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ARTICLE

Development and Validation of an Epistemological Profile Questionnaire in a Museum Environment

Analysis of Psychometric Properties and Their Application Using Scientific Apparatus

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Abstract
Museums and science centers are constantly changing scientific environments which exert a lasting positive impact on the society through the popularization of science. One of the most effective strategies employed by these science popularization venues is the organization of scientific exhibitions using scientific devices which are presented to visitors in an interactive way. In the present study, a questionnaire was developed based on the concept of epistemological profile derived from Gaston Bachelard's philosophical thoughts, where thorough analyses were carried out with a view to exploring the characteristics of the historical philosophical zones of scientific concepts. The questionnaire was used to analyze the manner in which visitors interacted with museum installations and exhibitions. The proposed instrument was validated using qualitative and quantitative analytical tools. The analysis of the psychometric properties of the questionnaire showed that the proposed instrument is a reliable and valid tool suitable for the purposes intended. The application of the questionnaire using an electromagnetic apparatus and future implications of the analytical instrument were also discussed in this work.

1 Introduction

Over the past few decades, science museums have been transformed into scientific environments which are in a constant process of re-adaptation, be it architecturally or in their traditional area of expertise and occupation, seeking to leave behind the conventional conception of their being places that merely housed and displayed ancient artifacts (Hooper-Greenhill, 2007). Bradburne (1998) explains that this process of transition from the environments that kept old things to science centers began in the 1960s in the context

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of the Cold War. The main idea was to increase greater contact with visitors, turning these environments into places of scientific inspiration. However, this process was far from being simple and straightforward, and in many cases, the transition failed to occur due to financial and bureaucratic constraints.

To better understand the needs of museums and science centers in the early 1990s, several international meetings and conferences were held; these international gatherings were intensified later and international meetings were held annually from that decade onwards. Some of these international events that merit mentioning are the meetings of the Association of Science-Technology Centers—ASTC (Garnet, 2002), the European Collaborative for Science, Industry and Technology Exhibitions (ECSITE, 2013), the International Council of Museums (ICOM, 2006), the International Committee for Museums and Collections of Natural History, and the International Committee for Museums and Collections of Science and Technology (CIMUSET, 2010).

At these meetings, a consensus was reached by the participants where they noted that the international institutions had the potential for social development, as they sought to engage different social classes and age groups, stimulating their interest in scientific thinking within the scope of the scientific universe.

According to Rodari (2006), Roppola (2013), and Martin et al. (2019), museums and science centers contribute toward the inclusion of visitors in the scientific universe, which is often distant from the popular environment. One of the main factors that have contributed toward making these environments welcoming to the public is the interactive capacity of their installations, devices, and artifacts which allow for an interactive engagement between the visitors and the exhibitions.

With regard to interactivity in museums, Falk and Dierking (1992, 2016) noted that this is a complex process; according to these authors, interactivity is the intersection that relates four contexts within which the visitor is immersed and engaged: the social, the personal, the physical, and the temporal contexts (Falk & Dierking, 2016). The social context involves introducing the visitors to the idea of belonging to the world, where the exhibition serves to introduce them to aspects of scientific knowledge and discoveries that are not necessarily explicit in their everyday life. The personal context is related to the visitor's previous scientific knowledge which makes the exhibition a unique experience for each individual who visits it.

The physical context is related to the physical architecture of the museum environment and the way the exhibits are built and organized; in other words, this context focuses on the visitors' interaction with the environment. Finally, the temporal context is related to the cultural, technological, and architectural changes that museum environments undergo over time. The first three contexts interact with each other, and the interactive experience emerges from their intersection; it should be noted however that there is a temporal process which connects the interactivities throughout the evolutionary process of museums.

Koster (1999) shows that the temporal context helps in the interpretation of what the past was like, what the present is like, and what the future might be like through comparative processes between historical moments. In this line of reasoning, Falk and Dierking (2016) point out that the ability to generate a scientific memory is also added to the context. In this sense, interactivity is not seen as an event that ends at the end of the museum visit, but as a lasting experience that can be maintained for many years due to a scientific memory (Falk & Dierking, 1997). In addition to its pedagogical aspects, this unique experience of visiting a science museum also helps in the popularization of science by the visitors, as they are shaped by the scientific experience they undergo at a given moment and feel inserted in the scientific universe (Falk et al., 1998, 2007).

The construction of a scientific memory takes into account that the visitor is not a tabula rasa in relation to the world around him/her. Long-term memory is related to remarkable emotional life experiences (Da Silva et al., 2013). Thus, one of the key functions of the museum environment, with its scientific apparatus and equipment, is to impact the visit so that the visitor will not only want to return, but will also want to spread/share this experience with other people.

Another related function found to be inseparable from the social role of museums and science centers is the generation of scientific thought and presenting it to visitors. Scientific thought is presented in the museum environment through exhibitions and mainly with the aid of scientific apparatus, which can be used to illustrate scientific phenomena, and scientific tools used in guided activities. The progress of the scientific mind in a museum environment is directly related to the visitors' interactivity with the environment and specifically to the breaking of barriers that can affect the understanding of a presented phenomenology. Epistemological obstacles are among the key factors that contribute to the development of the barriers that lead to the misinterpretation/misunderstanding of a scientific phenomenon/concept (Bachelard, 2004). A rupture with the epistemological obstacles meticulously addressed in an exhibition can help the visitor to develop a more realistic view of the world. One way of studying and constructing the scientific mind under any scientific approach is through the philosophical strategy of epistemological profiling (Bachelard, 1968); this methodology allows one to create a profile that shows the frequency of the usage of historical philosophical thoughts involving a given phenomenology.

1.1 The Epistemological Profile

According to Gaston Bachelard (1968), a phenomenology can be interpreted within features arising from a specific scientific thought which has its roots based on different historical philosophical moments. In this perspective, the scientific notion of an individual who interacts with phenomenology is constructed from influences that are based on these historical philosophical moments. Based on this line of reasoning, Bachelard noted that the influence of historical philosophical zones in the construction of a scientific notion configures an epistemological profile.

The epistemological profile is divided into three historical philosophical zones: these include naive realism (NR), positivist empiricism (PE), and rationalism (RA) (Bachelard, 1968). RA is divided into three parts, and each of these parts can be analyzed individually. These three sub-zones of rationalism include the following: (i) classical rationalism, which is mainly centered around the ideas of Newtonian mechanics; (ii) complete rationalism, which is based on relativistic ideas; (iii) and discursive rationalism, which can be described as a more dialogue way of constructing scientific knowledge, in which the individual manages to build an applied rationalism (Bachelard, 1949).

