Remote access experiment as a facilitator for teaching modern and contemporary physics in secondary schools

A Luciano¹, A P Giacomassi Luciano², P R Garcia Fernandes², H Takai³ and P Altoe Fusinato²

¹ UniCesumar, Maringa, Parana, Brazil
² University State of Maringa, Maringa, Parana, Brazil
³ Stony Brook University, Stony Brook, New York, USA

arquimedes.luciano@hotmail.com

Abstract. Many of today’s technological devices are grounded in theories of modern and contemporary physics (MCP). Their introduction into the high school classroom often requires access to sophisticated equipment. This is a difficult situation for public schools in Brazil, where the cost of implementing such laboratories is considered very high. This article introduces and discusses the concept of a Remote Access Laboratory for Modern Physics. This lab is possible because of the internet. It was designed to facilitate the teaching of modern physics in high school. Upon entering the laboratory, the physics teacher has the possibility to perform experiments in modern physics remotely. The lab is configured with remote cameras and automated devices to provide telepresence to attendees. The experiment used in this research was a cloud chamber, which detected cosmic rays and particles from a radioactive source. Two teachers and 150 students from two public high schools participated in this research. The lesson plan was developed to ensure a sequence of activities in the classroom. To evaluate our activities, we conducted interviews with the teachers and applied questionnaires to the students. We identified that after the activity was carried out by the students a greater demand for information on Physics on the internet. In addition, among the capabilities of the recognized laboratory, we mentioned the connection of MCP events to the students’ daily lives. The report of the participating teachers presents a favourable view towards the adoption of this initiative in the classroom for the introduction of modern and contemporary physics.

1. Introduction
The use of experimental activities related to the subjects dealt with by Modern and Contemporary Physics (MCP) can help in students’ motivation and understanding learning these themes. When approaching the concepts from the contact with physical phenomena related to this area of knowledge. For more than a century, the use of experimental activities in physics teaching has promoted students’ approach to physical phenomena [1]. This approach usually serves as a motivating element for the student. In this way, the planning of how to carry out such activities together with the students allows these practices to illustrate the way of doing science, stimulating them to engage in critical thinking [2].
However, in several regions of Brazil, the task of providing equipment to schools to make feasible experimental practices becomes complex, since such instrumentalization requires too many financial resources, in addition to the need to quickly train groups of teachers to carry out activities. An alternative to the problem of the flexible dissemination of laboratory equipment, especially for more expensive equipment, may be the use of remote access laboratories. These laboratories consist of the extension of one or more real measuring instruments through a distributed data network [3]. According to [4], a remote laboratory is characterized by the mediation of reality, allowing the students to directly trigger the experiment, being, however, distant from the operator, thus requiring specific hardware and software to perform this mediation.

Thus, we believe the use of a remote access system to conduct MCP experiments tends to allow the development of the necessary knowledge of our students. In this experimental model, the student controls the equipment and performs the experimental investigation. Visualizing in real time the images of the equipment that he uses for his laboratory practice. In addition, data collection occurs in an automated way, facilitating the organization of data related to the experiment, allowing the use time to be better used and the student's focus, or the understanding of the physical phenomena related to the experiment. In a remote access lab, thanks to the possibility of real-time video transmission of the experiment being carried out, an almost immediate response to changes made at a distance from the experiment is obtained. According to [5], it is possible to observe, in the practical activities of the Physics discipline, that the student learns to use schemes, to use mathematical relations. Therefore, it is necessary to consider the importance of symbolic languages in the learning of physics.

We characterize our research within the qualitative field, since “qualitative research methods highlight the importance of various perspectives, recognizing there are other ways of visualizing and explaining things, as well as the ways and alternatives to change them” [6]. In this way the evaluations carried out involved multiple possibilities of observation, interventions and data collection, so that we could better understand a group of individuals in a specific reality and, thus, also produce a conclusion about this specific situation. In this way, we established, for this research, the general objective of investigating the pedagogical potential of a remote access laboratory for the teaching of modern and contemporary physics (MCP) in high school.

