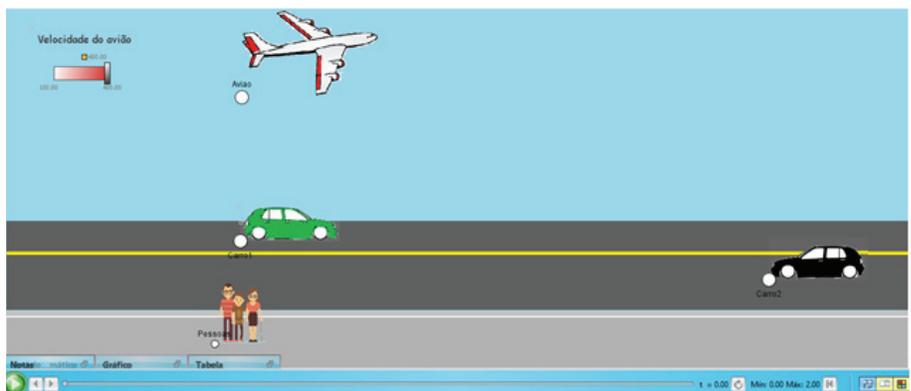*Figure 1.* Simulation screen "Bolinha no Trem". (Souza, 2020)

Figure 2. Simulation screen "Carros e Avião". (Souza, 2020)

Figure 3. Simulation screen "Contração do Espaço". (Souza, 2020)

Figure 4. Simulation screen "Dilatação do Tempo". (Souza, 2020)

In addition, two cardboard models of the graphic representation of the two transformations were made, as there was a referential change. The objective was to contemplate the four types of mediation (social, cultural, psychophysical and *hypercultural*) in the activities. Social mediation was present in the students' interaction with the teacher and among themselves during all activities. Through videos used, cultural mediation was addressed; psychophysical mediation was included in the demonstration models. And, finally, using computer simulations, *hypercultural* mediation was also present.

Two questionnaires were also developed, one on the Galileo Transformations and the other on the Lorentz Transformations, to be used as pre and post-tests. The Galileo questionnaire[4] was adapted from the one used by Monaghan and Clement (1999) in their research. It consists of four questions about Galileo's Transformations and four about the confidence of the answer in each question. The questions deal with movement and speed in the face of the change of referential. The questionnaire has images illustrating the situations and most of the questions were objective. Lorentz's questionnaire[5] was designed to analyze the students' conceptual understanding. It also has four questions about the Lorentz Transformations and four about the confidence of the answer in each question. Temporal dilation and spatial contraction were contemplated; it also has images illustrating the situations and has all the objective questions.

Application

First, pre-tests were applied with each class, as mentioned previously, a questionnaire for Galileo Transformations and one for Lorentz Transformations. After the application of the questionnaires, activities started. The contents were presented through lectures

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[4] Summary in Appendix 1.

[5] Summary in Appendix 2.

using the slides. We sought to bring a historical rescue showing problems that arose and the real need to develop a theory to solve them, which was not feasible with current theories. Thus, the students were able to observe a situation of exchange of models and theories within Physics.

After an introduction to the Theory of Relativity, Galileo's Relativity was first worked on. Videos, gifs and animations were used, as well as the demonstration of the model of Galileo's Transformations by the teacher. Then exercises were performed, and their correction was made. These activities lasted two classes of 50 min each.

Then two computer simulations were used, "Bolinha no Trem" and "Carros e Avião". The activities were carried out in groups, And the activity with the simulations was carried out in two classes of 50 min each. The control class did not perform this activity.

Continuing the activities, some more historical events were brought up briefly as well as the inconsistencies that arose between them and the Transformations of Galileo. Lorentz Transformations and the Michelson-Morley experiment were presented, using a representation video, and the expected and obtained results are discussed. These activities were carried out in two more classes of 50 min each.

Then comes Einstein's Theory of Special Relativity. The two postulates are presented, as well as their consequences, focusing on temporal dilation and spatial contraction. It shows how this theory could solve the problems that had arisen, and videos and gifs are brought. Then exercises are performed and corrected, using two more classes of 50 min each.

The last part of the activities was the use of the Lorentz Transformation simulations for Special Relativity, "Dilatação Temporal" and "Contração Espacial". This activity was also not performed by the control group and lasted two classes of 50 min each. Finally, two post-tests were applied, one for each situation. The same questionnaires used in the pre-tests were used in order to compare the responses of each student before and after the activities.