The realist does not question the causes and ends of a scientific phenomenon but seeks only to understand the existence of the fact. Bachelard (1968) observes that realism does not encourage any discussion around phenomenology, but the mere observation of superficial facts, often related to pre-existing beliefs and to the qualitative observational aspects of how the world presents itself. Realism does not allow a commitment to science, but rather a static way of thinking, which leaves no room for change. Bachelard (1968) considers the realist philosopher as lazy in the way he/she acts, since the individual avoids engaging in abstract thinking. The realist believes that the most complex facts should not be discussed, as this would be a waste of time, limiting the ontological conception of existence.

The positivist view of science leads the philosopher to look for a method that allows one to determine the truth of a phenomenon as a whole. This way of thinking promotes the idea that the truth can only come from science. However, under this positivist thinking, science is interpreted as an infallible tool. This conception of science infallibility promotes a linearity of thought which does not allow error to be part of the construction of the scientific mind. Positivism, in this way, builds a relationship with empiricism, which idealizes the method developed for testing a phenomenon as being the only and immutable way of dealing with the matter, something considered fundamental for the scientific knowledge. In his work, Bachelard criticizes positivism and its limitation around empiricism, since for positivists, all answers around an observable could be achieved following an optimized and testable method. In this way, when the method considered optimized was reached, it became a unique way to obtain the absolute truth.

As described by Bachelard (1968), the rationalist view of science arises from the need for the rational thinker to avoid actions that lead to the stagnation of scientific thinking. The rationalist philosopher is opposed to the realist philosopher in the sense that, unlike the latter, the former does not deal with the truth about scientific knowledge structured in the way phenomenology presents itself. Likewise, the rationalist philosopher's point of view clearly diverges from that of the positivist philosopher in the sense that the former believes that specific scientific knowledge is the result of a plurality of knowledge and, as such, it is impossible to adopt a linearity that makes thinking scientific as an infallible method. Thus, rationalism is considered the most logical form of scientific thinking, as it deals with issues related to phenomenology in an ontological way, allowing the construction of an approach to scientific thinking based on philosophical and applied rationalism (Bachelard, 1949, 1968).

Taking the notion of mass and energy as an example, Bachelard (1968) divides rationalism into parts; the author points out that there was a strong influence of classical physics in the rationalization of science (classical rationalism) prior to the advent of modern physics and the theory of relativity (classical or Einsteinian rationalism). Based on this line of reasoning, the development of applied rationalism is fundamentally required to be preceded by the development of discursive rationalism or surrationalism (Bachelard & Canguilhem, 1972). This construction process of scientific notion, where the different facets present in the historical philosophical zones are taken into account, allows the creation of an epistemological profile which considers radical ruptures in the development of scientific thought throughout history as an integral part of the process.

Bachelard employed historical philosophical zones for the construction of epistemological profile when he defined what mass and energy were. Figure 1 is an adaptation of the book "The Philosophy of No" (Bachelard, 1968) by Bachelard, where Fig. 1a corresponds to the epistemological profile for mass and Fig. 1b corresponds to the epistemological profile for energy. Both profiles were elaborated by Bachelard and grounded in his own notion of using historical philosophical zones to categorize knowledge around these observables.

According to the author, scientific notions are internalized throughout life and, based on that, one is able to build a specific profile for mass (Fig. 1a), where aspects of classical mechanics and mechanical tests play an influential role. However, the author contends that one needs more complex and abstract aspects of science in order to define what energy is; these aspects historically only present themselves scientifically with the accumulation of knowledge, reinterpretation of scientific knowledge, and the advent of new technologies.

Bachelard, however, warns that a profile is not the composition of a single historical philosophical zone, but a set of them; in this way, even if there is a greater predominance of one type of philosophy, this does not indicate that other ways of thinking scientifically

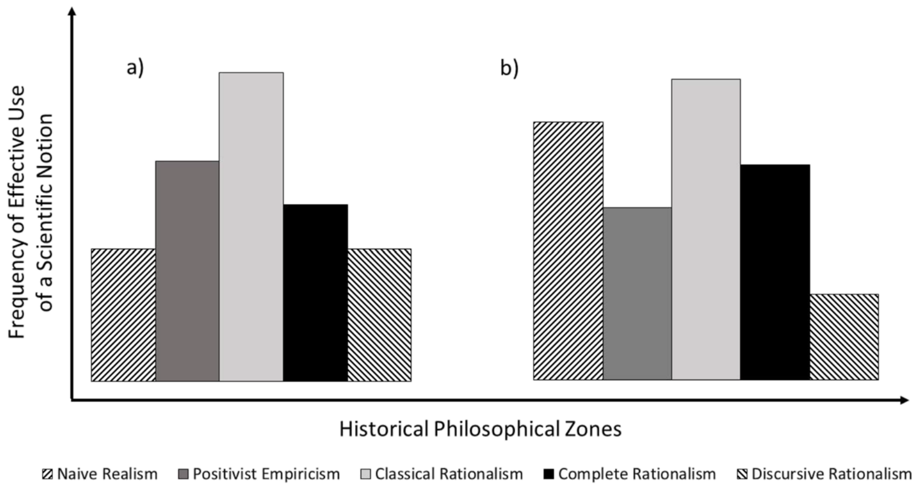


Fig. 1 Epistemological profiles for mass (**a**) and for energy (**b**), proposed by Bachelard

do not have any relevant influence. It is clear that Bachelard's choice of the theme "energy" to explain his thoughts was not merely made by chance, but rather as a strategy to demonstrate that phenomenology which has a greater degree of complexity can also nurture more static philosophical aspects, as is the case of realism. In the graphic profile elaborated by Bachelard for energy (Fig. 1b), it is more than evident that there is a certain degree of antagonism, since there is a high degree of frequency of use of the notions around rationalism, though they are also present, to a larger extent, in rationalism.

This view arises from the difficulty in defining what energy is, given that there are complex explanations regarding contemporary science, yet superficial observations of the world are still common—where common sense is regarded as a line of reasoning. Thus, the graphic profile of mass (Fig. 1a) elaborated by Bachelard is similar to that of a Gaussian, with a greater distribution around positivist aspects and classical rationalism. However, the distribution elaborated for energy (Fig. 1b) bears a more antagonistic pattern/profile due to the doubts that still persist in relation to the phenomenological definition of energy.

1.2 State of the Art

The state of the art of this work is primarily based on a review of works related to epistemology inspired by the work of Bachelard. Apart from that, the present work seeks to draw attention to the lack of ample research on historical epistemology and museology. It is also worth noting that the analyses presented in this study are not intended for the crude application of Bachelard's work (Bachelard, 1968); instead, they are employed as constructions based on his work, which has offered useful contributions in specific areas of knowledge, including science teaching and psychology.

Derived from and parallel to the Bachelardian epistemological profiling approach, Royce and Smith (1964) developed the psycho-epistemological profile concept which is aimed at studying the constructs of reality, reason, and vocations. The psycho-epistemological profile was constructed taking the following elements into account: intuition, empiricism, rationalism, and authoritarianism, and working on tendencies related to feelings and sensations.

