Detection of Particles With a Fog Chamber: Experiential Learning With IPN High School Students

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Abstract
This experience is derived from the SLTP (Spanish Language Teacher Programme) conducted at the European Organization for Nuclear Research (CERN), which is offered to science and technology teachers at the pre-university level. The SLTP integrates lectures, visits to the experimental facilities and workshops, particularly in this inquiry with emphasis on the fog chamber construction workshop. SLTP aims for teachers to return to their educational institutions as ambassadors to transmit and promote the study of particle physics with a scientific approach to their students. This work shows an experimental practice through the construction of a fog chamber in a high school of the National Polytechnic Institute in Mexico, this experience is a simplified version that is proposed in the teacher training courses at CERN. The exploratory qualitative approach methodology was implemented in a study with 40 students who participated in the fog chamber experiment. This study seeks to understand the perceptions and experiences of the students through semi-structured interviews and focus groups, allowing an in-depth exploration of their reactions and learning during the experiment. The data collected are oriented to how the visual results are interpreted and the impact of the exercise on the understanding of scientific concepts. The approach allows for capturing the richness of their experience and reflections, which provide a solid foundation for future research for extension throughout the IPN.

Keywords: Particle Physics, Fog Chamber, Scientific Knowledge

Introduction

The experience presented in this paper is based on the Spanish Language Teacher Program offered by the European Organization for Nuclear Research (CERN), which is designed for science and technology teachers at pre-university levels. The program is mainly aimed at bringing modern science to the classroom, contributing to scientific culture and promoting studies in related fields.

One of the objectives of this program is to improve the skills of science teachers, so that they can later transmit scientific advances to their students and their communities in the Spanish language; this CERN project was developed with the idea of bringing CERN's cutting-edge scientific work to a wider audience.

Among the activities carried out in this program is the specialized workshop, in this research the emphasis is on the fog chamber workshop, which is one of the most popular educational and informative activities in the field of experimental physics (CERN, n.d).

In order to disseminate the knowledge understood at CERN is that the strategy is implemented with students of a high school in Mexico considering that they are studying the last semester in the educational institution and the last course of Physics in the same, being the objective of this inquiry was oriented in analyzing how the experience of the construction of the fog chamber and the observation of particles promotes the development of scientific skills, the formulation of questions and critical reflection of the study and understanding of particle physics with high school students, considering as research axis question: how does the observation of particle trajectories detected in the fog chamber influence the reflective thinking of the student?

Particle Physics

The physics of elementary particles, whose objective is to discover the basic pieces of which it is built and the laws that these obey, is a fundamental part of science (Barradas and Alameda, 2010) and when we talk about particles in educational institutions with students sometimes it seems frustrating, since students consider something unreal, The fog chamber activity takes into account that students can become familiar with the subatomic world and thus generate the curiosity that leads them to a critical and reflective attitude, but based on experimental verification (Barceló et al., 2010).

Prior to the construction of the fog chamber, questions about charged particles were considered, such as: how do they reach the Earth, where do they come from and how do they obtain so much energy? And with that, the concept of cosmic rays, which continually strike the atmosphere, is initiated. These cosmic collisions produce large amounts of high-energy particles that are scattered in all directions, some of which reach us here on the surface of the planet. However, most people are unaware of this bombardment; the particles are usually smaller than an atom and do not stimulate any of our senses, using a fog chamber, students can visualize the actual particle trajectories resulting from these cosmic rays (Hine & Davidowsky, 2018).

The fog chamber is a device used to visualize charged particles, such as cosmic rays, interacting with air in the atmosphere.

One way to observe cosmic rays is through a fog chamber that can be constructed with materials such as isopropyl alcohol, dry ice, and containers to supersaturate the chamber. When a charged particle, such as a cosmic ray, passes through the chamber, ions are generated along the particle's path and the alcohol vapor condenses (NMNS, 2024). This physics phenomenon is intended to allow students to observe particles and, in the process, become engrossed in learning particle physics through arguments and interaction with their peers.

Curriculum

The high school of the National Polytechnic Institute (IPN) offers several areas of knowledge, among which are: (1) Engineering and physico-mathematical sciences, (2) Social and administrative sciences, (3) Medical-biological sciences, this inquiry is based on area (1), according to the plan and program of studies, the physics learning unit is studied in the last four semesters. The Physics IV learning unit is in the last semester and the study methodology is based on the study of competencies, emphasizing the development of didactic sequences that meet the Learning Results (RAP).