Among the activities developed in this work, we use constructionism as a methodological contribution to guide teaching actions, for “the kind of knowledge that children need most is what will help them gain more knowledge.” [7]

2. Methodology
Considering improvements in the learning process, allowing interdisciplinarity, a remote access laboratory was built in the Department of Physics of the State University of Maringá, aiming to expand complementary teaching actions. With the objective of reaching the pedagogical potential of our proposed research, we established contact with a network of teachers attending the high schools of the city of Maringá. These students study in the high schools Silvio Magalhães Barros and Tomaz Edison Vieira.

The choice of these actors was intentional, because the teachers sought methodological changes in teaching and showed interest and willingness to participate in innovative activities in teaching. This educational action had the involvement of approximately 150 high school students, activities taught by two teachers of the physics discipline. We organized the activities of this research in two stages: (1) construction of the MCP experiments to be accessed remotely, and (2) preparation of teachers to use this teaching platform with their students.

2.1. Step 1: Building the Remote Access Lab
We built the entire web access framework using the HTML5 language and the control system through the language Node.js, which is a programming platform, built in the JavaScript mechanism. These languages have open code, which facilitates the understanding of the built blocks.
For the construction of the interface units between the experimental devices and the internet, we used the Arduino prototyping platform [8] in the data acquisition stage. This Arduino controlled a set of relays that controlled the experiment, as well as providing a measure of the temperature inside the cloud chamber. It is connected to a Raspberry Pi mini-computer [9], which is the unit that serves as an internet connection. We use this hardware for the great freedom of construction allowed by these devices, the processing power of Raspberry Pi, and the possibility of not using proprietary software [9].

Video cameras used for image capture are based on Internet Protocol (IP) technology, given the versatility of the internet connection, since they are video cameras built to work while connected to the internet. Thus, all experimental devices were connected to the internet interacting as an organism in an automated way. The various connected equipment remains able to communicate, independent of the action of an operator, to exchange information and maintain the functionality in a way that is transparent to the user.

During the planning of the devices to be considered, we evaluated both the stability of the equipment (it needs to stay connected for a long period) and the cost of installation, considering users would not need to use any host program on their computer to use the lab. Figure 1 shows a diagram of the devices connected in our remote access lab.

![Diagram of the devices connected in the remote access lab.](image)

**Figure 1.** The remote access lab.

To produce an experiment that could be remotely controlled and be within the scope of content addressed in the MCP, we chose the diffusion cloud camera. This apparatus, originally implemented by as a cloud chamber by expansion [10] and reworked by Alexander Langsdorf Jr in 1938 [11] allows, from the production of a supersaturated fluid, observation of the traces left by ionizing particles traveling through supersaturated steam. The cloud chamber consists of one of the first devices to observe and measure radioactivity.

The diffusion chamber used by us, therefore, follows the Taylor model, but also presents an electric field gradient between the upper surface and the lower surface, according to the model of Ref. 12. “In all cases, the vapor diffuses from the heated surface until it is sufficiently cooled to produce the supersaturation necessary for the formation of condensation by the ions” [13]. Fundamental in this apparatus is the production of the necessary condition for the fluid to be condensed by ionization during the passage of the ionizing particles.

As ionizing particles, we used two possibilities: At the first moment of the experiment, the students could see the traces left by a radioactive source of $^{210}\text{Pb}$ with emission of alpha and beta radiation. Then they were able to remove the radioactive source, and so the marked trajectories in the chamber came only from high-energy particles, naturally available in the laboratory environment. Alpha, beta and muon particles, characteristic of cosmic rays, could be identified. Cosmic rays are particles inside and outside our galaxy that continually bombard the Earth. Many of these particles are neutrinos.
As we showed, students accessed the lab’s web address, and using the available controls could turn on the device by cooling the cloud chamber. And through these controls request the insertion or removal of a radioactive source. At the end of the experiment, the system could be shut down remotely or automatically when it identified a connection at the address.