The idea about the development and application of a conceptual profile emerged in the early 1990s; this idea was employed in the teaching of chemical concepts in the classroom setting (Driver et al., 1994; Mortimer, 1993). Mortimer (1993) described conceptual profile as being divided into four philosophical zones based on chemistry; this author worked on realism and empiricism positivist in the same way as described by Bachelard (1968). The idea of rationalism was divided into two new zones: classical chemistry and modern chemistry, and it basically sought to promote a better understanding of how chemistry presents itself in the classroom setting, since this field of science has its bases rooted in rationalism.

Solsona et al. (2003) proposed a second way of categorizing conceptual profiles for teaching Chemistry; this approach is largely based on the characteristics of the form of expression of the research subject matter as opposed to the techniques used in teaching. The authors proposed four possible zones under this approach: the interactive, the mechanical, the kitchen, and the incoherent.

Currently, one of the most widely applied approaches in the area of epistemology is related to epistemological beliefs. According to Muis and Franco (2009), epistemological belief is based on the individual's beliefs about the nature of knowledge and how it is created. Quite similar to the concept of epistemological profile, Muis (2008) worked on a profile divided into three philosophical zones: metaphorism, empiricism, and rationalism; this approach seeks to study the beliefs in institutions and methods, as well as in logic. It is worth noting that the applicability of epistemology is not only present in the theoretical universe but can also be used in practical work. In a study published recently, Muis et al. (2016) reported to have developed a questionnaire which was used to study the nature of epistemological beliefs of students from different educational levels; based on the results obtained from the application of the questionnaire, the authors were able to categorize the level of constructive beliefs of the participants.

Zhou et al. (2019) also investigated, using questionnaires, the correlation between epistemological beliefs and the features of motivation and guidance among undergraduate students in a Psychology course. The findings of their study show that, through the epistemological approach, one is able to understand how different objectives can interact with the motivation and cognitive abilities of individuals.

With regard to the number of publications, the early 1990s saw a considerable growth in the number of works published related to the field of epistemology and, more specifically, in the area of epistemological profile and epistemological beliefs; the growth in the number of publications on this subject matter endured throughout the 2000s, mainly with works of Mortimer (1993), Solsona et al. (2003), and Muis (2008, Muis and Franco, 2009, Muis et al., 2016).

1.3 Importance of this Study

Considering that museums and science centers have great potential to educate visitors on how scientific thinking is constructed and to promote social justice in terms of science popularization, the question that this work seeks to answer is how visitors rationalize when they interact with the apparatus and equipment in the science museum.

As part of the central objectives of this work, we also seek to encourage the use of statistical tools not only for data collection, but also for developing a comprehensive analytical framework that allows the construction of a more qualitative view. To answer the research question (how visitors rationalize when they interact with the apparatus and equipment in the science museum), the present study sought to develop and validate a questionnaire designed to build the epistemological profile of visitors during their interaction with scientific apparatus in the museum environment.

The objectives of the present study can thus be summarized as follows:

(1) Validate a scaled data collection instrument, which is centered around the analysis of historical philosophical zones of museum apparatus
(2) Apply the validated instrument in a research study conducted using electromagnetic induction apparatus present in a museum environment, with the aid of high school students from State-funded institutions in Brazil
(3) Analyze the data collected statistically and qualitatively to build a profile based on the proposed historical philosophical zones
(4) Analyze the epistemological profile generated by a school community based on the application of a scientific apparatus in a museum environment
(5) To make a cut of a historical tendency of use of the scientific notion around an observable at a given moment
(6) Promote social justice by providing needy students the opportunity to visit a science center in Brazil
(7) Bring useful contributions to the fore through our research which is targeted at helping in the reconstruction of museum environments so as to make them more inclusive and tailored to the modern needs of interactivity and presentation of scientific knowledge

2 Methodology

2.1 Determination of Research Apparatus

The apparatus used as an observable for student visitation and interaction was an adapted version of Tesla coil; the adapted version of Tesla coil employed in this study is a more modern re-interpretational tool which uses electronic components that did not exist at the time when the original Tesla coil was created. To be precise, our data collection tool is an electromagnetic induction apparatus which is able to perform the same function as the original Tesla coil equipment. It is worth pointing out that the term Tesla coil was used in the science center to refer to the data collection tool but in the present article we will refer to the tool as electromagnetic induction apparatus (EIA).

Another factor that led us to choose the EIA as observable in the research was that the equipment draws considerable attention in the museum environment, since its visual features and functionality are not generally known by the public compared to other museum equipment, and this helps to arouse the visitors' curiosity, promoting an investigative interaction on the part of the visitors. In this carefully designed exploratory and investigative milieu, it becomes possible to study aspects of scientific thought that fit into specific scientific historical moments; thus, this paves the way toward the study of epistemological profile which will be explored in the research.

2.2 Construction and Validation of the Questionnaire

2.2.1 Preparation of the Questionnaire

The questionnaire was prepared using 15 statements in Portuguese language, based on a Likert-type scale with five levels of agreement (Likert, 1932), which were arranged in an increasing level of agreement: strongly disagree, partially disagree, neither agree nor disagree, partially agree, and strongly agree. The statements were divided into three factors which corresponded to the three philosophical zones of the epistemological profile (Bachelard, 1968). The full questionnaire can be found in Appendix 1 Table 4 in English. However, it was initially built in Portuguese.

While the historical philosophical zones investigated in this work are primarily based on the Bachelardian epistemological profile, they also follow the model of reconstruction and thematic adaptation explored by Mortimer (1993) and Solsona et al. (2013)—both inspired by the work of Bachelard. It should be noted that the research setting explored in the aforementioned studies (Mortimer, 1993; Solsona et al., 2003) is the school environment and the focus of the research is confined to chemistry; in our present study, the research setting is a science center/science museum and the focus of the research is centered around an electromagnetic induction apparatus which illustrates the phenomenology behind electromagnetic induction.

To conduct our analysis, we employed three historical philosophical zones, which were related to naive realism (NR), positivist empiricism (PE), and philosophical rationalism (RA). Unlike Mortimer (1993), who divides rationalism into two categories, in our present work, rationalism was kept in a single category with no division. As the research target is high school students, ideas largely related to the relativistic discussion of science will be scantly explored, since high schools in Brazil do not usually address this issue. Thus, the three rationalist zones mentioned by Bachelard (1968) will be placed under a single historical philosophical zone.

The statements prepared for the NR were aimed at gathering analytical information to determine whether the interviewees had a phenomenological understanding of a superficial observation process and the first impressions they had about their experience with the device. In other words, the statements made for the NR were intended to survey whether students felt more comfortable with scientific explanations or they preferred an approach in which the superficiality of the visual features is more important than the abstract features.