Physics as a natural and experimental science requires a practical approach that integrates knowledge and reflection on the study of natural phenomena based on the laws and principles of Physics (IPN, 2008).

Project Based Learning (PBL)

PBL is one of the active strategies of teaching and learning, which allows the development of competencies according to the graduate profiles (Castro, 2022; Botella & Ramos, 2019) point out a reference that is oriented to meet the urgencies of reality by implementing research strategies, knowledge and skills that will be part of their new learning. One of the benefits indicated by Fernandes et al. (2018) is that collaborative and/or team work with which it is possible to build shared knowledge and in that sense, as mentioned by Cardoso (2018), collaborative work involves participation, the exchange of ideas of the members, enabling the acquisition of new knowledge.

Cobo and Valdivia (2016) mention and consider the following stages of PBL:

- Project approach and organization; where a series of ideas of the students' interests are presented, and the activities are designed.
- Research on the topic is the collection of information and is where the teacher guides and provides feedback for the realization of the project.
- Definition of the objectives and work plan; the objectives are established, what the students are expected to learn, as well as the resources to be used, the times and activities to achieve these objectives.
- Implementation; with a very relevant role for the teacher, since he/she must be attentive to the process, monitor and be aware of the difficulties and opportunities to make the necessary adjustments.
- Presentation of a particle physics expert and evaluation of the results; it is the implementation of the competencies, establishing the evaluation criteria to determine the objectives achieved.

In this active methodology that constitutes PBL involves the acquisition of knowledge, beliefs, attitudes, skills and behaviors, considering the implementation of linguistic, cognitive, motor and social skills (Castro, 2022; Schunk, 2012), this methodology also entails that teachers are all the time vigilant and attentive to the resolution of doubts or solve problems that may arise during the process (Cesar et al., 2021); in addition this educational approach allows students to engage in critical thinking, collect information and analyze data (Osman et al., 2021), considering that it also stimulates interests (Ojaleye et al., 2018), with this PBL is a powerful tool, which significantly improves students' performance in physics (Nicholus et al., 2023).

In agreement with the previous authors, this staging is justified, due to the construction that the students carry out with their own means, and the questions that arise, in addition to issues that are proposed and that are jointly triangulated with the plan and syllabus of the educational institution.

Problem

A problem that has been identified in the learning unit of Physics IV is the extensive programmatic content, which integrates the study of physics; relativistic, quantum and high energy, the curriculum and syllabus states that these studies will be carried out at the end of the semester, which causes students to conduct a study without much depth, or even more so without a reflection of the subject associated with the laws that justify in physics phenomenon. On the other hand, the laboratory does not have the necessary resources to carry out these experimental practices with topics of this nature.

Physics is distinguished by the practicality of the experiments of physical phenomena, but in high energy physics it becomes a bit complex, being in this way has been chosen because students build their own fog chamber with simple materials available in their daily environment and thus relate the theory studied in class and verify with experience with particles.

Methodology

The methodology with qualitative approach based on Project Based Learning (PBL), in which 40 high school students of the Centro de Estudios Científicos y Tecnológicos No. 11 of the Instituto Politécnico Nacional in Mexico City participated in the year 2023, considering the plan and program of studies 2008, the students are studying the penultimate semester in the educational institution. The project was carried out in a period of 5 weeks.

The didactic sequence was planned according to the active PBL strategy, considering the objective of building a fog chamber for the observation of subatomic particles, promoting experiential learning and the development of scientific skills. The didactic sequence is described below:

Week 1. Approach to the activity, time: 2 hours.

Phase 1. The challenge and approach of the activity, to know the interests of the students, an initial survey was carried out with open questions: What do they understand by particle; if they have heard of the European Organization for Nuclear Research CERN, if they know the acronym of CERN, with a Likert scale: how much do they know about subatomic particles, how much they would like to know about particle physics, if they know the traces left by an airplane, if they know the traces left by an airplane, if they know the traces left by an airplane, if they know the traces left by an airplane, How much do you want to know about particle physics, do you know about the traces left by an airplane, do you know that a particle can be observed through a detector, would you like to observe one or several particles? The form for this initial survey was hosted in the following space: https://bit.ly/3C7qNqo.

Subsequently, the concept of subatomic particles and their importance of study in Physics was presented; and images of a fog chamber were transmitted.

Week 2. Project design, time: 2 hours.

Phase 2. Research on particles and how to build the fog chamber; organization of work teams to start with the research on particles and the functioning of the fog chamber, the materials to carry out the construction of the chamber, possible challenges that would be faced in the search for the material, making block diagrams to keep track of the steps to follow in the construction of the fog chamber.

