Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: M G Adesso *et al* 2022 *J. Phys.: Conf. Ser.* **2297** 012022

Inquiring Electricity in Primary School: A Non-Formal Teaching Education Case Study

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Abstract. In this paper we describe a primary school teachers' training project which includes laboratory activities as part of non-formal education curricula. Fifty teachers and three researchers in the South of Italy were involved in the project. Some inquiry activities were proposed, while teachers and researchers co-planned some further laboratory activities and experiments, all of which were carried out with 9-10 aged pupils. In the case study described, children used artifacts made from simple and low-cost materials, and transformed them into instruments to experiment with electrical phenomena. By observing the researcher who directly acted in the classroom and actively attended the students during the laboratory phases, the teachers improved their professional knowledge in teaching Physics through laboratory activities within a non-formal environment.

1. Introduction

In primary school, Science laboratories play a significant role in students' active participation in the learning process [1] and fill the gap between theory and practice [2]. Laboratory applications have been stated to help students define science concepts in a more comprehensive and meaningful manner [3]. Moreover, laboratories have long been regarded as an important component in Science education [4]. Although the relevance of the Science laboratory in primary school, teachers often disregard the lab practices. An interesting starting point is a preliminary analysis about "What is the role of the laboratory in the daily teaching at primary school? Why is it not so widely used?"

By analyzing the training plans (where the teachers' needs are included) of ten schools, teachers don't feel safe and confident with the use of the laboratory and, specifically, to conduct experimental Physics activities in their classrooms.

Nevertheless, in Physics education, three different teaching approaches may be used at the primary level: formal, informal, and non-formal teaching [5].

Formal education is a structured and systematic form of learning, and trained teachers usually deliver it systematically within a school. Everything a student learns comes from books and other educational materials to educate students.

Informal education lacks the structure and standards of formal education. Learning happens outside the classroom, whether in educational locations like museums and libraries or non-educational sites like at home or non-educational organizations. It is gained under the influence of society and the community. The most excellent teacher of informal education is the experience and encounters that one faces throughout their life. Informal education consists of learning activities motivated mainly by intrinsic interests, curiosity, exploration, manipulation, fantasy, task completion, and social interaction.

Non-formal education is a mix of formal and informal. While it doesn't have a syllabus or curriculum and it is not necessarily taught by licensed teachers, it's more structured than informal learning.

Hence, an additional essential element is "what type of teaching is relevant for an active participation of the students, mainly in the laboratory practices?"

Our idea is that only formal teaching is not enough to improve interest and motivation in Physics studying. In contrast, informal education is not easy to include in daily teaching practices.
Starting from the analysis of the teachers' training needs, the authors organized teacher training focused on Physics teaching in primary school, including Physics laboratory practices, in a non-formal education path. We guided the teachers to cross the "non-formal education bridge" from the formal shore to the informal ones, whereas their students will cross it in the opposite way (Fig.1).

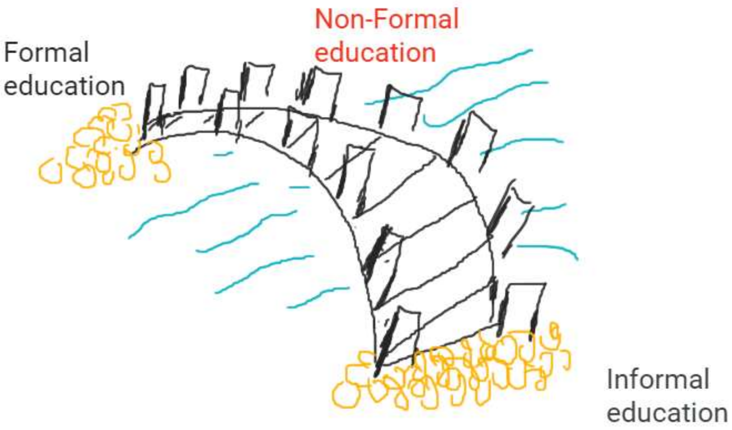

Figure 1. The "non-formal education" bridge, connecting the formal and the informal education, crossed oppositely by teachers and students: the teachers from formal to informal shore whereas the students from the informal to the formal ones.