Analysis

The questionnaires of each student were analyzed individually and classified into four categories of comprehension according to their answers, total comprehension (TC), partial comprehension (PC), spontaneous conception (SC) and no comprehension (NC). The answer to each question was classified in one of the categories and, according to the result, the student's performance in that questionnaire was classified in one of these categories.

The *total comprehension* (TC) category comprises students who were able to understand the phenomena fully. The questionnaires include students who managed to correctly answer all the questions in the questionnaire in question, that is, who obtained TC for all their answers in the test.

In the category *partial comprehension* (PC) are students who understand the phenomena, but still have some difficulties with certain situations. They are those who understand that speed is relative, but have some difficulty with the referential change. They understand that space and time change, but they do not understand these changes well. Through questionnaires, it is students who answered a question incorrectly, be it PC, SC or NC, for example, or even two questions, but maintaining their answers between TC and SC, being mostly PC.

The *spontaneous conception* (SC) category includes students who base their responses mainly on spontaneous conceptions. These students have difficulty understanding inertia and an intrinsic idea of absolute movement. They also cannot conceive of the idea of time and space changing. In the questionnaires, these students answered most questions incorrectly, but always taking into account their response categories, that is, they could present some answer in TC, but also NC, being classified in SC.

Finally, the category *no comprehension* (NC) comprises students who have comprehensions with a level of understanding below spontaneous conceptions or have not provided an answer. Many are students with pre-Galilean conceptions, who strongly believe in the idea of absolute movement. In the questionnaires, they answered virtually all questions incorrectly, and may have some correct answers, but being mostly in the NC category.

In the present study, we performed an analysis of the results obtained with the tests. For this, the categories were converted into values 4, 3, 2 and 1, being TC, PC, SC and NC, respectively. The analysis of quantitative data sought to identify whether there was learning by students, comparing the pre and post-tests of each group and whether it was possible to identify differences between those who used and did not use computer simulations, comparing the experimental group with the control group. The data received statistical treatment, and the results of the nominal variables were expressed through frequency analysis and the results of continuous variables through mean ± standard deviation. The discussion of the data will take place based on the theoretical framework.

To assess the association between the results of the responses in the pre and post-test in each situation (Galileo transformations and Lorentz transformations) the Chi-Square test for independent samples was used, respecting the assumptions of the test. The Chi-Square test is a non-parametric test used for nominal variables and samples larger than 30. The choice of the test was since the distributions of two or more unrelated samples differ significantly in relation to the given variable and whether the variables are independent, or variables are not associated. The test is exclusively for nominal and ordinal variables, not applied if 20% of the observations are less than 5 and there can be no frequencies below 1.

The Wilcoxon test was used to compare the averages between the pre and post-tests in each situation. When the data do not satisfy Student's t-test, it is replaced by the Wilcoxon test. It is a non-parametric method for comparing two independent paired samples, and it is possible to see an increase, decrease or equality. The objective of the test is to verify if there was a significant difference in the performance of the subjects in

both situations, that is, for the two samples, pre and post-test, in relation to their averages in the tests.

Mann-Whitney test was used to compare the averages of the experimental group with the control group in each test. In some situations, Student's t-test could falsely report a significant result, so the Mann-Whitney test is used. It is a non-parametric test for unpaired groups used to check for evidence to believe that the values of one group are higher than the other.

Kolmogorov-Smirnov test was used to verify the normality of the data and a p <0.05 was considered significant in all analyzes. Kolmogorov-Smirnov test observes the maximum absolute difference between the cumulative distribution function for the data, in this case Normal, and their empirical distribution function. This difference is compared with a critical value, for a given level of significance, in our research, less than 0.05. The Statistical Package for the Social Sciences (SPSS) 21.0 software was used to perform the analyses.

RESULTS AND ANALYSES

As previously mentioned, 82 students from the third year of high school from a public school in the city of Montenegro / RS were analyzed during the Physics classes, with 62 students from the experimental group and 20 from the control group. In the present study, the associations with the pre and post-test in relation to the two situations were compared, as well as the mean responses between the pre and post-test, both for the Galileo Transformations and for the Lorentz Transformations, in addition to the relationship experimental and control group.

Experimental Group

The experimental group participated in all the activities that were carried out, that is, it had contact with the four types of mediations, social, cultural, psychophysical and *hypercultural*.