2.2. Step 2: Elaboration of didactic material and application in schools

In order for teachers to be motivated to participate in activities, we include them in all stages of construction and planning. Then, together with the teachers, a didactic sequence was developed, following the assumptions of Zabala [14] in which we selected which activities would be developed involving the cloud camera experiment.

In this didactic sequence, we reinforced the concern to use the experiment, following the assumptions of constructivism as a methodology to try and guarantee the effectiveness of the cycle of cognitive activities of Valente and Canhette [15]. The objective of the didactic sequence was that teachers could apply it in the classroom, with their students, so that the activities using the remote access laboratory as a didactic resource were favorable to learning selected content.

We structured the didactic sequence in the following way: In the introduction we present physical concepts related to the new technologies, and to motivate the reflections of the students we put the following question: what things are done? We also raise questions about solar storms and their impacts on human activities. This content is often excluded from the curriculum due to the small number of classes in the physics discipline. The experiment was the cloud chamber, dealing with fundamental concepts for the understanding of its functioning, like structure of matter and elementary particles, radiation and cosmic rays, as well as their interactions with matter.

Thus, the conceptual problem related to the constitution of matter, with the intention of understanding that there are other particles besides electrons, protons and neutrons. Therefore, they presented the students with particles such as quarks, muons, gluons and neutrinos. In addition to presenting the interactions, differences and classification of elementary particles. Students were also described how a cloud chamber works. There was teaching material that provided clues for students to identify the observed particles. The total duration of the didactic sequence was six hours, two of theoretical introduction and discussions and two working with the remote access laboratory. At the end of these four classes, a focus group activity was held to discuss the actions developed and the contents learned.

The cloud chamber has played a very important role in the advancement of high-energy particle detection systems and is an experimental activity with great conceptual gain because it shows the interaction of the particles with the supersaturated vapor present in the chamber in a very perceptible way. The main objective was to familiarize students with concepts of particle physics, covering the composition of matter, nuclear physics, in addition to the use of new technologies in the classroom, in this case, the remote access laboratory.

In the evaluation process, we observed, from what was done, what was useful for students, to increase their knowledge about the concepts of particle physics and that nature that surrounds them still contains beautiful elements to be observed and understood in their entirety. Thus, during the experiment the teachers were moderators of knowledge helping students to access the laboratory. However, after class closing, students still continued to access the lab remotely.

For the data collection we applied a questionnaire prior to the experiment that produced a first set of student statements. After the experiment was carried out, we applied another questionnaire. By comparing the students’ utterances before and after the experiment, it was possible to establish an analysis of the use of this experiment. And to corroborate these statements, we interviewed the teachers before and after the experiment. Thus, we can produce a triangulation between the perspectives and learnings produced through the use of this activity.
3. Analysis of Results

According to [16] and [6], it is of the utmost importance in a research process to organize the data collected and to treat them through a (technical) method of analysis that allows the researcher to separate the statements and observations that are relevant from those that are not.

To maintain the anonymity of the research participants, we will use the following standardization: A1 will represent the student’s utterance 1. In this way, when we use the binary compound, beginning with the letter A and appending to a natural number, we will indicate a student’s utterance. In the same way, we will use the binary P1, to indicate the teacher’s utterance 1.

We used as theoretical reference for the analyzes the Discursive Textual Analysis [17], a qualitative method developed by the researcher Roque Moraes. We present below three categories analyzed in the testimonials of students and teachers that were investigated in this research.

3.1. Category 1: The reality of particles

The first questioning, done to the students, investigated their perceptions about the solar storm. The students thought about such a phenomenon after reading a story about an event that produced great destruction after a solar storm hit planet Earth. With that motivation, they had to answer about how a solar storm, coming from outside planet Earth, could cause harm to society.