According to Bachelard (2004), the first contact with a phenomenology can lead to the internalization of an epistemological obstacle, which limits the individual's understanding only to the visual, thus creating a barrier to the abstract interpretation of scientific concepts. In essence, the objective behind the NR-type statements was to find out whether aspects of common sense could be related to the creation of an epistemological obstacle in the respondents. This analytical phenomenon was measured based on the level of agreement of the respondents, which was distributed in a traditional Likert scale.

With regard to the statements associated with PE, the ideas employed in the questionnaire were intended to help the respondents know how to determine something through physical tests with the manipulation of the apparatus and evaluate their perception regarding the need to accept proofs and absolute truths to determine a truth related to a given phenomenology. This construction is based on the most linearized aspect of positivist thinking, which only accepts the truth as a uniquely scientific, tested, and proven fact, without leaving any room for theoretical questioning and the possibility of error as part of the learning process. The positivist method is based on Hegelian thinking centered around dialectics, where a thesis is faced with an antithesis to generate a synthesis. In this process, all knowledge generated from the error is excluded, and this leads to a unique way to reach the truth of a fact. In this sense, the testing and proof processes are linearized and considered as the only inductive process of truth. Thus, the construction of the statements for the PE was intended to determine whether the students considered the test as the only source of truth, without leaving any room for other possible ways to determine what was observed and tested.

The statements constructed for the historical philosophical zone RA were based on the need to stimulate scientific thinking through the development of an argumentative process aimed at explaining the phenomenon presented in the device using a multifaceted scientific knowledge. The construction of the RA-based statements took into account that there are rationalist aspects related to scientific thinking which need to break with realistic and positivist aspects. In this process, the individual begins to reject common sense and the methodological linearity of positivist thinking and to accept that there are facts that Newtonian mechanics cannot address; in other words, the individual begins to understand that there are scientific facts that cannot necessarily be proved visually but rather require a more mathematical abstraction to make sense of them.

A good example that springs to mind is the current explanation about atom, which is no longer defined as a solid tangible particle, but rather as a probabilistic density of finding positively or negatively charged particles, with different energy levels interacting with each other in a given spatial region. In other words, one needs to understand mathematical functions to describe orbitals and consequently the entire system that represents an atom. Based on this reasoning around the advent of contemporary physics, the main idea explored in the RA-type statements was to determine a possible rupture with realistic and positivist aspects of scientific thinking through a direct comparison between the data that would be collected.

Another remarkable feature of the questionnaire was that it sought to unify the three historical philosophical zones employed in this work with the museum aspect. Through the application of scientific apparatus, one can extract information that can be employed for a deeper analysis of a scientific exhibition that will enable us to determine specific contexts, such as those presented by Falk and Dierking (2016). The analysis of scientific apparatus using an instrument based on historical philosophical zones to generate an epistemological profile has great potential to serve as a framework for the reconstruction of exhibitions, uniting aspects of Bachelardian philosophy with the contextual aspects described by Falk and Dierking; this helps generate an important intersection in terms of reading and conceptualizing these environments.

2.2.2 Questionnaire Pilot Test

After preparing the questionnaire, six university students who did not take part in the construction of the data collection instrument were selected: four from the field of Exact Sciences and two from the field of Humanity. Together with an experienced researcher, the students were taken to a science center in the city of São Carlos, São Paulo, Brazil, where they were allowed to interact with previously chosen scientific apparatus and answer the first version of the questionnaire.

The main objective of this first visit to the science center was to test the functionality of the questionnaire as a pilot study and not to necessarily collect data. In addition to responding to the data collection instrument, the university students also provided their individual opinions regarding the objectivity and clarity of the questionnaire and whether its layout was easy to understand.

This first interaction with the students helped generate a second version of the questionnaire, which was sent to specialists in Bachelardian philosophy. The specialists helped to redesign the questionnaire making profound changes to its philosophical and thematic structure. The EIA was chosen for the conduct of the initial test of the questionnaire. This apparatus is a common scientific tool found in science museums; the equipment exhibits a wireless energy effect through the generation of an electromagnetic field (Skeldon et al., 2000). One of the main reasons why this equipment was chosen was because it presents a not so trivial phenomenology.

Another factor worth mentioning is the presentation of the device; students/visitors were able to touch the scientific apparatus and were also offered full access to its non-electronic components. This helped improve the visitors' active engagement in scientific research. It is important to point out that the students were aware that the room where the device was located was a thematic room related to electromagnetic induction, so they knew that the arguments they were expected to use when explaining the scientific phenomena they were going to be presented were probably related to this field of physics. Apart from testing the EIA, the visitors were also required to determine what the equipment was used for; in this way, the students were expected to argue and search in the scientific memory developed in the school years for possible explanations that would be consistent with the statements.

2.2.3 Questionnaire Validation Strategy

The questionnaire was validated using two procedures: qualitative and quantitative mechanisms (Steckler et al., 1992). For the qualitative analysis of the questionnaire, two specialists in epistemological profile were consulted. In this phase, the experts contributed individually toward improving the writing of the statements under the Bachelardian epistemology.

The quantitative analysis consisted of using statistical tools from the Statistical Package for the Social Sciences (SPSS); this tool enabled us to perform the Cronbach's alpha and principal component analysis (PCA) in order to determine the validity and reliability of the questionnaire.

The qualitative and quantitative procedures used to validate the questionnaire were not executed simultaneously. The procedures were applied in separate and sequential moments, since the quantitative procedure was dependent on the completion of the qualitative procedure.

2.3 Research Subjects

Data collection for the present study was performed in a science center located in the city of São Carlos, São Paulo, Brazil. The data was collected from the participants who visited the science center; the participants consisted of high school students from public schools in the neighborhoods situated on the outskirts of the city. The stratigraphic profile of the research subjects corresponded to 50% males and 50% females, who were aged between 15 and 18 years. In total, 139 questionnaires were collected, and 40 students were taken for each visit to the science center, totaling 4 days of visits.

In an initial contact with the schools that agreed to allow their students to participate in the visits to the science center, the principals of the schools requested that the students be allowed to return to the schools during the normal closing time of the schools and were also required to be given a meal during the visit to the science center.

Due to the existing widespread economic disparity in the Brazilian society, most of the students have one of their main daily meals at school and, in some cases, due to the economic hardship of their parents/guardians, some of the students need to work during the periods when there are no classes. Due to these socioeconomic constraints, these students are unable to engage in extracurricular activities, since they need to exchange hours of study for work in order to earn money to supplement their household income. Thus, the visit to the science center was the first opportunity for these students to go on a school trip which was done during school time. For most of the students, the visit to the science center was a unique experience because they lived in peripheral regions situated far from scientific institutions, and this usually limited their access to science centers where the dissemination of scientific knowledge usually took place.

