Analysis of the Pedagogical Potential of the Virtual Laboratory of Gravity and Orbits in the PhET Platform

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ABSTRACT

This article is a segment of a dissertation on the pedagogical potential of virtual laboratories for the teaching of physics, specifically for the study of Kinematics. In this work, the virtual laboratory "Gravities and Orbits," available on the PhET platform, was analyzed. The methodology employed to obtain the data presented in this research is the three-analysis of pedagogical potential, a methodological tool for analysis. This method operates based on three predefined criteria: technical feasibility, depth levels, and contact Index. The three-analysis of pedagogical potential enables a comprehensive understanding of the requirements for its utilization, the potential for in-depth exploration, and the interaction with the concepts addressed in the tool. The analysis of the laboratory yielded a percentage of 94.5% for the index that quantifies the interaction between the laboratory and the user.

Author Keywords

Virtual laboratory; Kinematics; Physics Education; PhET platform.

ACM Classification Keywords

• Human-computer interaction;

• Physical sciences and engineering;

• Education.

INTRODUCTION

The teaching of Natural Sciences in traditional formats, especially in physics, where the teacher is at the center of the process (6), no longer meets the interests of students, much less the needs of Society (31). In addition, the technological advancements of modern society no longer allow for only classic teaching tools, such as a board and chalk (20).

The job market demands advanced skills in technological resources, and this is reflected in the classroom, where teachers must enable their students to solve problems encountered in current Society (4). In this context, it is necessary to make the students an integral part of the construction of their knowledge (13), making them active agents in their own formation.

Although the discipline of physics aims to aid in the understanding of phenomena present in the world, it is still viewed by many students as an obstacle to their Education (8) turning them into passive learners. This difficulty is faced by teachers; however, the discipline of physics has an extensive syllabus for a reduced number of weekly classes, which further complicates the teaching-learning process (17).

Including Information and Communication Technologies (ICTs) in Education is to educate citizens within Science, to form people capable of meeting current societal needs (28). Forming individuals who will be able to act, understand, and make decisions based on their knowledge [(10), (11)].

According to Moreira (18), the use of technological resources in Education can provide the necessary educational advancement in the field of Education, contributing to overcoming the crisis that exists in areas such as physics, where teachers at various levels of Education face problems in teaching, especially regarding the use of educational technologies in teaching.

Based on Moreira (17), there are several problems faced when conducting a laboratory activity in physical spaces, such as limited facilities, limited time allocation, and insufficient laboratory conditions to work with specific concepts. This ends up leading to laboratory experiences in overcrowded spaces that are not very encouraging and are far from any knowledge construction.

Safety problems, such as physical damage and handling of dangerous materials, are also considered in physical laboratories, depending on the instrumentation used. Considering the problems faced in this type of environment, virtual laboratories can be a viable alternative to overcome these problems (30).

Virtual laboratories simulate the environment and processes of physical laboratories and are defined as a learning environment in which students convert their theoretical knowledge into practical knowledge through the completion of experiments (3).

This text discusses the use of digital simulations as a tool for teaching and learning, particularly in the context of Science Education. The simulations are designed and sequenced in a way that simulates reality and can sometimes be a preferable alternative or a supportive learning environment for physical laboratories (7). Various studies in the literature have investigated the impact of laboratory activities on students' conceptual changes, comparing physical experimentation with digital experimentation. However, these studies do not provide an in-depth understanding of the pedagogical characteristics of these resources.

Malheiros (15) argues that the use of teaching materials in the teaching and learning process provides benefits for both students and teachers, such as simplicity in presenting data, easy visualization of phenomena, and the concretization of concepts, making the class more participatory and stimulating for students.

To promote the use of digital simulations as a teaching strategy capable of assisting students in constructing meaningful knowledge, the text focuses on analyzing the pedagogical potential present in the virtual laboratory of Gravities and Orbits from the PhET Interactive Simulations platform at the University of Colorado. The three-analysis of pedagogical potential (TPP) methodology will be used to investigate the virtual laboratory's potential.