Week 3. Research and application, time: 4 hours.

Phase 3. Definition of the objectives; indicating to the students what is expected during the process of construction of the fog chamber, if there is need to make some modifications with respect to the material, time to achieve the activities for the achievement of the objectives, which in this case is to achieve that the students relate the theoretical concepts with the assembly of the fog chamber.

Week 4. Experimentation, time: 4 hours.

Phase 4. In this week, students carry out the construction of the fog chamber in the laboratory in a period of four hours, take photographs, record observations, take video and in teams reflect on the differences they find in the observed traces, guided by the questions.

Week 5. Presentation and evaluation, time: 2 hours.

Phase 5. In this phase the teams prepare presentations integrating their findings, challenges if any during the construction of the fog chamber. Presentation of the results and evaluation using the previously known rubric. As a closing, a self-evaluation of the experiment and group reflections are made. Finally, an expert culminates with a lecture on particle physics and other novelties of the universe, the guest is Dr. Javier Santaolalla, an expert disseminator.

Thus, teaching strategies as a set of actions that are projected and implemented in an orderly manner achieve a certain purpose (Jiménez & Robles, 2016); during the process of building the fog chamber four elements that acquire roles according to the moments are interrelated, which according to Castro (2022) are: the teacher, the student, the content and the variables in context (which refers to the characteristics of the school/classroom).

Results

With reference to the results of week 1, they are shown in the following table:

Table 1: Results of the Initial Survey on Particle Knowledge

Question	**Answer**	**Descriptor**
What do you understand by particle?	Something very small Structure of the atom The smallest part of the atom	This question considers the prior knowledge that students must identify improvement after implementation.
Have you heard of the European Organization for Nuclear Research (CERN)?	Yes = 2 students No = 38 students	The purpose of the question is to find out how much they know about the most important particle physics research center to date.
How much do they know about subatomic particles?	More than I would like = 1 About right = 30 Less than I would like = 9	Knowledge of this answer will be for the teacher's initiation to the topic.
Do you know the traces left by an airplane?	Yes = 8 No = 32	As can be seen from the responses, most do not know the traces, so the construction of the fog chamber will be an incentive to generate curiosity.
Do you know that a particle can be observed through a detector?	Yes = 12 No = 28	With this response, students show that they have at least heard of particle detectors.
Would you like to observe one or more particles?	Yes = 39 No = 1	The interest shown by students in this response is a first approach to what is expected in practice.

Table 1 shows the results and openness to the study of particles by the students and shows a good indication for collaborative work towards the construction of the fog chamber.

From phase 2, the students carry out a brief investigation on the particles and the operation of the fog chamber, together with the materials to carry it out, they make a block diagram that considers the steps to be followed for the construction. The research was discussed in class through brainstorming, from which the following main ideas were obtained and shown in Figure 1.

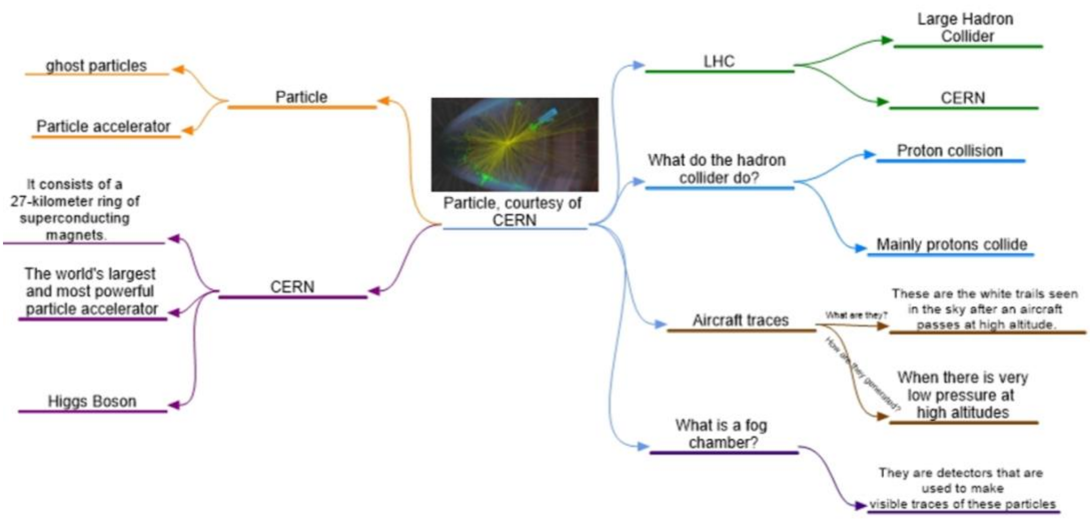

Figure 1: Brainstorming Is Based on the Research Carried Out. Own Production

In this sense, answers oriented towards the study of particles have been generated. Figure 1 shows the main ideas that were generated in the classroom during the review of the investigations.