Galileo Transformations

This group showed a statistically significant increase in understanding from the pre to the post-test in relation to Galileo's transformations. Figure 5 shows an increase in the average of the post-test responses in relation to the pre-test, which is statistically significant for the Wilcoxon Test ($p = 0.01$), the average increased from 2.39 in the pre-test to 2.76 in the post-test.

Figure 5. Graph comparing the means of the pre and post-test of the Galileo Transformations in the experimental group.
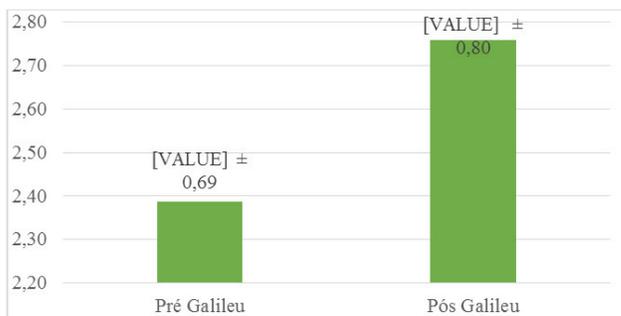

Figure 5. Graph comparing the means of the pre and post-test of the Galileo Transformations in the experimental group. (Souza, 2020)

When analyzing by categories, according to table 1, there is also a statistically significant difference in the Chi-square test of independent samples ($p = 0.03$), between the responses of students in the pre and post-tests of the Galileo Transformations. There was a drop in the number of students in the NC category, from 5 (8.1%) to 3 (4.8%) and in the SC category, from 30 (48.4%) to 20 (32.3%), the which is desirable, since they are the two categories of the lowest levels of understanding.

On the other hand, there was an increase in students in the PC category, from 25 (40.3%) to 28 (45.2%), and more significantly an increase in the TC category, from 2 (3.2%) to 11 (17.7%). Another desirable result as these are the two categories of greatest understanding.

Table 1
Association between pre and post-test for Galileo Transformations in the experimental group

Category	Pre n = 62	Post n = 62	p
			0,03*
NC	5 (8.1%)	3 (4.8%)	
SC	30 (48.4%)	20 (32.3%)	
PC	25 (40.3%)	28 (45.2%)	
TC	2 (3.2%)	11 (17.7%)	

*Significant at the 0.05 level

One can clearly see an increase in understanding regarding Galileo's Transformations for the experimental group, which participated in all activities. While we had a majority (35) in the categories that represent little or no understanding (SC and NC) in the pre-

test, we have a minority (23) in them in the post-test. On the other hand, while there was a minority (27) with greater understanding (PC and TC) in the pre-test, we found a majority (39) in the post-test.

Lorentz Transformations

Regarding the Lorentz Transformations, the experimental group also showed a statistically significant increase in their understanding. It is observed, in figure 6, a growth in the average of the responses of the post-test in relation to the pre-test statistically significant for the Wilcoxon Test (p = 0.01), the average went from 2.85 in the pre-test to 3 in the post-test.
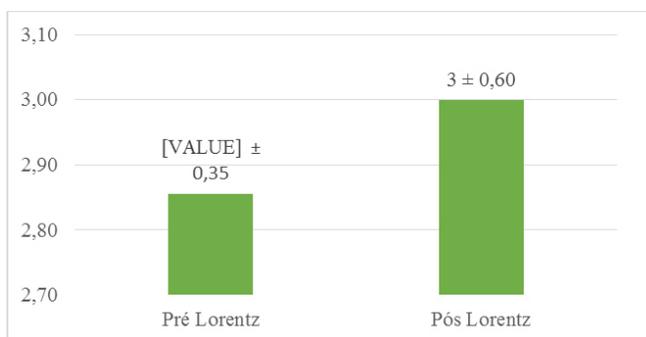

Figure 6. Graph comparing the means of the pre and post-test of the Lorentz Transformations in the experimental group. (Souza, 2020)

Table 2, analyzing by categories, also shows a statistically significant difference in the Chi-Square Test of independent samples (p = 0.02) between the students' responses in the pre and post-test of the Lorentz Transformations. There were no students in the NC category in the pre- or post-test.

There is an increase in the number of students in the SC category, from 9 (14.5%) to 11 (17.7%) and a decrease in students in the PC category, from 53 (85.5%) to 40 (64.6%). Although these numbers may give the impression of a negative result, in the TC category there was a large growth in students. While in the pre-test there were no students in this category, in the post-test we have 11 (17.7%). Thus, it is noticed that a significant number of students started to present a great understanding of the Lorentz Transformations in the post-test.