RESEARCH CONTRIBUTIONS

The main contributions that emerged from this research, in the scientific, technological, and social scope, are:

- Development of an analysis methodology that will assist Education professionals in studies on educational tools;
- Encouragement of discussions about the use of technology in Education;
- Provision of studies on the application of virtual laboratories for the teaching of mechanics;
- Creation of scientific material for the development of strategies for technological Education.

PHYSICS TEACHING LABORATORIES

Studies on the use of instruments in laboratories have been going on for over a hundred years within the Sciences. As early as the 1880s, laboratory activities were used for teaching chemistry (9). Teaching with the aid of laboratories was considered an essential part, as it provided training for students' observation skills and offered more detailed information on scientific processes, as well as stimulated students' interest. These considerations are still accepted today (27).

Online laboratories are technological tools that allow users to explore experimental activities, and this interaction is mediated by digital technologies (5). There are different categories of online laboratories: virtual, remote, and hybrid. Virtual laboratories are simulations where any situation found in physical environments can be reproduced. Remote laboratories are environments in which students can manipulate real equipment from a different location, i.e., at a distance. Hybrid laboratories mix virtual and remote components in an effort to take advantage of both [(25), (27)].

Physical laboratories can also facilitate the teaching-learning processes of physics, but they come with some problems. Pyatt & Sims (25) claim that experiments in physical laboratories do not always promote conceptual changes in users' knowledge because they do not always solve students’ problems in understanding phenomena.

Virtual laboratories simulate real laboratory environments and processes and are defined as a learning environment in which students convert their theoretical knowledge into practical knowledge through conducting experiments (5). They are designed and sequenced in such a way that they enable the user to have real sensations of handling and interacting with equipment and/or substances. A virtual laboratory can sometimes be a preferable alternative or simply a supportive learning environment for physical laboratories (30).

RELATED WORKS AND PHET PLATFORM

Through a systematic literature review conducted on the following databases, journals, and periodicals: ACM, ACAAP, SciELO, Educitec, Renote, RBEF, Redalyc, RBPEC, FIE, IEEE Explore, OasisBR, and SBIE, it was noticed that the most used virtual laboratories in the literature are the ones present in the PhET platform, and therefore, in this work, the laboratory present in this platform will be analyzed.

The PhET platform offers free, interactive, and research-based Science and Mathematics simulations, where tests and evaluations are performed on each simulation to ensure educational effectiveness. In these simulations, the connections between real-life phenomena and the underlying Science are emphasized, and an effort is made to make the visual and conceptual models of physics experts accessible to users. A research-based approach is used in the projects, incorporating the results of previous research to create environments that support student engagement and understanding of physics concepts.

The virtual laboratories present in the platform use the Hypertext Markup Language version 5 (HTML5) markup language, with some simulations in Java or Flash programming languages (in the process of being updated to HTML5), and can be run online or installed on your computer.

THREE-ANALISYS OF PEDAGOGICAL POTENTIAL

The constant evolution of technologies causes a sense of relentless pursuit of adaptation to new technological means, and when it comes to Education, it is imagined that ideal tools have a motivational character for Learning. However, with the analysis of technological tools, concerns arise in Teaching, because, as Kenski (13) comments, the technologies employed in Education are characterized by the involvement of several procedures, in a process of synthesis and the emergence of new styles of reasoning, as well as the stimulation of the use of new perceptions and sensitivities.

The Three-analysis of Pedagogical Potential was developed to meet the need to analyze the pedagogical potential of an educational tool, using predefined criteria to study the characteristics present in these tools, and in this work, to investigate the virtual laboratories of the PhET platform for teaching Mechanics, which studies the movement of bodies.

This methodological analysis tool was developed in a research group funded by a CNPq technological development scholarship, of which the author of this article was a part.