The science center where the research was carried out is publicly funded and entrance is free for all visitors; the funds are provided to the center by the University of São Paulo and other public funding institutions. Thus, apart from being allowed to develop specialized research and experiments in the science center, the visitors were also informed that the science center was funded by the taxes paid by all citizens; as such, having the opportunity to visit the place to improve one's scientific knowledge was a right guaranteed to all. This observation is quite important, since it helps to enforce social justice in several aspects, by guaranteeing the inclusion of all citizens in the scientific environment, providing everyone with the opportunity to enjoy spending time and exploring science in a place funded by the taxpayers' money, and helping the students to explore science and scientific concepts under different approaches and outside the confines of their school.

It is worth noting that the students who took part in the research were not completely ignorant about electromagnetism, since they were in the final stages of completing high school. The students had already been learning about the concept of electromagnetism at school, and this paved the way for a more functional interaction of the visitors with the EIA.

2.4 Data Collection

Data collection was performed in the morning at the science center, where students were initially received and were given instructions and guidelines related to the visit. The students were divided into two groups (A and B) with 15–20 members. Group A took part in a lecture on environmental education, while group B visited the apparatus room of the science center where data collection was performed. It is important to mention that, although the application of data collection is not part of the normal activities of the science center, it was designed so that there would not be major changes in the way visits take place in the daily life of the institution. That way, the guides did not have to change their roles or prepare for anything new compared to normal science center activities.

The visit to the science center lasted approximately 100 min, and the students had the opportunity to interact with various devices related to the universe of electromagnetism and participate in the lecture. However, even though there were other interesting devices, greater attention was paid to the students' interaction with the EIA. Students initially tested the EIA without receiving any information about how it works from the guides. This strategy aimed to allow students to explore the apparatus without the use of a script, leading them to observe, move, and try to discover the function of the equipment. The interaction with the equipment took approximately 20 min, and after that, the students were taken to a different room for data collection. The data collection room was prepared with chairs and tables for the students to be able to sit down and answer the questionnaire. Although the questionnaire was easy to answer, the students were given 10 min to reflect on the phenomena they observed in the EIA.

After the data collection with the questionnaire, the guides went on to explain the functionality of the equipment. It is worth pointing out that the area of the electromagnetic universe of the science center was designed for the visitor to explore the equipment, and the explanations on how each of the machines was operated could be found in a large, illustrated, and well-detailed timeline board found on the wall of the room. The students were allowed to test the equipment and subsequently find out whether their hypotheses regarding its functionality were correct.

The students' interaction with the apparatus, the data collection, and the explanation of the guides took approximately 45 min, and the lecture also lasted the same time; this helped to maintain a temporal synchronism between the activities. At the end of this first stage, breakfast was offered to the students. The second stage occurred in the same way as the first stage, but with different groups. Figure 2 shows the interaction between students and the scientific apparatus. Figure 2a presents a close-up of the apparatus while a student is testing it; Fig. 2b shows a student testing the equipment individually; and Fig. 1c shows students testing the equipment in a group. It is noteworthy that during the students' initial interaction with the apparatus, some of the students preferred to watch their colleagues interact with the equipment in order to learn from them. During this observation stage, the students were allowed to see how the equipment worked so they could test it later. This observation stage allowed many students to test the equipment more than once, and most of them tried to apply different strategies based on what other students had previously investigated and tested. It is relevant to explain that during all stages of the research, from the reception of students at the institution and even data collection, the researchers were present.

It is worth mentioning that all the research, from the pilot test, to the definitive data collection, was developed in the pre-pandemic period.

3 Results of the Validation Process

3.1 Questionnaire Analysis by Experts

The qualitative analysis of the questionnaire validity was conducted with the help of specialists in epistemological profile. These experts developed an interpretative analysis of the statements, making it possible to understand whether the statements were suitable for the epistemological profile approach adopted. Each of the experts conducted an individual analysis of the features of NR, PE, and RA.

The specialists (who were consulted individually) provided quite similar positive observations regarding the validity of the questionnaire; this showed that the statements were appropriate to be used for the epistemological profile analysis. The experts also provided some recommendations to help make the statements more objective; however, the core meaning of the statements suffered no changes.

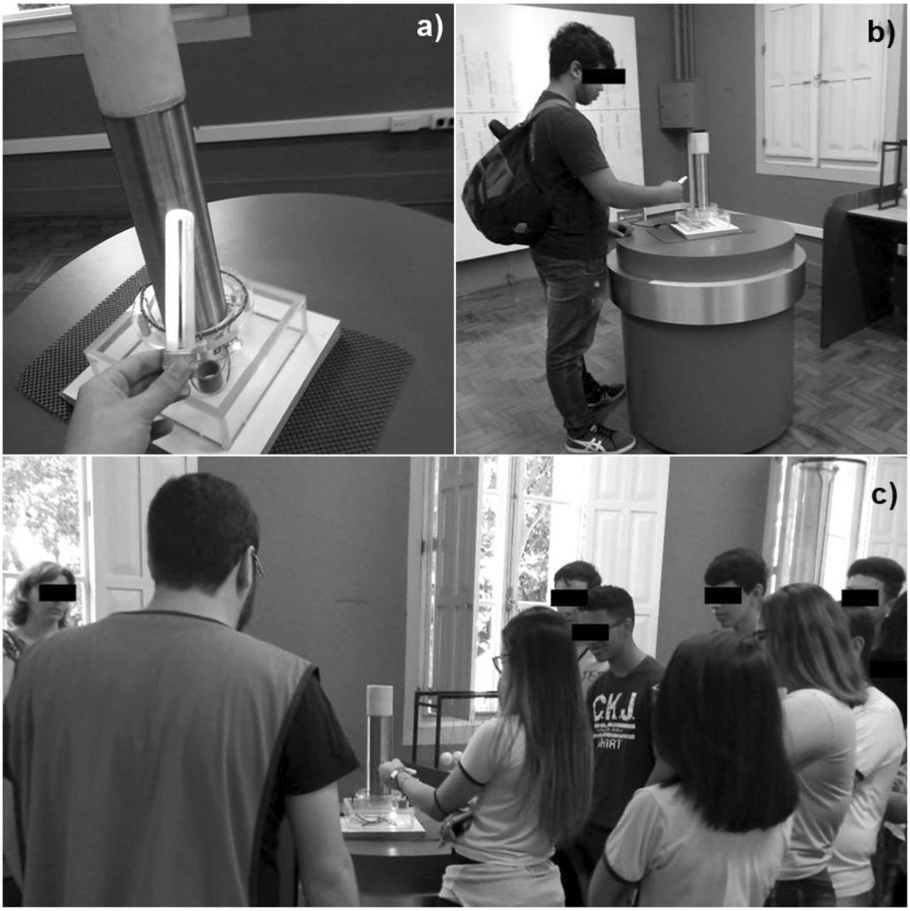


Fig. 2 The moment in which the students were interacting with the EIA

3.2 Quantitative Analysis

3.2.1 Cronbach's Alpha and Principal Component Analysis—PCA

The qualitative analysis conducted was divided into two parts. The first part involved the analysis of the reliability of the questionnaire, and the second part involved the analysis of the main components. The questionnaire reliability analysis was conducted using the Cronbach's alpha statistical tool (Cronbach, 1951).