Among the utterances, we highlight Student A2’s utterance: “The solar storm emits radioactive particles that radiation could affect satellites and compromising the media could also affect the Earth's magnetic field and bring about future climate problems.” The same student, when questioned about the possibility of observing these particles from space, pointed out that, “we cannot observe them because they are not visible to the human eye because of its size and structure”.

Lack of understanding of the aspects of the MCP can lead students to an incorrect judgment given their lack of knowledge in these respects. Thus, even in the initial discourses of the students, we observe descriptions like the student A16: “Because they are being released by a radioactive source that harms us, because the particles are also radioactive and when they reach large amounts we can have health problems”; another student A15: “As they are particles of High Energies, I believe that with their junction they increase even more energy, so when it finds the High Energy it has here on earth it causes a very great destruction.”

The student A7 points out that “particles damage or destroy all electrical appliances in their path, like energy overload, leading to major disasters to places dependent on the operation of electrical appliances, such as the regulation of nuclear power plants”. All early utterances denoted a naive view of the existence of high-energy particles. However, considering the need for scientific literacy, “there is a broad consensus on the need for scientific literacy to prepare citizens for decision-making” according to [18].

Thus, the proposed experiment allowed teachers to approach the treated content of the students' reality, because, according to the student's discourse A13, when asked about the prior knowledge of the existence of the fundamental particles present in the experiment: “Yes, I had only the theoretical concept, with the experiment I was able to visualize in practice.” The experiment, therefore, made it possible to bring the existence of the particles of high energies into the reality of the student. According to student A4, “In the cloud chamber particles were observed, which normally remain ‘invisible’ to our eyes.”

Among the particles, there are traces with three differences in which one had a thin line, one thick, and finally one undulating. Another student, A22, points out that “we saw alpha particles and electrons, they have different charges and therefore take different directions.”

Student A6 indicates that “knowledge about particles is in fact existent, but their origin and function were unimagined ... after the experiment, the understanding was broadened and was making clear the importance of the particles in our lives”. The cloud chamber is a device for detecting charged particles, since only electrically charged particles can produce the ionization required to form the expected droplets to perceive the passage of a particle [19].
What draws attention in the students’ utterance is the understanding that there is a phenomenon occurring in the camera and that this phenomenon also occurs in the classroom, but the effect is not revealed by the absence of a means that allows observation. Our intervention allowed these students to change their way of perceiving the world through the use of a didactic resource that contemplated the new technologies of information and communication.

3.2. Category 2. MCP Concepts

It is fundamental, in a teaching process, that learning has meaning for the learner, recognizing the prior knowledge of the learner. Therefore, it is necessary to evaluate students’ perceptions of everyday problems, even if they appear to be very advanced problems. So we asked about common situations to gather the necessary information, and we identified several conditions of previous knowledge. The issues that generate the discussions analyzed in this section are organized in Table 1.

| Question                                                                 | Goal                                                                 |
|-------------------------------------------------------------------------|----------------------------------------------------------------------|
| Considering that such particles can be found on planet Earth, explain why you cannot observe them at this time (while answering the questionnaire). | Find previous concepts of the students in front of the MCP. |
| What do you believe could be done to see these particles? Describe or draw how you imagine these particles, are they colored? Are they geometric? | Find previous concepts of the students in front of the MCP. |

However, we also identify lines that associate the unknown with something frightening, such as student utterance A11: “Particles from the Sun would overload the Earth’s electrical networks, leaving the planet dark and with great damage.” Or, even more catastrophically, student A41: “The particles cause such destruction because they are very hot.” Both lines depict an attempt to adapt the cosmic radiation to the concepts associated with the presented report, that is, the search for associating the observed phenomenon with the current paradigm.