The predefined criteria are technical feasibility, depth levels, and contact index and serve as analysis instruments and will underpin the discussions in the present work. Below is the contextualization of the criteria.

1. **Technical feasibility**

The use of virtual and remote laboratories has shown promising results as resources that provide an excellent strategy to enhance learning without the high costs of creating, designing, and maintaining physical laboratories. It is noteworthy that their use is recommended for any discipline that requires a laboratory, as they are resources that also allow access with the required distancing required by health protocols in emergency situations, such as those caused by the Covid-19 pandemic, which makes it impossible for students to be present in physical laboratories (27).

Understanding the ways to access a tool is an important criterion in the analysis of an educational resource [8], and with the aid of technical feasibility, it is possible to investigate how to use a pedagogical tool, with important information about the resource to be explored, such as the machinery necessary for its use, whether it is used online or offline, specific requirements for its operation, inclusive resources, and other functions that depend on each educational resource analyzed.

2. **Depth levels**

Remote experimentation is an educational application that allows users to obtain information from the real world through a computer, enabling them to execute actions on external devices in order to obtain instant results [(1), (2)].

This process aims to collect data to guide users on how to use the laboratory for a specific task in a certain environment. It is crucial to determine the pedagogical assumptions present in the tool for each user. Understanding its functionalities, applications, and properties is an essential part of the study of technologies employed in Education (19).

3. **Contact Index**

The Contact Index is a quantitative measure that accounts for the percentage of interaction between the user and a particular content studied mediated by an educational tool.

When inspecting an interface, the evaluator assumes the position of an end user (student) and takes into account their knowledge and experience in some activities offered by the resource, in order to identify problems, and errors in these proposals, that is, pedagogical paths that the user can follow and assist them in the learning process. This inspection method allows examining a technological resource and predicting of the possible consequences of its use.

The following formula 1 demonstrates how the index is calculated:

$$Contact\ index = \frac{user\ contact\ time\ [seconds]}{total\ time\ [seconds]} * 100$$

The user's contact time is a measure of how long the laboratory user is in direct contact with the concept being worked on in that environment. The total time used in this research is ten minutes (600 seconds). Multiplication by 100 is to obtain the final value as a percentage.

LABORATORY ANALYSIS

Table 1 details the three-analysis pedagogical potential Analysis, where the pre-defined criteria and their results will be presented, using the virtual laboratory Gravity and Orbits present in the PhET Platform[1].

Criteria	Analysis
Technical feasibility	Access can be done online or offline if the laboratory download has been previously made; Compatible with Google Classroom platform; HTML5 simulations work on portable computers (iPads and Chromebooks) and updated browsers regardless of the Operating System (Windows, Mac or Linux).
Depth levels	The laboratory has many functionalities, allowing the analysis of different properties present in the study of kinematics, such as: Describing the relationship between the Sun, Earth, Moon, and space station, including orbits and positions; Describing the size and distance between the Sun, Earth, Moon, and space station; Explaining how gravity controls the motion of our solar system; Identifying the variables that affect the strength of gravity; Predicting how the motion would change if gravity were stronger or weaker.
Contact index	In this simulation, a value of 94.5% was found for the contact index. For the calculation, formula 1 presented earlier was used with the values below: User contact time: 567 seconds; Total time: 600 seconds; Thus, the result is: $CI = \frac{567}{600} * 100 = 94,5\%$

Table 1. Analysis from the gravities and orbits laboratory

It is also noteworthy to highlight some observations made for each analysis criterion.

Criteria	Observation
Technical feasibility	The user is able to modify several functions within the laboratory, such as changes in visualization, measurements, physical concepts (velocity, gravity, mass, and others), and the execution of movements. The modifications made by the user during the simulations use sliders located in the laboratory's side menu or by manually moving the available celestial bodies in the virtual environment. The access interface is self-explanatory and highly interactive with the concepts of kinematics.