A teaching methodology for linking informal and formal learning is Inquiry-Based Science Education (IBSE). Solms and Turnbull [6] claim that the educational approach to research provides an arousal activation that stimulates our interest in the world around us. Moreover, it is known [7] that in a laboratory where inquiry-based experiments are used, students are most likely to make real science; as a result, inquiry-based experiments will make students more active in the learning environment, and so, they play an active role in solving the real-world problems. Hence, some inquiry-based activities have been analyzed in the training course, co-planned, and experimented.

50 Primary school teachers and three researchers have been involved in the training course. The project has been carried out in a primary school near Naples, in the South of Italy, 25 hours timing.

The focus was on the following research questions:

a) Which formal/informal/non-formal education elements are relevant in Physics laboratory teaching?
b) Has the teachers' training been effective in organizing, planning, and experimenting with some inquiry lab activities in a sustainable and replicable environment?

2. Conceptual framework

The Vygostikan socio-constructivism [8] and the process of instrumentation and instrumentalization of Rabardel [9] have been the reading lens to interpret the orchestration of researchers in guiding the teachers in the laboratory, as well as the conceptual framework that guided the choices of teachers, helped by researchers, in the co-planning phase. In this process, working in two directions, researchers/teachers, starting from a set of resources which are the "artifacts", with specific schemes of use, change them in instruments. The affordances of the resources influence teachers' practice *instrumentation process,* as the teachers' dispositions and knowledge guide the choices and transformation processes between different resources (the *instrumentalization process).* Here, the scheme is in the sense of Vergnaud: "A *scheme* is a stable organization of the activity of a given subject for a given aim. This stability is reached along various situations corresponding to the same aim: a teacher meeting a new situation (characterized by a new aim) can mobilize and adjust existing schemes or can develop a new scheme" [10].

In his essay "Things that make us smart," Norman [11] uses the term "cognitive artifacts" to underline the role that every tool, both material and symbolic, can play in implementing the cognitive potential of those who make use of it. Furthermore, he distinguishes two fundamental thought processes: "experiential cognition" and "reflective cognition". The experiential modality involves an immediate, effortless, appreciable reaction to external stimuli; reflective thought processes lead to confrontation and new ideas and new responses. Well, based on this distinction, this educational experiment on the use of simple artifacts for the improvement of science skills was kept in mind that the game itself can be configured as "experiential cognition", that is, as a simple automatism that does not contribute to broadening disciplinary knowledge of the students. However, if the teacher prepares, plans, and designs specific paths, he can induce processes of "reflective thinking". The teacher can promote the comparison of the students' solutions and facilitate the emergence of patterns use.

3. The teachers' training course

The training course was organized in a blended model. Google Suite was used to share educational materials and to fill the questionnaires. The time was 25 hours, organized as follows:
- teachers' needs analysis (1h)
- a discussion about formal/non-formal/informal education (2h);
- some active learning methodologies, such as IBSE (2h):
- a co-planning phase, where teachers and researchers co-planned some inquiry activities in non-formal education and organized the artifacts (8h);
- experimentation of some lab activities in the classrooms (12h).

3.1 Need analysis

A form was asked to fill by the teachers, focused on their "confidence" about the Physics laboratory in their teaching. The questionnaire was sent to the teachers via Google Forms. The multiple-choice ones have been set according to the Likert [12] scale, as shown in Table 1, where five levels representing agreement, frequency, or satisfaction may be chosen.

Table 1. Likert scales about statements of agreement, frequency, and satisfaction

1	**2**	**3**	**4**	**5**
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Never	Rarely	Sometimes	Often	Always
Not at all Satisfied	Slightly satisfied	Moderately Satisfied	Very satisfied	Completely Satisfied

Here we show the results about three questions: for Q_1, the percentage about each 1-5 levels is reported, whereas, for Q_2 and Q_3, the medians are shown in Fig.2.