Another catastrophic perspective comes from student utterance A47: “Particles damage/destroy all electrical appliances on their way with an overload of energy, leading to major catastrophes.” But we have some very intriguing answers like the A41 student utterance: “It must be the dotted green dot and its red outline and make a spectacle to see them.” The utterance of A47 also points to an interesting view of the problem: “Because human perception is limited to a certain size, the particles we perceive are understood as the heat of sunlight.”

These representations of the particles of cosmic radiation were fundamental to establish the activities in our didactic sequence, since we carried out the application of the questionnaire and, with the answers in hand, we established the planning of the teaching [14]. We believe that these initial visions of the students represented a good knowledge base to produce links with the information and experiences that we would work with the students to assist them in the production of their knowledge [7].

3.3. Category 3: Changes produced through the remote access laboratory.

In this theme we evaluated the questions regarding the use of the remote access laboratory, as well as the observed changes in the utterances of the actors, after performing the experiment. We also confront the utterance of the teachers who mediated the actions with the students. Table 2 contains the generating question answered by the students, and Table 3 organizes the generating questions answered by the teachers.
Table 2. Questions for students analyzed in category 3.

| Question                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Goal                                                                                                                                                                                                                                                                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| In previous classes they maintained contact with concepts of modern physics, referring to solar storms and elementary observable particles. Describe what you viewed in the cloud camera. Were you able to perceive traits with different characteristics? How many different traits did you see?                                                                                           | Investigate the learning potential of the project.                                                                                                                                                                                                                                                                                                        |

Table 3. Questions for teachers, analyzed in category 3.

| Question                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Goal                                                                                                                                                                                                                                                                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Describe what has changed in your teaching perspective after participating in this project.                                                                                                                                                                                                                                                                                                                                                                               | Check the teacher’s position on the methodology                                                                                                                                                                                                                                                                                                       |
| Was the students’ understanding of the contents perceptible?                                                                                                                                                                                                                                                                                                                                                                                                           | Investigate the learning potential of the project.                                                                                                                                                                                                                                                                                                        |

In the first utterances, both by the students and the teachers, a certain distrust arose. Students doubted the possibility of such particles, or how to observe them. On the teachers’ side, there was the suspicion of difficulties in evaluating such an innovative cycle of activities.

When asked about the observations, student A12 reveals: “I could observe in the cloud chamber small particles that can only be seen through this chamber, showing certain risks in opposite directions”. Possibly, according to [19] and [20], what our student was observing was low-energy muons like those of Figure 2. In the figure it is possible to observe, in addition to the low-energy muons, an event of a more massive particle, probably an alpha particle.

![Observing particles.](image)

Figure 2. Observing particles.

For Professor P2, “with the opportunity to use this experiment, the students experienced in a practical way what they had contact with the theoretical part”. He added that “when students were able to access the lab, they were very motivated and questioned about new experiments being accessed”. According to [7], [21] and [22], constructivism tends to encourage learning to learn. And together with this learning theory, we have the methodology of [14], which was also considered to be aligned with the learner autonomy, being the approximation path to allow an adequate interaction between teacher-student-computer.

Professor P1’s utterance highlights that “the way to have experiments in physics that is not a video is real, not only in the book, or in the teacher's utterance and students can also see how it is assembled, follows the mounts” and in this discourse we can again identify the possibility of using the remote experiment to allow change in the teaching methodology of a school.
Thus, following the propositions of [23], we can identify the cycle of interactions of the technique, produced by the temporal culture of that society, leading to a change of attitudes in society, developing this cycle.

According to Professor P1, “some students came to draw on what they saw in the notebook, it was perceptible to change the behavior of the students before the discipline, even if there was a strike, the students still remembered the activity”. The teacher’s utterance brings a relevant question, because during the development of this research there were strikes, paralyzes and even occupation of the college, situations that clearly interfere in the learning process.

But the teacher’s utterance about the possibility of performing an activity that was real, even at a distance, brought a unique possibility to his classes, which, he said, allowed to associate significantly theory to practice, revealing a daily but not very identifiable physical phenomenon in the students' reality.