[1] https://phet.colorado.edu/pt/simulations/gravity-and-orbits

Criteria	Observation
Depth levels	There are two ways to use the laboratory: scaled and model. Each of these ways has peculiarities that allow the user to explore various functions working on kinematics concepts. Several factors modify the events in the laboratory, such as changes in the location of the stars, mass, gravity, and velocity. The laboratory allows the user to have contact with situations that simulate the reality of a solar system, with various characteristics present in this environment, which is an essential part of making the user an active subject in educational actions, allowing them to experience everyday events in a free, interactive, and conceptual way. It can be used at diverse levels of learning, both in a superficial and introductory way to the idea of motion and in a more in-depth manner for calculations.
Contact index	The values were obtained from simulations carried out by the authors in the virtual laboratory and, depending on the user, this value may vary. The user is an influencer and controls the actions within the laboratory, changing all events. The high value of the contact index confirms that this laboratory is a potential tool for the teaching of physics.

Table 2. Observations on the criteria of the virtual laboratory

Figure 1 illustrates a simulation conducted in the virtual laboratory of the PhET platform. The image showcases the central simulation, depicting the motion between the sun, earth, and moon, along with the velocity vector and gravity vector.

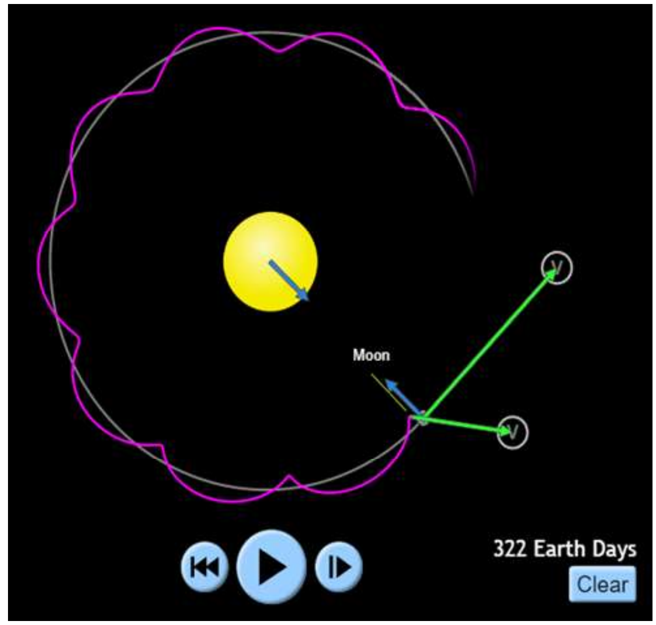

Figure 1. Virtual laboratory of gravity and orbits.

The demonstrations of Gravity Force, Velocity, path, and grid are optional and depend on whether the user wants to visualize them.

In this environment, it is possible to work with the contents of Circular Motion, Gravitational Force, and Velocity.

The virtual laboratory Gravity and Orbits is a flexible tool in its operations and can be used at different knowledge levels and in various ways, serving as an introductory resource or an object present in evaluations.

This laboratory makes the user highly influential in the events within the experimentation, making them an active subject in educational actions (19).

Moran (16) comments that many times technologies in Education end up becoming just a content demonstration, but when analyzing the laboratory, it is found that it has a 94.5% contact index.

It is noticeable that the user can alter and control what happens in the simulation, allowing for free exploration, without pre-established content, offering the user a high range of probable situations and not just a content demonstration.

Figure 2 illustrates the configuration panel of the virtual laboratory, where the user can modify various functions of the environment.