Under the Cronbach's statistical analysis, the internal variances of each of the variables in the data set collected were investigated; this helped evaluate the cohesion of the variables in relation to the questionnaire as a whole. This study is essentially important in the sense that it helps one to determine whether any of the variables are out of touch with the global set.

Table 1 Individual values of Cronbach's alpha and the commonalities of each statement in the questionnaire

Variable	Cronbach's alpha	Commonality extraction
1RA	0.9523	0.950
2PE	0.9519	0.986
3NR	0.9567	0.926
4NR	0.9648	0.999
5RA	0.9525	0.997
6NR	0.9670	0.949
7RA	0.9616	0.986
8PE	0.9540	0.997
9PE	0.9524	0.998
10NR	0.9616	0.983
11RA	0.9534	0.980
12PE	0.9515	0.985
13RA	0.9513	0.980
14NR	0.9516	0.978
15PE	0.9553	0.958

Based on the results obtained, none of the statements evaluated using the Cronbach's alpha statistical tool presented values less than 0.9500 (Table 1); thus, there was no reasonable justification to exclude any of the statements after this initial assessment. For the analysis of the global aspect of the questionnaire, the value obtained for Cronbach's alpha was 0.9739; this shows that the analytical instrument presented a high degree of reliability (Cronbach, 1951, Cronbach and Meehl, 1955, Cronbach and Shavelson, 2004; Taber, 2018; van Griethuijsen et al., 2015).

For the analysis of the descriptive capacity of the questionnaire, we analyzed the values obtained for commonalities shown in Table 1. These values indicate the ability of the instrument to describe the system; in other words, the closer the value extracted is to 1.000, the greater the ability of the instrument to describe the system. In general, the commonality extraction values obtained were all above 0.920; this shows that the system has a high degree of descriptive capacity. Thus, there is strong evidence that the questionnaire is reliable as a quantitative instrument for data collection (Hair et al., 2014). With regard to total variance, the cumulative value obtained was 97.77%; this value is used to explain the entire data system in question (Hair et al., 2014).

Thus, three main components were found in our investigation; these components were attributed to the historical philosophical zones of the epistemological profile. As can be noted in Fig. 3, the results obtained from the PCA showed that three clear points were found above 1 on the scale of eigenvalues.

These points indicate the relevance of the components, since they describe 97.77% of the study. Thus, all the points that were below 1 were discarded, as they provided an insufficiently little description of the system. The analysis of the component matrix (Table 2) helps one to understand the manner in which the distribution of responses occurs in relation to the components found. The individual analysis of each of the components, based

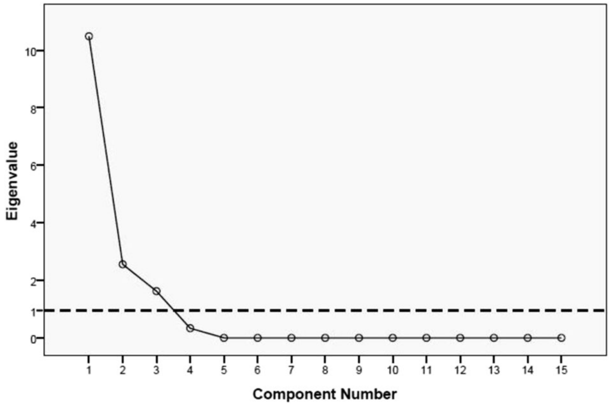


Fig. 3 Eigenvalues of the components found in the statistical analysis

Table 2 Matrix of the components obtained from the PCA

Variable	Component		
	1 (NR)	2 (PE)	3 (RA)
3NR	0.790	-	-
4NR	0.826	-	-
6NR	0.934	-	-
10RA	0.573	-	-
14NR	0.977	-	-
2PE	-	0.971	-
8PE	-	0.981	-
9PE	-	0.959	-
12PE	-	0.976	-
15PE	-	0.876	-
1RA	-	-	0.964
5RA	-	-	0.987
7RA	-	-	0.670
11RA	-	-	0.926
13RA	-	-	0.989

on the statements they were constituted by, made it easier to determine which one corresponded to which historical philosophical zone.

The statements related to each of the historical philosophical zones which make up the epistemological profile were divided into three distinct categories; the statements that belonged to a specific theme were placed under the same category. The PCA helps to determine how the variables are close to each other and to evaluate whether they have any relevant similarity. It is worth mentioning that the initial cut for calculating the PCA was set at 0.50; thus, values below this value were hidden for each variable shown in Table 2.

With regard to the thematic area of the variables, all the variables that corresponded to the NR zone were grouped under component 1 (Table 2). The variables that corresponded to the PE zone were grouped under component 2; and all the variables that corresponded to the RA zone were grouped under component 3. The analysis of these data (Table 2) showed that there was an internal cohesion between the statements related to each of the proposed historical philosophical zones, and this allowed them to be grouped under specific components.

The results presented in Table 2 can be found to be essentially important in the sense that if the statements that corresponded to a specific theme were grouped under different components, there would be evidence pointing to the lack of cohesion or (or dissimilarity) between them. This would directly imply the existence of a weak structuring of the historical philosophical zone for these statements.

When any of the aforementioned problems were discovered, three actions were taken in order to rectify the mistakes. The first action involved the exclusion of the variables that did not correspond to the component in which the other variables of the same theme have been grouped correctly.

The second action involved assessing whether a new statement needed to be added to the set. To solve this problem, a new statistical analysis was conducted using the data set collected, with the exclusion of the problematic variables. This analysis helped us determine whether the instrument cohesion has been strengthened or weakened following the exclusion of the problematic variables, thus enabling us to verify the reliability of the instrument. The third step involved the collection of new data using the new version of the questionnaire reconstructed after the statistical analysis.

4 Construction and Analysis of the Profile for the EIA

After the validation of the questionnaire, the data collected was then subjected to analysis; this was done initially through the application of a numerical analysis to generate the profile. It was observed that there was a predominance in the concentration of responses around the statements that expressed more positivist perspectives. This result showed that most respondents exhibited a high degree of agreement with the issues raised in the statements related to the historical philosophical zone of PE. The data distribution can be found in Table 3.