In the words of A14, “Yes I could observe various traits, many were ordered and others were disordered by their strength and speed, some were totally crooked and confused and other straight and linear movements. I observed several types of traits”, it is striking that he has established a relationship between variables that he already knew about mechanics with the new concepts studied in this intervention, which makes us realize there was to some extent a learning about the content.

In the expression taken from A24: “We realized it was possible to see the path of the particles in the chamber, some went straight down, some curved, some even spiraled. As far as I can remember, I could see four different types of path”. Looking closely, we find one of the events described by the student and presented in Figure 3.

![Figure 3. Multiple events on the screen.](image-url)

According to A27, “In the cloud chamber there were thinner, thicker features, some with greater speed than others, some with the shortest path and some with the longest path”, and A29, “There were traces with different characteristics, some and with different paths as well”. We observed it was possible for these students to associate the content discussed in class with that observed in the experiment. Student A31 states that “in the cloud chamber I was able to observe the path of the elementary particles (just the path), I noticed that some particles had different paths: some went straight and curved.” In this utterance, we perceive the student's understanding that it is not really the particle we are seeing, but the effect it produces when it passes. Apparently, for this student, the paradigm of cosmic radiation is completely accepted.

The same observation can be made regarding the utterance of A4: “In the cloud chamber particles were observed, which normally remain ‘invisible’ to our eyes. Among the particles, there are traces with three differences where one presented a thin line, a thick line and finally, corrugated cardboard. These characteristics were observed fifteen to twenty in the chamber”.

According to A8, “In the experiment we can observe the electrons, alpha and muon, we can also see the cloud of electrons. I could observe three types of strokes muons, the widest (alpha) and an irregular trajectory (electron)”, and as shown in A10: “I observed three types of particles with different traits as
they passed, electrons passed with alpha ripples leaving a larger path as if it were an explosion”, also present this perception of even associating trajectory design with a possibility. In this case, we can observe at least four events of particle passages, possibly coming from cosmic radiation. However, in addition to the statements of the students that changed after the intervention, the teachers’ points of view have also been changed.

4. Conclusion

The teaching of MCP needs new methodologies and new didactic resources, to allow the expansion of its teaching for all the school stages, like high school. Among the reasons for teaching MCP in high school, we highlight the “subsidy to understand and critique current issues involving science, technology, society and the environment” according to [24]. As we have described, research aimed at building resources for experiments related to MCP has developed in education, but its effective insertion in school faces problems like the lack of preparation of teachers, the difficulty of physical spaces and laboratories in them, the lack of funds for acquisition of equipment, which, in many cases, are easily unfound in all Brazilian cities.

In this way, reflecting on new formats of educational strategies is relevant to remedy such difficulties. As we have pointed out, a laboratory that can be allocated at a university and can be used remotely by schools around the world represents a new possibility to overcome some of the problems mentioned above. However, a laboratory without methodological guidance will not guarantee results favorable to learning. Thus, in addition to the equipment being available for teachers and students, it is necessary to provide adequate ongoing training to teachers so that they are properly prepared to promote appropriate teaching.

In our proposal, due to the innovative possibilities that the current electronic technologies allow, we built a system that uses hardware at an affordable cost. All programming was done using free software tools, that is, the source code is available so that other researchers who follow our proposal build their own remote access laboratories, at no software cost.

As revealed by the analyzes, the experimental intervention, reconciled with the constructionist educational proposal, produced positive effects in the learning of the contents worked, positioning the remote access laboratory as a facilitating element for the teaching of particle physics in high school. In this way, it is pointed out that this research has provided, for the teaching of modern and contemporary physics, the possibility of performing experimental activities without the need of a local laboratory, allowing the study of such an important concept for the understanding of nature, which are the cosmic rays and favoring experimentation in teaching content that is often addressed only superficially.

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