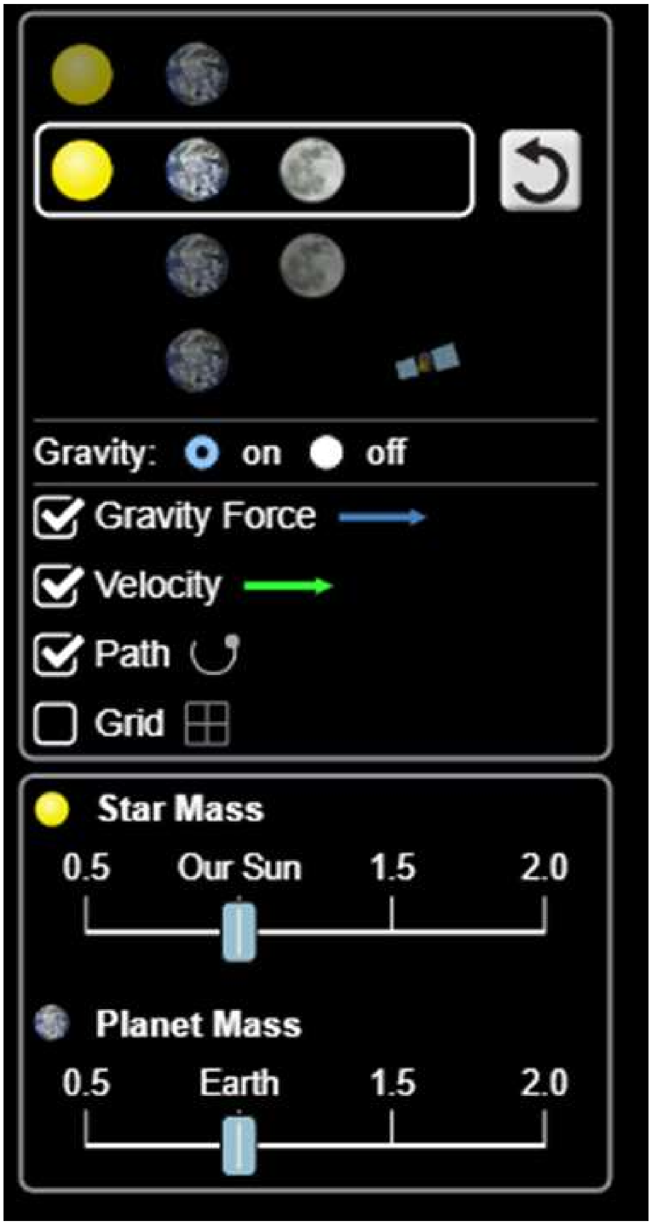

Figure 2. Virtual laboratory control panel.

The first section of the panel pertains to the type of simulation the user would like to perform, ranging from the Sun, Earth, Moon, and artificial satellite. The second section allows for changes in the visualization modes of the effects present in the laboratory. The third section directly modifies the units of the systems in the simulation.

This data collection was conducted to study the use of technologies employed in education. By performing tasks within the environment provided by the laboratory, the aim was to determine the characteristics present in it that can be used in real educational settings, thus assisting students and teachers in the construction of concepts.

DISCUSSIONS AND FINAL CONSIDERATIONS

Studying and understanding the relationships among the numerous variables related to physics education, such as Velocity, Gravity, and Vectors, can be a challenging task with static demonstrations in the classroom. These difficulties can be overcome by utilizing a virtual laboratory as an empowering strategy for educational environments.

Physics content needs to enable the development of competencies in students and necessitates the search for new didactic alternatives capable of provoking conceptual changes in physics Education, as well as the development of a set of strategies.

The interactive process that underlies the use of a virtual laboratory allows this resource to have a high level of contact index, corroborating with [(12), (22), (23), (24)] and enables citizens to become literate in Science and form individuals capable of meeting the current needs of society, as highlighted by Santos & Schnetzler (29) as a requirement for contemporary life.

To study the use of technologies employed in Education, data collection was conducted, focusing on the execution of tasks available within virtual environments. The aim of this search was to determine the characteristics present in the laboratory that can be used in real teaching environments to assist students and teachers in concept construction.

Many researchers utilize inspection evaluations to predict the consequences of using technological resources in educational environments [(26), (28), (32)] and consider this resource fundamental for improving technological interaction mechanisms.