In phase 3, the objective and the relation of concepts that the students have investigated are related. The lines followed in the inquiry are shown in Figure 2.

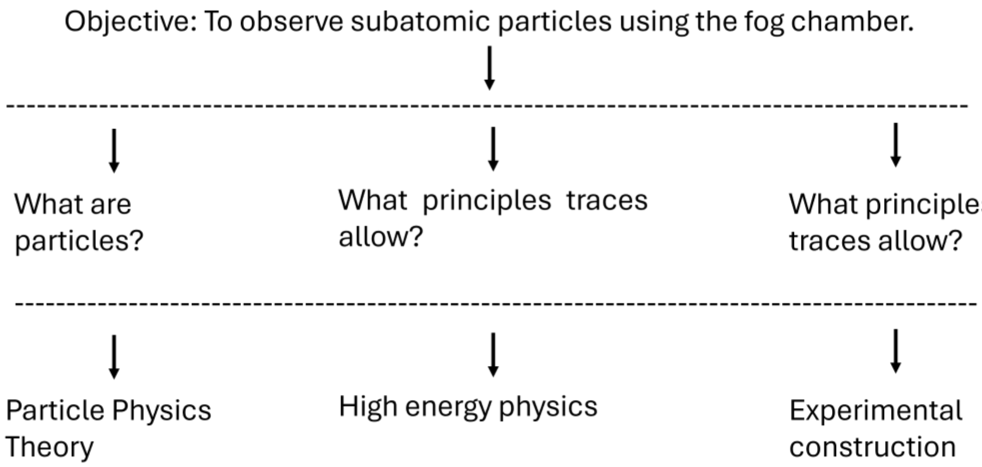

Figure 2: Relationship of Objectives and Concepts for the Construction of the Fog Chamber

Phase 4 is the heart of this inquiry, the construction of the fog chamber allowed a degree of interaction among students that enriched the little previous knowledge and exceeded the initial expectation that the teacher author of this work had, since at least two students will be dedicated to Physics in university studies. Organized into 8 teams of 5 people, they worked on the construction of the fog chamber.

The construction of the chamber generated new ideas that are illustrated in Table 2 below:

Table 2: Results of Questions Categorized by Order of Repetition

Category	**Frequency**	**Example of a textual response**
Significant learning	25	I enjoyed watching the experiment, it takes a long time, but it is worth it.
Conceptual learning	15	The concept of particles is a little clear to me, but I would like to know more.
Procedural learning	35	Experiments have something magical in science, you see it and understand it better.
Collaboration and teamwork	40	While some were making observations, others were building and that helps a lot because you realize where you are going wrong.
Technical challenges	30	It took a long time, I thought we could observe fast, the average was 35 minutes. But it was great.
Personal reflection	35	I keep the idea that the experiments are linked to the part you are investigating, it is very interesting to check something that is not simple to the human eye.

Creativity and innovation	25	Since the experiment wasn't coming out, we had to flip the sheet over, but the dry ice was starting to stop working. A darker place is what makes it easier, as well as using the dim light from the cell phone.
Project impact	38	I liked the project and the research I did so much that it made me want to study physics. I know that I must first study classical physics.
Difficulties	20	At the beginning, since we didn't read, we didn't know how to start making the camera. And I think all the teams were like that. But the teacher explained it to us and from there it was easier.
Improvement proposals	25	I know it is not valid to say that we should be told to wait some time, so as not to despair. But maybe it is good to mention it.
Interdisciplinary connection	21	Knowing mathematics and chemistry complements this experiment, because when I did the research, they mentioned equations and above all I saw a periodic table.

These results show the understanding of the theoretical concepts related to the project of the construction of the fog chamber, in addition to showing that through the experience through the construction and manipulation of materials it is possible to acquire certain skills such as observation, formulation of questions, reflective thinking and teamwork, in addition to the collaboration that is noticeable when they support each other and contribute ideas to solve technical issues, which led them to face challenges by adjusting the ideas they had at the beginning of the experience. Also, in addition to these learnings mentioned, it is relevant to note that students express personal emotions and a change of perception, for example, in the case of the two students who had no interest in making a fog chamber construction for particle observation.