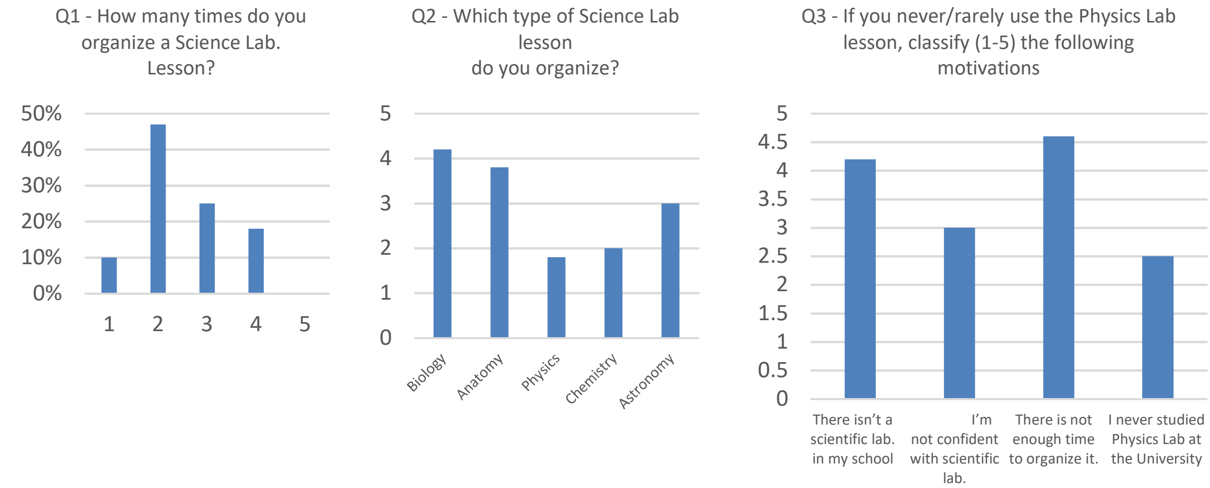

Figure 2. Teachers' answers about the use of Science/Physics Lab

From Figure 2, it is possible to deduce that most teachers rarely use the Science laboratory in their daily teaching. Moreover, among the science lab teachers, the Physics ones were the less used, concerning Biology and Anatomy lab.

The teachers argued that they don't use the Science lab because there isn't a scientific lab in their school, they have not enough time to organize a lab lesson, and last but not least, they should be better trained in a Physics lab lesson. This training course has been organized in order to increase the use of Physics lab, also where the scientific lab is absent in the school: each classroom, in a non-formal context, may be changed in a Physics laboratory by using simple and easily available materials, by realizing some instruments, starting from a set of resources (artifacts), with specific schemes of use.

3.2 Formal/non-formal/informal education

All the teachers were asked to discuss the main features of formal, non-formal and informal aspects of Physics education at the primary level.

They deduced that the boundaries between these three educative models are more blurred than in the past.

The discussion was focused on some key parameters which are different from formal to informal education:

a) The "structure" of the education model, which is highly structured in formal education, is semi-structured in the non-formal and de-structured informal ones.
b) The assessment, which is compulsory in the formal approach, is generally absent in the informal ones. It is often a relevant part of the teaching in non-formal education. Still, it has to be organized innovatively.
c) The students' motivation, which is increasing when the students have some experience in the real world (informal education) or an environment that is a laboratory where they make "real science" (non-formal).
d) The student's active participation in the learning-teaching process increases in the non-formal and informal education.

In Table 2, the teachers' considerations have been summarized as organized by the researchers: a blue UP arrow represents an "increasing" level whereas the red DOWN arrow is a decreasing level, a double green horizontal arrow represents an intermediate level. About the assessment, in the "non-formal" column, we have both a UP and a DOWN arrow because the assessment is not compulsory, but it is preferred to have it, to evaluate all the education activities; a circle has been added to the UP arrow to stress this preference.

Table 2. Main features of formal, non-formal, informal education in primary school

	Formal	Informal	Non-formal
Structured model	↑	↓	↔
Compulsory assessment	↑	↓	↑ ↓
Students' motivation	↓	↑	↑
Students' active participation	↓	↑	↑

3.3 IBSE: an active teaching methodology

Inquiry is a series of processes implemented by students intentionally [1], such as: knowing how to diagnose problems, critically commenting on experiments and identifying alternative solutions, knowing how to plan an investigation, formulating conjectures, searching for information, building models, learning how to discuss and compare between equal, developing coherent arguments [13].

The first studies on inquiry and the IBSE (Inquiry-Based Science Education) method are due to Rosalind Driver [14]. Nowadays, it is considered the most effective teaching strategy in laboratory lessons. IBSE teaching guides students to follow, step by step, the scientific process starting from observation, then enunciating the problems, checking the variables, making hypotheses and predictions, and describing the conclusions. In IBSE teaching, laboratories are an integral part of the course. Moreover, it encourages personal thinking, asking questions, peer discussion, and debate. During these activities, students work in groups to promote the higher mental functions originated by the interaction and to allow the development of skills such as social negotiation of meanings.