It is evident that virtual laboratories allow users to efficiently manipulate different environments and processes at a low cost. They also assist users in making associations between theory and practice. This process is made possible through the planning and construction of this resource, which is designed directly for user utilization, aiming for their interaction, theoretical input, and dynamism [(14), (21), (31)].

Finally, it is hoped that this work can contribute to the creation of public school policies that improve the school environment. It would also be of great importance for teachers to participate in continuous training courses as a way to update their theoretical and practical knowledge, enabling them to conduct more elaborate and productive lessons.

REFERENCES

1. Akpan, J., & Strayer, J. 2010. Which comes first the use of computer simulation of frog dissection or conventional dissection as academic exercise?. Journal of Computers in Mathematics and Science Teaching, 29(2), 113-138.

2. Barnea, N., & Dori, Y. J. 1999. High-school chemistry students' performance and gender differences in a computerized molecular modeling learning environment. *Journal of Science Education and Technology*, 8(4), 257-271.

3. Bastos, A. M. 2020. Tecnologias digitais: uso do Physics Education Technology Project (PhET) no ensino de eletrodinâmica. *Research, Society and Development*, 9(9), 146-163.

4. Borges, A. P., Peres-Lisboa, M. O., & Alexandre, S. E. 2000. Virtual Laboratory Associated to Intelligent Instrumentation. In *IES 2000 Internet Education Science,* Ucrânia.

5. Delamuta, B. H., Neto, J. C., Junior, S. L. S., & de Souza Assai, N. D. 2021. O uso de aplicativos para o ensino de Química: uma revisão sistemática de literatura. *Educitec-Revista de Estudos e Pesquisas sobre Ensino Tecnológico*, *7*, 14-28.

6. dos Santos, C., da Silveira Freitas, P., & Lopes, M. M. 2020. Ensino remoto e a utilização de laboratórios virtuais na área de ciências naturais. *In Salão Internacional De Ensino, Pesquisa E Extensão*, *12*(1).

7. Dos Santos, R. V. 2016. A utilização do software livre Phet como material de apoio ao professor no processo de ensino-aprendizagem de física. Master's thesis. Universidade Federal do Piauí, Centro de Ciências da Natureza. Teresina, Piauí.

8. Evald, T. C. 2021. Experimentação em circuitos elétricos como uma prática metodológica de Ensino. Master's thesis. Instituto Federal Sul-rio-grandense, câmpus Pelotas Visconde da Graça. Pelotas, Rio Grande do Sul

9. Fay, Paul J. 1931. The History of Chemistry Teaching in American High Schools. *Journal of Chemical Education*. v.8, n. 8, 1533-1562.

10. Fourez, G. 1995. *A construção das Ciências: introdução à filosofia e à ética das ciências*. Editora da Universidade Estadual Paulista, São Paulo, Brasil.

11. Gadotti, M. 2012. Educação popular, educação social, educação comunitária. In: *Congresso Internacional de Pedagogia Social.*

12. Jaakkola, T., Nurmi, S., & Veermans, K. 2011. A comparison of students' conceptual understanding of electric circuits in simulation only and simulation‐laboratory contexts. *Journal of research in science teaching*, *48*(1), 71-93.

13. Kesnki, V. M. 2003. Aprendizagem mediada pela tecnologia. *Revista Diálogo Educacional*, v. 4, 47-56.

14. do Prado, M. D. F. W., Hecher, D., & Boff, E. 2010. Um Objeto de Aprendizagem para apoio a Aprendizagem de Física. *RENOTE*, *8*(3).

15. Malheiros, B. T. 2012. *Didática Geral*. LTC. Rio de Janeiro, Rio de Janeiro.

16. Moran, J. M. 2004. Os novos espaços de atuação do Professor com as Tecnologias. *Revista Diálogo Educacional*, v. 4, 13-21.