Table 2

Association between pre and post-test for Lorentz Transformations in the experimental group

Category	Pre n = 62	Post n = 62	p
			0.02*
NC	0 (0%)	0 (0%)	
SC	9 (14.5%)	11 (17.7%)	
PC	53 (85.5%)	40 (64.6%)	
TC	0 (0%)	11 (17.7%)	

*Significant at the 0.05 level

These results may suggest that, while some students were less clear when studying the theme more deeply, a significant portion managed to have a full understanding of the phenomena. This result is quite satisfactory since this is a topic of great difficulty for students to understand (Alias & Ibrahim, 2013; Kizilcik & Ünlü Yavas, 2016). In general, there was an increase in the understanding of Lorentz Transformations by students in this group.

Control Group

As mentioned earlier, the control group did not interact with the computer simulations but performed the other activities that were also performed by the experimental group. In this way he had contact with social, cultural and psychophysical mediations.

Galileo Transformations

Unlike the experimental group, the control group showed a difference that cannot be considered statistically significant between the results of the pre and post-test of the Galileo Transformations. As seen in figure 7, there was a certain increase in the mean of the post-test responses, going from 2.70 to 2.90, and this increase was considered significant for the Wilcoxon Test ($p = 0.01$).
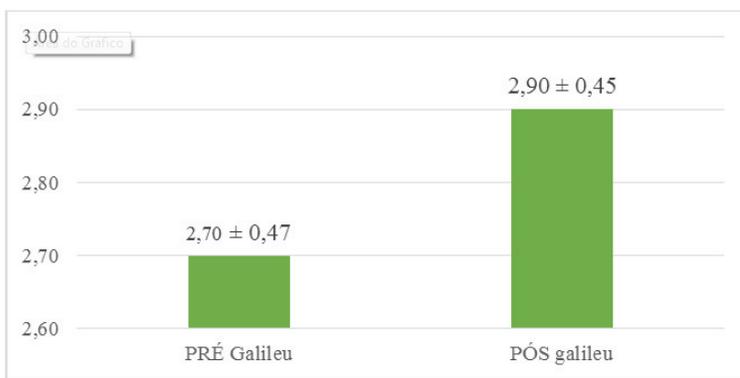
Figure 7. Graph comparing the pre- and post-test averages of Galileo Transformations in the control group. (Souza, 2020)

However, when analyzing by categories, as shown in table 3, we did not find a statistically significant difference for the Chi-square test of independent samples ($p = 0.34$). In the pre- and post-tests, there were no students in the NC category. The SC category had a decrease in the number of students from pre to post-test, from 6 (30%) to 3 (15%). The PC category had an increase in the number of students, from 14 (70%) to 16 (80%), as well as the category TC, which in the pre-test did not present any student, while in the post-test it presented 1 (5%).

Table 3
Association between pre and post-test for Galileo Transformations in the control group

Category	Pre n = 20	Post n = 20	p
			0.34**
NC	0 (0%)	0 (0%)	
SC	6 (30%)	3 (15%)	
PC	14 (70%)	16 (80%)	
TC	0 (0%)	1 (5%)	

**Not significant at the 0.05 level

These results suggest that the students in the control group already had previous knowledge about Galileo's Transformations, which is evidenced by the fact that we do not have students in the NC category even in the pre-test. Although they showed growth in their averages from pre to post-test, indicating that they started to understand better, this growth is not statistically significant. It is possible that, if they had interacted with the four mediations, this growth would have been higher.

Lorentz Transformations

For the Lorentz Transformations, the control group showed a regression in their averages from pre to post-test. While the mean of the pre-test was 2.75, in the post-test it was 2.60. This difference is shown in figure 8, but it cannot be considered significant for the Wilcoxon test ($p = 0.46$).
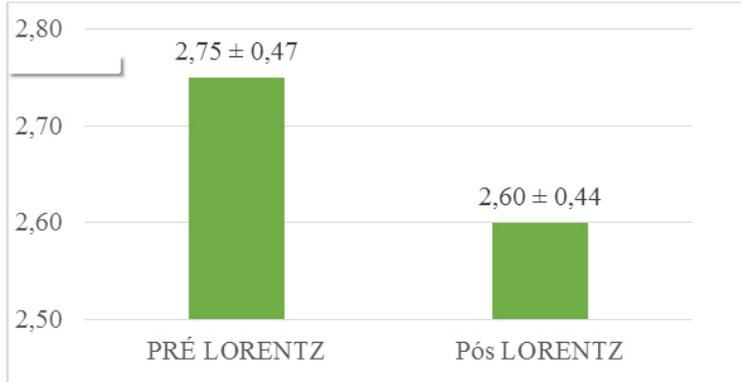