A discussion about the advantages and disadvantages of IBSE in Physics teaching was carried out. The researchers in Table 3 have summarized an analysis of the discussion. The numbers in the columns are the medians of the Likert scale levels [12].

Table 3. Advantages and Disadvantages of the IBSE, as perceived by the teachers

Advantages	**Disadvantages**
The IBSE experiences guide the students to have experiences about the real world (4,1)	Too much time is required (4,2)
The resources are generally easily available materials (3,7)	Too many resources are required (3,5)
The classroom may be de-structured and changed in a laboratory (3,8)	It isn't easy to experiment with it in a classroom (2,1)
Some projects (see TEMI [14], for example) give the planning of several IBSE lessons. (2,2)	The textbooks are not enough to plan an IBSE teaching lesson at Primary School (3,3)
The scientific method is included in IBSE (2,5)	The teachers are not so confident with IBSE (3,5)

The teachers' argumentations are in agreement with [15], [16], [17]. Specifically, in [15], it is shown that the teachers at primary school *believed that inquiry was more appropriate for upper-level science majors than for introductory or nonscience majors*, which summarizes some of the disadvantages the teachers outlined. Moreover, in [16], some inherent problems associated with the construction of inquiry activities are shown, similar to the disadvantages in Table 3. Nevertheless, in [17], the inquiry is similar to authentic science, as the teachers found that it is the 1st advantage of the IBSE.

In order to overcome the initial teachers' diffidence and difficulties about IBSE, the researchers proposed to critically analyze and have experiences about some activity in the TEMI project [18], [19], [20] in the training course. TEMI is the European teacher training project "Teaching Enquiry with Mysteries Incorporated" that gathers 13 partners from 11 countries across Europe. It adopts a clear definition of inquiry regarding a cognitive skillset and sets out a stepwise progression to push students towards becoming confident enquirers. TEMI aims to embed four innovations in teachers' practice: teach skills with gradual release of responsibility and maintain motivation with showmanship.

3.4 Co-planning phase

The project group co-planned five different activities (Table 4), all based on inquiry teaching methodology, in a non-formal environment:

Table 4. Co-planned inquiry activities

Activity	**Educational objectives and learning outcomes**
1) The water is not wetting the paper…	Impenetrability of bodies
2) Sing and play with us… on the seashore	Sounds and waves properties
3) The strange world of the water	Liquid properties
4) Lights and colors	Light properties
5) *Let's play to discover electricity and magnetism*	Electrical and magnetic properties

The experimentation was carried out in 10 classes, with about 20 pupils, 9-10 aged, in each class group. Thanks to simple and low-cost materials, the classroom has been transformed into laboratory space.

The authors suggested the IBSE methodology in the 5E Model [21], [22]. This model is based on 5 phases:

1) Engage: The teacher creates a "surprising" scenario, taking care of all details to highlight the main characteristics of phenomena to be analyzed.
2) Explore: students "explore" by themselves, organizing specific experiments to verify their preliminary idea and trying to discover "*what is happening*".
3) Explain: students try to explain the main results of previous experiments, just searching for an explanation to the question "*what is causing it?*".
4) Extend: The guide question is "*what is similar* to previously discovered phenomena?". They apply the results of previous experiments in different interest areas.
5) Evaluate: the authors agree that the education path, although it is a non-formal one, must be evaluated in all the phases.

Table 5. Co-planning form

Activity	Educational objectives and learning outcomes	Resources/ artifacts	Schemes of usage	Instruments	Non-formal education activity
5) Let's play to discover electricity and magnetism	Electrical and magnetic properties	a) Balloons, salt, sugar, puppet… b) Balloons, Coke-can c) …	Use the puppet to "charge" the balloons to attract the salt and sugar, and rolling the Coke can	"charged balloons" to have experience with electricity	"Realize the atoms by using mimosa and tissue paper."

In Table 6, there are details about the 5E phases for the same activity.

All the details about the resources necessary for the process: artifact - scheme of usage –instruments, specified in the co-planning form. The time of each activity has also been planned in a detailed way.