More specifically, based on the analysis of the data in Table 3, it is quite clear that, if the results obtained for the highest levels of agreement (strongly agree and partially agree) are isolated, one will see that approximately 80% of the responses related to PE are concentrated around these higher levels, and this shows that the remaining 20% are distributed around the lower levels of agreement. When we perform this same analysis for the other

Table 3 Average ranking of the scores obtained for each level of component and the respective percentage value

Scaling level	Number of responses for NR	Number of responses for PE	Number of responses for RA
1	60 (8.6%)	12 (1.7%)	24 (3.4%)
2	104 (15.0%)	25 (3.6%)	54 (7.8%)
3	172 (24.7%)	96 (13.8%)	100 (14.4%)
4	213 (30.6%)	218 (31.4%)	250 (36.0%)
5	146 (21.0%)	344 (49.4%)	267 (38.4%)

profiles, one will observe that approximately 50% and 70% of the responses related to NR and RA, respectively, are concentrated around the higher levels.

With regard to NR, this is an indication that many respondents still accept realistic ideas; however, because half of the distribution is found at lower levels of agreement, this indicates the beginning of a rupture with the realistic perspective. This observation occurs when the intermediate level of agreement is analyzed, with 24% of the responses being allocated around this level for this distribution. This is essentially important because it demonstrates that a portion of the respondents does not find the realistic perspective to be sensible. In general, when much of the information in a scaled questionnaire is at the intermediate level (neutral level), the respondents may prefer not to provide any response or may be confused about how to respond. This confusion can be related to the concept of paradigm breaking, where a previous idea of the individual, ends up not making more sense in front of a phenomenological observation presented. This paradigm shift can point to the beginning of a rupture of epistemological obstacles; although this is a strong indication that the realistic obstacles still exist for the respondents, it also shows that the respondents are already passing through a process of acceptance that more complex phenomena cannot be explained by common sense.

With regard to RA, the data demonstrate that there is a tendency to concentrate the responses around the highest levels of agreement. However, the levels of disagreement represent half of the responses for NR and double for PE; this shows that it is likely that respondents who preferred to corroborate the answers with high levels of NR considered the levels of disagreement in RA as the most consistent with the rationalist perspective. In other words, by analyzing the data presented in Table 3, it is possible to observe that despite the high levels of agreement for RA, there are still doubts in the minds of the respondents which, in some cases, are catered for by the realistic perspective in the profile.

An interesting fact that emerged in the analysis of the second highest level of agreement (I partially agree) was that, for the three historical philosophical zones evaluated, the agreement index was found to be very similar and practically indistinguishable from one another in terms of numerical analysis. In this case, when the percentage of responses for the level of agreement (4) ranges from 30 to 36%, it is necessary to analyze the internal distribution, comparing it with the closest levels. With regard to NR, the results obtained from the analysis clearly demonstrate that the highest concentration of agreement occurs between the highest intermediate levels (neither agree nor disagree and partially agree); this shows that the respondents have some important level of disagreement in relation to the realistic statements. However, in the case of PE and RA, the highest concentration of agreement occurs at the higher level, with emphasis on PE; for RA, the two upper levels exhibit quite similar results. These results demonstrate that there is a greater tendency among the respondents to completely agree with the statements related to PE, while they find it less comfortable to strongly agree with the statements related to RA.

Based on this internal comparative analysis of the levels of agreements for each philosophical zone, one can elaborate a graphic representation similar to that constructed by Bachelard for mass and energy (Bachelard, 1968).

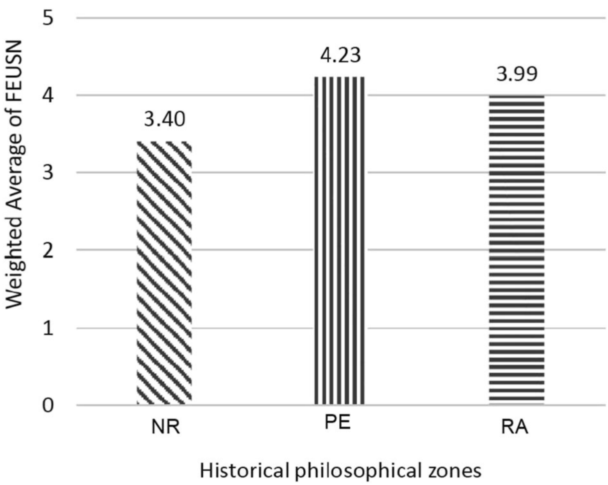
To categorize the data and finally build the epistemological profile, it was necessary to study the frequency of effective use of scientific notion (FEUSN) in order to verify the phenomenology of electromagnetic induction and, in this way, categorize how it was expressed within historical philosophical zones. FEUSN is a subjective idea developed by Bachelard (1968), in which the author constructs his thoughts based on his own ideas, beliefs, and methods which are related to the observable phenomenon. Obviously, this process of interpretation and identification of an existing phenomenology in relation to what is observed changes over time, as new knowledge is acquired. In this sense, one can say that scientific knowledge is something that flows in a non-linear way as the positivists expected. This fact interferes with how the process of FEUSN takes place, as historical moments provide the strengthening of various facets that were not used before. Assuming Bachelard had witnessed the technological advances we are experiencing today, he probably could have considered new aspects around the profiles he developed for mass (Fig. 1a) and energy (Fig. 1b), since FEUSN may have changed over time. This creates an analogy to the thinking of Falk and Dierking (2016) in relation to the contexts of interactivity, since they are also dependent on the temporal context.

The use of average classification/ranking helped to determine the trend by which respondents preferred to categorize the EIA; in other words, which philosophical areas had more or less influence on the EIA profile. Along with the numerical analysis, a bar graph was constructed (Fig. 4). As can be observed in Fig. 4, the graph delineates the characteristics of the historical philosophical zones in a chronological way, passing through NR, PE, and RA, thus creating a chronological categorization of the construction of scientific thought based on the EIA.

The analysis of the relationship between the FEUSN and the Likert-scale data is performed based on the average ranking of these data, which varies from 1 to 5. With this process, it is possible to transpose the statistical data into the frequency analysis. This process leads to the construction of the graph in Fig. 4, in which it is possible to see the FEUSN variation numerically, within each historical philosophical zone.

Basically, the graph shows that the frequency of use of scientific notions around each of the historical philosophical zones is related to the level of agreement of respondents in the Likert scale. In this way, there is a tendency to group values for each historical philosophical zone, within the scaling created by the average ranking. The results are shifted by the concentration density around a specific level, thus making the numerical weight relative

Fig. 4 Epistemological profile related to the EIA based on the frequency of effective use of scientific notion (FEUSN)



to higher concentration around a level of agreement. In this case, when we look at the values (Fig. 4) for NR, PE, and RA, it is possible to observe that NR is around 3.40 out of a maximum of 5.00, indicating that people had a more moderate agreement in relation to the frequency of use of realistic notions. However, for the PE, it is possible to see that there is a greater tendency of agreement with higher levels in relation to the frequency of use of positivist notions for the statements, reaching 4.23 out of a maximum of 5.00. Finally, the RA also showed a relatively high value for agreement with the frequency of use of rationalist notions, reaching a total of 3.99 out of a maximum of 5.00; however, most respondents agreed at lower levels than for the PE.