Figure 8. Graph comparing the averages of the pre and post-test of the Lorentz Transformations in the control group. (Souza, 2020)

On the other hand, when analyzing categories, according to table 4, there is a significant difference for this decrease according to the Chi-square test of independent samples ($p = 0.02$). As with the Lorentz Transformations experimental group, students in the NC category were not identified, either in the pre- or post-test.

In the CE category, there is an increase in the number of students from pre to post-test, from 6 (30%) to 9 (45%). On the other hand, the category CP had a decrease, from 13 (65%) to 10 (50%), while the category CT that presented a student (5%) in the pre-test continued presenting only one student (5%) in the post-test.

Table 4
Association between pre and post-test for Galileo Transformations in the control group

Category	Pre n = 20	Post n = 20	p
			0.02*
NC	0 (0%)	0 (0%)	
SC	6 (30%)	9 (45%)	
PC	13 (65%)	10 (50%)	
TC	1 (5%)	1 (5%)	

*Significant at the 0.05 level

These results indicate that, in general, the students in the control group showed a setback in relation to the Lorentz Transformations, which is evidenced, mainly, by the growth of students in the SC category in the post-test. Although through averages this difference is not significant, in the analysis by categories, it becomes.

The obtained result may indicate that, when they have more in-depth contact with the theme, however, without interacting with the simulations, that is, without contact with the hyper-cultural mediation, the students started to have less clarity regarding the phenomena. Our main hypothesis here is that, without the hypercultural mediation, the student is unable to develop mental images and drivers that would allow them to generate mental simulations of the Lorentz transformation. Therefore, they started to be more conscious of their lack of knowledge, show more doubts and performed poorly in the post-test.

Experimental Group vs. Control Group

For the comparison between the two groups, both for the Galileo Transformations and the Lorentz Transformations, the Mann-Whitney test was performed.

Galileo Transformations

Regarding the means of the groups in the Galileo pre-test, it is possible to notice that the control group had a higher average (2.76) than the experimental group (2.39), indicating that they already had some previous knowledge about the theme. However, this difference becomes small in the means of the post-tests, where the control group reached 2.90 and the experimental group 2.70, indicating that the experimental group showed more significant growth, as shown in figure 9.
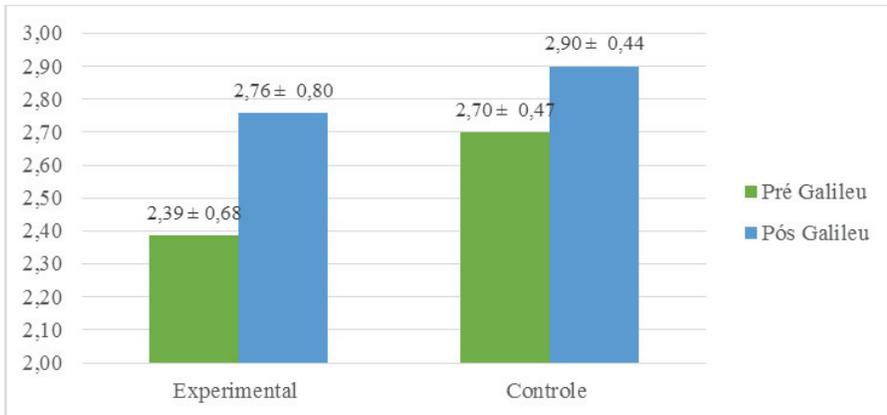
Figure 9. Graph comparing the means of the experimental and control groups in the pre and post-test of the Galileo Transformations. (Souza, 2020)

The Mann-Whitney test shows that the difference in means in the pre-test is statistically significant ($p = 0.02$); however, in the post-test it is not ($p = 0.32$), as shown in table 5. It is clear then that the experimental group reached a score very close to the control group in the post-test, indicating that they showed a higher growth.