In the planning activities, in order to bridge the gap among formal and informal education through non-formal training, it is also necessary to consider two main features:

1) to develop activities that bring out the creativity of physics and that leads to surpassing the standard textbook presentation
2) do not disregard some technical details (experiments, images, graphs) to give a multimodal flavor of deep physical insights.

Considering these considerations, a final product has been added to the co-planning form, which is named "non-formal education activity," and it is a part of the assessment.
Table 5 shows a row of the co-planning form for activity n.5, which is the case study of this research work.

Table 6. Planning of the activity about the discovery of the electricity: the 5E model

"Let's play to discover electricity and magnetism."		
Phase	Activity	Time (h)
Engage	A puppet has to be used to change the balloons into "electrical balloons", able to attract confetti	2
Explore	Pupils "play" with balloons to discover how they may attract some small pieces and what they may attract.	8
Explain	Pupils use the LIM and try to explain their experimental results	8
Extend	Pupils "discover" the existence of two charges. They also have some experiences with magnets	8
Evaluate	Posters, questionnaires, final product (an atom realized by using mimosa and tissue paper)	4

4. The case study: researchers and teachers in action

Here we show a case study involving three teachers, three researchers, 23 pupils 9-10 years aged. Specifically, here we refer to an activity aimed at discovering the existence and properties of electrical charges, as well as some magnetic phenomena.

Co-planning of the activity has been organized with teachers and researchers altogether, as an active part of the teacher training, as shown in Tables 5, 6.
In the experimentation phase, the teachers preferred to be observers and cooperate with the researcher, whereas a researcher carried out the teaching.

In Figure 3, some pictures of the experimented 5E phases are shown to discover the electricity: the researchers engaged the students (a: Engage) with some colored balloons, attracting some confetti. Afterward, the children were given balloons, confetti, pieces of paper, salt, sugar, iron filings, a Coke can, and more. Pupils explored (b: Explore) and tried to explain (c: Explain) the phenomenology of the electric attraction. Specifically, they discovered that balloons loaded by rubbing might attract salt, sugar, paper pieces, and they could also roll a Coke can. In the Extend phase (d), they organized an experimental setup using two plastic bottles, a long can, and two tapes. They also observed the electric repulsion by using it, thus showing the existence of two different electric charges. Moreover, they also investigated some magnetic properties in order to have a comparison between electrical and magnetic phenomena. Some evaluation processes have been organized through posters (e) and questionnaires (f) during all the phases.