17. Moreira, M. A. 2017. Grandes desafios para o ensino da física na educação contemporânea. *Revista do Professor de Física*, v. 1, 1-13.

18. Moreira, M. A. 2018. Uma análise crítica do ensino de Física. *Estudos avançados,* v. 32, 73-80.

19. Mota, F. A. C.; Mesquita, D. W. O.; Farias, S. A. 2015. Uso de materiais alternativos no Ensino de Química: o aluno como sujeito ativo no processo de ensino e aprendizagem. In *Encontro Nacional de Pesquisa em Educação em Ciências–X ENPEC*, p. 1-8.

20. Nicolete, P. C.; Herrmann, R. F. D.; Herpich, F.; de Oliveira Júnior, E. T.; Tarouco, L. M. R. 2021. A motivação de estudantes ao utilizar laboratórios online para aprendizagem experiencial de circuitos elétricos durante a pandemia do Covid-19. *RENOTE*, *19*(2), 152-162.

21. Oliveira, K. K. de S., Fioravanti, M. L., Barbosa, E. F., Souza, R. A. C. 2021. Avaliação dos Habilitadores da Educação 4.0: Transformação Digital da Educação Multidisciplinar em Mudanças Climáticas. In: *Simpósio Brasileiro de Informática na Educação*. p. 58-67.

22. Ortiz, J. O. de S., Kwecko, V., Tolêdo, F., Devincenzi, S., Botelho, S. S. da C. 2020. Recursos Educacionais Abertos: Uma Análise dos

Objetivos de Aprendizagem Referenciados pela Taxonomia Digital de Bloom. In: *Simpósio brasileiro de informática na Educação*. p. 122-131.

23. Peres, F., Morais, D., Queiroz, S., Santana, B. 2020. Desenvolvimento de Artefatos Digitais por Estudantes na Educação do Campo: Uma Pesquisa-Ação em Comunidades de Prática. In: Simpósio Brasileiro de Informática na Educação. p. 212-221.

24. Pinheiro, A. J. M. 2020. Atividade lúdica e hábitos digitais: um estudo com acadêmicos em processo de formação no curso de Pedagogia EaD. Master's thesis. Universidade Pitágoras Unopar. Londrina, Paraná.

25. Pyatt, K.; & Sims, R. 2012. Virtual and physical experimentation in inquiry-based science labs: Attitudes, performance, and access. *Journal of Science Education and Technology*. 21(1), 133-147.

26. Ribeiro, J. F.; da Silva, B. S. 2022. Avaliação automática de acessibilidade do portal da UFRN. *#Tear: Revista de Educação, Ciência e Tecnologia*, v. 9.

27. Rodriguez-Gil, L.; Zubia, J. G.; Orduña, P.; Lopez-de-Ipina, D. 2017. Towards new multiplatform hybrid online laboratory models. *IEEE Transactions on Learning Technologies*, v. 10, p. 318-330.

28. Santos, R.D.; Silva, B.S. 2022. Comparação de Métodos de Avaliação de IHC sob a Perspectiva do Autor da Interface. In: *Congresso Pesquisa e Desenvolvimento em Design*. p. 5302-5316.

29. Santos. W. L. P., Schnetzler, R. P. 1997. Educação em química: compromisso com a cidadania. Ijuí: UNIJUÍ.

30. Tatli, Z.; & Ayas, A. 2013. Effect of a Virtual Chemistry Laboratory on Students' Achievement. *Journal of Educational Technology & Society*. 16(1),159-170.

31. Tuyarot, R. D.; Tesseroli, de C. R. 2016. Objetos Educacionais Digitais na EAD e Educação Inclusiva na Área de Física. *RENOTE*, 14(2).

32. Valentim, N. M., da Silva, T. S., Silveira, M. S., & Conte, T. 2013. Estudo comparativo entre técnicas de inspeção de usabilidade sobre diagramas de atividades. In: *XII Simpósio Brasileiro sobre Fatores Humanos em Sistemas Computacionais*.