Table 5

Comparison between the experimental and control groups in the pre and post-test of the Galileo Transformations

Group	Pre Galileo	Post Galileo
Experimental	2.39 ± 0.68	2.76 ± 0.80
Control	2.70 ± 0.47	2.90 ± 0.44
p value	0.02*	0.32

*Significant at the 0.05 level

This result may indicate that, when interacting with the computer simulations, the experimental group was able to overcome the differences found in the pre-test, most likely caused by the previous knowledge of the control group. Thus, the contact with hypercultural mediation apparently caused a difference in the results of the groups.

Lorentz Transformations

Regarding the Lorentz Transformations, as shown in figure 10, it is clear that the experimental group showed an increase in its average from the pre-test (2.85) to the post-test (3). On the other hand, the control group showed a reduction in its average from the

pre-test (2.75) to the post-test (2.60). Thus, the experimental group had a higher mean than the control group both in the pre and post-test of the Lorentz Transformations. This may indicate that the experimental group had some prior knowledge about the Lorentz transformations, but that it did not cause a significant difference with the control group; however, it still showed growth.
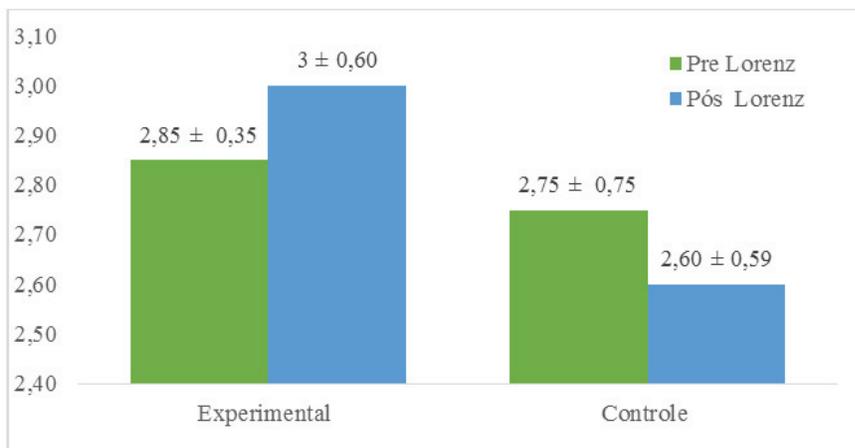

Figure 10. Graph comparing the averages of the experimental and control groups in the pre and post-test of the Lorentz Transformations. (Souza, 2020)

When we performed the Mann-Whitney test to compare the results, it is clear that in the pre-test there was no statistically significant difference between the means ($p = 0.43$). However, in the post-test, there was a difference considered statistically significant ($p = 0.01$) between the means of the groups. This result highlights the setback that occurred with the average of the control group, as well as the growth of the average of the experimental group.

Table 6
Comparison between the experimental and control groups in the pre and post-test of the Lorentz Transformations

Group	Pre-Lorentz	Post-Lorentz
Experimental	2.85 ± 0.35	3 ± 0.60
Control	2.75 ± 0.75	2.60 ± 0.59
p value	0.43	0.01*

*Significant at the 0.05 level

These results indicate that, for not interacting with the computer simulation, the control group ended up regressing when having more in-depth contact with the theme. This indicates that many gaps have emerged in the understanding of these phenomena.

These gaps can originate mainly, due to the fact that they are phenomena not observed in everyday life; thus, only through simulations are they visible. Thus, the interaction with *hypercultural* mediation lacked for these students.

On the other hand, the experimental group showed significant growth after having this contact, which indicates that they started to understand the phenomena better after the activities. That is, by having contact with the four mediations, mainly with *hypercultural* mediation, they were able to have a complete understanding of the Lorentz Transformations.

CONCLUSIONS

In this article, we bring a quantitative analysis of data from an application of activities on Einstein's Theory of Special Relativity. The activities were based on the Theory of Cognitive Mediation in Network, covering its four types of mediations - psychophysical, social, cultural and *hypercultural*.

While the experimental group interacted with all mediations, the control group did not interact with *hypercultural* mediation. The objective of the study was to verify if there was an increase in the students' comprehension after the activities as well as to compare the understandings of the experimental and control groups before and after the activities.

Through the results of the Qui Square and Wilcoxon tests, it was possible to verify that in the experimental group there was an increase in their understanding for both the Galileo Transformations and the Lorentz Transformations. The growth in relation to the Galileo Transformations was mmore significant, due to the greater complexity of the Lorentz Transformations, in which students generally have more considerable difficulties, as we could see in our literature review (Alias & Ibrahim, 2013; Kizilcik & Ünlü Yavas, 2016; Ünlü Yavas & Kizilcik, 2017).