It is worth noting that the epistemological profile presented in this work is not intended to be infallibly precise; in other words, the profile does not claim that an element belongs exclusively to a determined philosophical zone. The main objective here is to demonstrate how a community of students expresses its scientific knowledge on the concept of electromagnetism. Another relevant point that deserves mentioning is that the epistemological profile developed in this study can be changed because some of the variables cannot be controlled—these variables include level of experience of the respondents in relation to science, regional differences, period of analysis, etc. The period of analysis is found to be very important when it comes to building an epistemological profile related to scientific apparatus, since interactivity changes over time, as pointed out by Falk and Dierking (2016); also, as noted by Bachelard, knowledge undergoes constant reconstruction and evolution, based on the formation of the scientific spirit (1946, 1968, 2004).

The results obtained in this study show that there is a relative numerical equality between the evaluated historical philosophical zones. As Bachelard points out, there is no need to overemphasize the fact that there is no profile that is exempt from some specific philosophical zone; as such, people can employ high, low, or equal rates of FEUSN to explain a given phenomenology. In the data obtained with the questionnaire, it is observed that the vast majority of respondents still maintain some realistic elements in their way of thinking, although there are some ruptures with this model, mainly because the discordance rates are higher for the realistic statements. This finding points to a break with the realist obstacle, since they are indications that the ontological aspects around phenomenology began to weaken. It is also possible to observe that there is still a great need, on the part of the respondents of the analyzed group, that they feel more comfortable with the determination of an absolute truth in relation to the phenomenology presented. This fact goes back to the use of more positivist notions internalized in the students' prior knowledge. In this sense, there is blind acceptance of authorities, who demonstrate absolute truths, such as books and even teachers, exempting the need for argumentation.

This behavior explains the higher rate of FEUSN observed for PE compared to RA (Fig. 4), even though the two historical philosophical zones recorded similar values in terms of levels of agreement. Thus, the profile exhibits a slightly upward trend for PE in relation to RA and a pattern of disuse of realistic criteria, which is an indication of the beginning of a rupture with NR.

Overall, a careful analysis of the graph (Fig. 4) shows that there is a tendency for the respondents to associate themselves with stronger characteristics of PE, as they found the aspect of the test as one of the vital bases that can essentially help an individual to determine a truth related to the apparatus. Concomitantly, some more complex aspects of electromagnetism can end up being presented simplistically in a realistic perspective of the world even though more advanced knowledge is required for the individual to actually grasp these concepts; this essentially promotes distrust in the abstract world. This distrust in the abstract world creates a realistic obstacle, where individuals tend to accept a new universe without questioning, leaving no room for any abstraction. Thus, even though there is a process of rupture with realism, there are still aspects of this philosophical zone in the way of thinking of most individuals who participated in the research.

5 Conclusion

The present study proposed and validated a questionnaire based on historical philosophical zones for the study of museum scientific apparatus. The results obtained from the validation analysis conducted using principal components analysis and Cronbach's alpha (with the grouping of the statements into three philosophical zones as initially expected) showed that the instrument has a high degree of reliability and ability to describe the system. Thus, the instrument proved to be functional and reliable for the application of the research. Data obtained from the validated instrument helped to build an epistemological profile of an electromagnetic induction device.

Bearing in mind that the application of the questionnaire is not limited to a single museum apparatus, future studies should contemplate the application of the instrument on new equipment and using more heterogeneous audiences, especially the general public who usually visit museums and science centers; this will certainly help boost the reliability and validity of the questionnaire.

The questionnaire can also be employed as an interpretive tool in the administrative and creative environment of museums and centers for scientific dissemination and popularization and for analyzing the historical philosophical aspects in which the exhibitions are immersed. The application of the questionnaire as an interpretive tool in museum environments can help in the construction of new exhibitions which are not static in terms of their presentation of scientific apparatus, as it occurred in the second generation of science museums. This will also help promote more reflective research in which visitors become the parameter to interpret scientific apparatus, thus paving the way for nurturing a greater understanding of the various facets of scientific thinking. Future exhibitions can also add features that address more social, scientific, and chronological aspects in their presentation, making them more inclusive through dialogue between thoughts, methodological approaches, and different fields of study.

Finally, the present study was found to be essentially important as it helped to promote social justice and citizenship awareness, apart from improving the students' knowledge in electromagnetism. Most of the students who participated in the research were not aware that the science center they visited was funded by the taxpayers' money and that visitation was free; this, to a certain extent, stimulated a paradigm shift in relation to elitism that exists in science.

Appendix 1

Table 4 The questionnaire based on a Likert-type scale with five levels of agreement

nº	Statments	Strongly disagree	Partially disagree	Neither agree nor disagree	Partially agree	Strongly agree
1RA	This apparatus helps to understand abstract scientific phenomena					
2PE	With this apparatus, it is possible to determine a scientific phenomenon					
3NR	The scientific concepts represented in this apparatus are simple					
4NR	To handle this apparatus, I just need the knowledge of everyday life					
5RA	To conduct an experiment using this apparatus, it is necessary to use scientific concepts					
6NR	This apparatus presents a scientific concept that is difficult to explain					
7RA	One needs to know scientific concepts in order to interact with this apparatus					
8PE	The handling of this apparatus is simple					
9PE	This apparatus illustrates an example of a scientific concept					
10NR	It is possible to understand the apparatus just by looking at its operation					
11RA	This apparatus helps one to learn a scientific concept					
12PE	With this device, it became easier to visualize a scientific phenomenon					
13RA	This apparatus stimulates my scientific thinking					
14NR	This model allows one to contextualize a scientific phenomenon					
15PE	With this apparatus in hand, it is possible to test a scientific phenomenon					

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Author Contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Israel Rosalino, Ana Cláudia Kasseboehmer, Israel Rosalino, Israel Rosalino, and Ana Cláudia Kasseboehmer. The first draft of the manuscript was written by Israel Rosalino, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability The SPSS (Statistical Package for the Social Sciences) was used to apply the analysis to the data collected and to generate the images of this work. The license to use the SPSS was provided by the University of São Paulo—USP.

Code Availability Not applicable.

Declarations

Ethics Approval The project was analyzed by the Research Ethics Committee of FFCLRP-USP, at the 173th ordinary meeting, held on 12/14/2017, and classified as approved. CAAE Nº 7943917.2.0000.5407.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The authors declare that they have no conflict of interest.

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