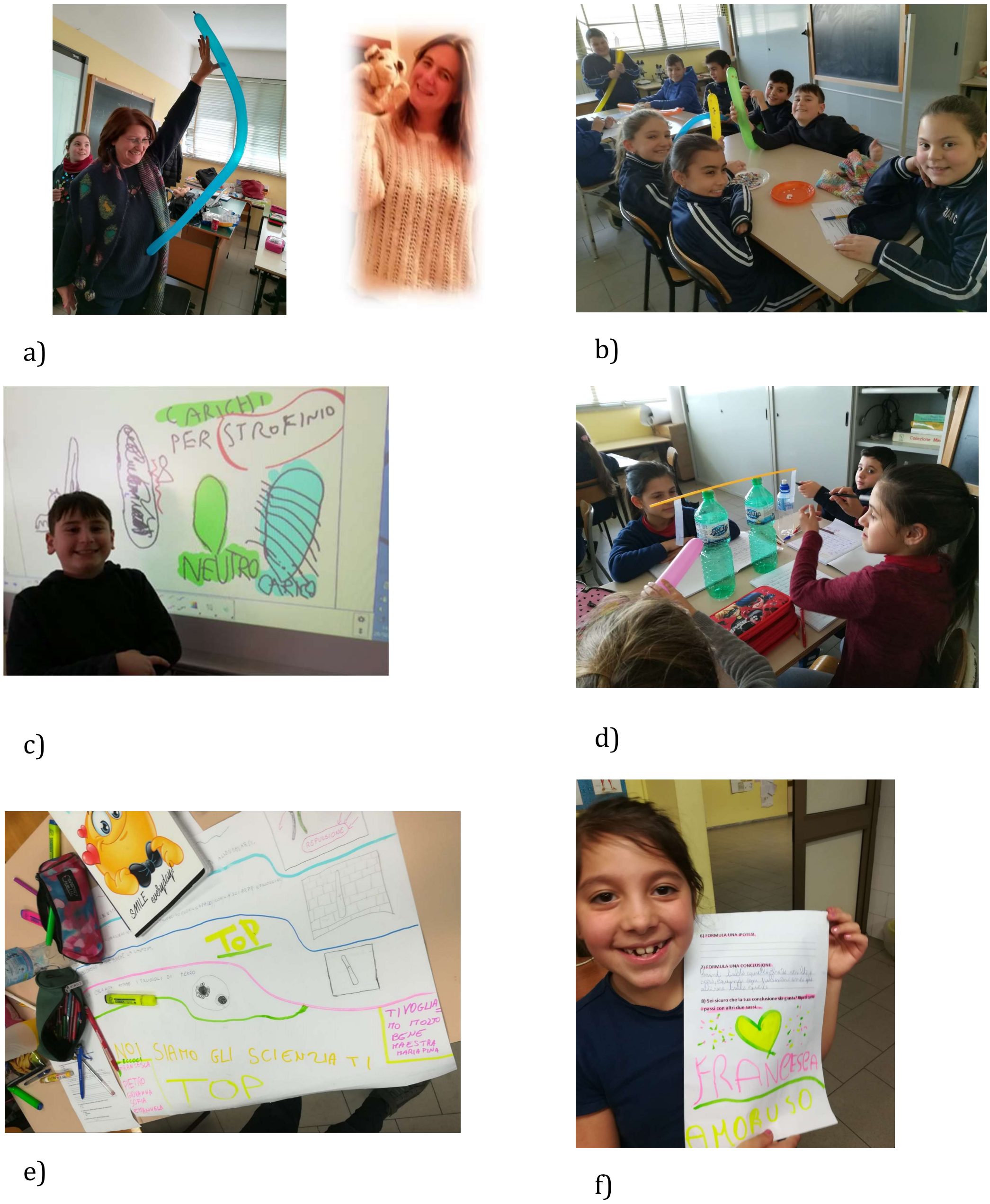

Figure 3. Inquiry-Based Science Education, 5E Model (a: Engage, b: Explore, c: Extend, d: Explain, e-f: Evaluate)

A further evaluation was given to a final product, including some features of the non-formal education: creativity and physical details (Fig. 4). Specifically, the pupils were asked to realize the atom's structure with blue (protons) and pink (neutrons) paper ball and mimosa (electrons). They "discovered" that the atom is neutral but that when an electron flows from an atom to another, both become "charged" differently. They called the "current" a flow of "mimosa" flowers.

Figure 4. A non-formal product: the representation of an atom, including creativity and scientific details. Blue paper ball: protons; pink paper ball: neutrons; mimosa: electrons. A neutral atom and two charged atoms with the flowing "current."

5. Discussion and conclusion

To summarize, Physics researchers have organized a Primary school teachers' training to enable 50 teachers in primary school to use tools, methodologies, and teaching strategies to make them autonomous in designing and testing Physics laboratory lessons in non-formal educational teaching.
At the end of the training, the teachers were asked to "evaluate" the course, mainly focusing on the main features of non-formal education in the Physics laboratory, IBSE teaching methodology, and their renovated confidence about the Physics lab. In Table 7, some of the questions with a corresponding number, the medians of the Likert levels, are shown.

Table 7. Final questionnaire by the teachers

Questions	Mean of the Likert levels
1) Has the training met your expectations?	4,2
2) Was the helpful training for your daily teaching?	3,9
3) Do you think to use similar activities in your daily teaching practices?	4,5
4) Has the training been helpful to understand the IBSE better?	4,8
5) Are you more confident in the use of the Physics lab?	4,0
6) Do you think that non-formal education is more effective in organizing a laboratory activity?	4,8

From table 7, we deduced that the involved teachers had strengthened their ability to plan and carry out some laboratory activities and have planned to include similar activities in their curricular teaching practice. The teachers confirmed that the non-formal education is well fitted with the laboratory lessons, and it should consist of both creativity and some technical details. Active teaching methodology has to be used in this non-formal environment. Specifically, they confirmed that the experimented inquiry activities effectively had experience about the real world (from the formal to informal education, through a non-formal way).

Some teachers attended the didactic activities carried out by the researchers. Then they have re-proposed similar activities in other classes, sharing the teaching practices among all the teachers at the school. The IBSE cycle has been repeated in other classrooms, with these and further activities, and the "trained teachers" carried out all the activities without the help of the researchers.

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