On the other hand, the control group showed significant growth in the Galileo Transformations for the Wilcoxon test, but not for the Chi-Square test. It is noticed that this group had lower growth than the experimental group. Regarding the Lorentz Transformations, the control group showed a setback in both tests, indicating that, after having a more in-depth contact with the theme, they had less clarity regarding the phenomena.

Comparing the two groups, using the Mann-Whitney test, the experimental group showed a higher growth for the Galileo Transformations, and, in the Lorentz Transformations, it had significant growth, while the control group retreated. From these results, it can be concluded that the interaction with the four types of mediations is of great importance for students' learning. In addition, the importance of hypercultural mediation is evident, through computer simulations, which enhances learning.

Our results are in agreement with the literature since, in our review, other studies presented the efficiency of the use of Information and Communication Technologies

(ICT) in teaching the Theory of Relativity (Carr & Bossomaier, 2011; Hosson et al., 2011; Chu; Humer & Eckherd, 2019).

Therefore, the importance of using ICT is emphasized, allowing students to observe phenomena, especially in more abstract topics, such as the Theory of Relativity, which they cannot directly observe in their daily lives. The use of this type of resource brings significant differences in students' learning, as we can see with our results.

AUTHORS' CONTRIBUTIONS STATEMENTS

All the authors have made substantive contributions to the article and assume full responsibility for its content. All those who have made substantive contributions to the article have been named as authors.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, MGS, upon reasonable request.

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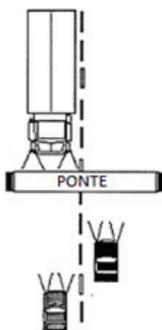# APPENDIX 1

Galileo Questionnaire Synthesis

Note the image:

You and your classmate are on the bus going to school, which is stopped at a traffic light. Suppose you are going to throw a paper ball and hit your colleague on the bench in front of you.

1) How strong do you have to throw the paper ball from one seat on the bus to another seat in front of you when the bus is running?

a) In the same way as if the bus was stopped.

b) Stronger than if the bus was stopped.

c) Weaker than if the bus was stopped.

d) It is impossible to hit the seat in front of you when the bus is running.

Note the image:

In the picture, you are in the gray car.

Your speedometer measures 40 km/h.

5) What is the speed of your car in relation to a helicopter flying very low going in the same direction as your car, with a speed relative to the ground of 200 km/h?

APPENDIX 2

Lorentz Questionnaire Synthesis

Two trucks are on the same road, in opposite directions, as shown in the figure. The distance between them is 100 m. Truck 2 is stopped due to an engine problem.
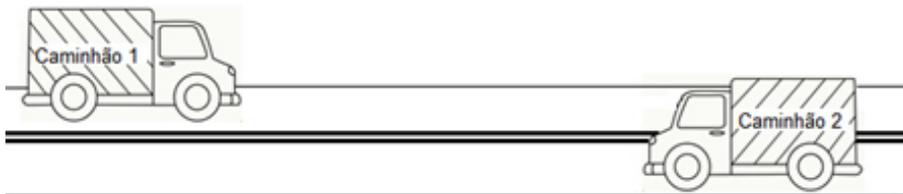

1) If truck 1 moves at 80 km / h, the distance it will travel to truck 2, measured by it, will be:

a) Equal to 100 m.

b) Greater than 100 m.

c) Less than 100 m.

d) Impossible to state.

3) Now, considering that truck 1 moves at a very high speed (0.7c), the distance it will travel, measured by it to truck 2 would be:

a) Equal to 100 m.

b) Greater than 100 m.

c) Less than 100 m.

d) Impossible to state.

Consider two friends who are the same age. One goes on a cruise trip, while the other stays in the city where they both live. The one who traveled back to your city 1 year after departure.
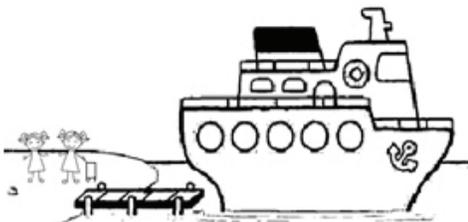
5) If the cruise travels at an average speed of 30 knots (56 km/h), the time that will have passed for the friend who traveled will be:

a) One year.

b) Greater than one year.

c) Less than one year.

d) Impossible to state.