The impact of this project goes beyond learning, it shows an interest in science, particularly in particle physics, by mentioning that they are eager to continue with this type of studies at the university level.

Each obstacle allowed them to enrich their visions, when comparing the comments of the teammates, although the students indicate the need to mention the waiting time to observe the particle or particles in the fog chamber, that this was the surprise inside the laboratory, it is undoubtedly that they optimized the time of observation and recording of anomalies during the experiment.

Only some students achieved a connection of other disciplines and that at the time of sharing a deeper reflection regarding chemistry was known in depth, since the research conducted by the students consisted of how the use of hydrogen in the form of compressed gas and it starts with this gas because it is the starting point to obtain protons needed for experiments, and it is an element studied in chemistry.

Castro (2022) insists that collaborative work involves participation and especially the exchange of ideas of the members, in this case the team members, which facilitated interaction and communicative skills through experiential learning, where also teacher played a crucial role because the guidance mentioned by the students that they received when they saw that their fog chamber did not work.

Phase 5. Evaluation and presentation by an expert researcher with Dr. Javier Santaolalla who attended the IPN facilities.

First, use was made of the rubric shown in Table 3, considering the following aspects.

Table 3: Rubric for Evaluation of the Presentation

	Descriptor		
Indicator	**Excellent**	**Intermediate**	**Low**
PPT presentation of the experimentation	The presentation shows photographs of the experience, explaining the events that occurred and justifying each of the events.	The presentation only shows pictures of the experience, ambiguously explaining either the facts or the justification of the facts.	Does not present any type of information.
Learning reflection	Reflects on the learning achieved for each activity and question posed. Shows the corrections of possible errors, indicating where he/she made a mistake and how he/she managed to understand the topic.	Reflects on the learning achieved by some activity and question posed. Shows the corrections of some possible errors, indicating where he/she made a mistake and how he/she managed to understand the topic.	Does not reflect on the learning achieved for each activity or question posed. Does not show corrections of possible errors, does not indicate where he/she made a mistake and how he/she managed to understand the topic.
Presentation and handling of concepts related to the fog chamber.	Explain scientific principles with precision and clarity, using appropriate technical terms and relevant examples. Correctly integrates related physics and chemistry concepts.	Explain the principles in a basic way, but with conceptual errors or oversimplifications. The use of technical terms is limited or confusing.	Fails to explain the scientific principles related to the fog chamber or shows significant misconceptions.

As a result of the rubric in each aspect, the following results were obtained:

Table 4: Results of the Evaluation Rubric

		Descriptor	
Indicator	**Excellent**	**Intermediate**	**Low**
PPT presentation of the experimentation	25 out of 40	8 out of 40	7 out of 40
Learning reflection	8 out of 40	20 out of 40	12 out of 40
Presentation and handling of concepts related to the fog chamber.	15 out of 40	15 out of 40	10 out of 40

Finally, the conference with Dr. Javier Santaolalla allowed students to realize and especially to corroborate the information they had already investigated and put into practice, the conference gave rise to a deeper reflection of the content of particle physics, some of the comments of the students are expressed below:

> [...] These conference experiences if that I like because of my learning I consider that this complete, it is a lot of emotion that if I could understand several things that Javier Santaolalla mentioned.
>
> [...] Javier Santaolalla is one of my favorites, I always follow him, seeing him in person and talking about what we did in the lab makes me excited. I have a very good knowledge in physics.
>
> [...] I think that now we had a very good tour of knowledge, and the conference, well, I can only say that it was great, it made me change my perspective of a common class.
>
> [...] Keep bringing lecturers of that stature, but I also hope that the teachers give us a well updated class, this was something very modern for me, combining many issues to learn the concept of particles.

Figure 3 shows an image of the lecturer and the students, who had the opportunity to interact briefly.

Figure 3: Relationship of Objectives and Concepts for Construction

Conclusions

PBL is a methodology that undoubtedly adds some gain in the conceptual part, in this case the progress of students becomes evident with the different stages that were experienced in the classroom laboratory.

For PBL to be a success in the classroom or in this case in the laboratory, the didactic design and the strategic plan, as well as the guidance of the teacher is undoubtedly a set of elements that allow an effective process and application.

The relationship of the different processes that lead to knowledge in students refers to the skills of dexterity, but above all of motivation and interaction with their peers in such a way that they build their knowledge using research and corroborating in an experiential way the theoretical part.

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