An analysis of the influence of the international masterclasses hands on particle physics on the self-efficacy beliefs of physics teachers

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Abstract. The official curriculum of the state of São Paulo, in Brazil, includes the study of elementary particles and other modern and contemporary physics (MCP) topics among the subjects to be taught in the topics say they do not feel confident to teach them. In this study, we consider that one of the variables that may influence teachers' decision to accept or not the challenge of promoting innovations in teaching is their self-efficacy beliefs: the subjects' beliefs about their ability to perform a given action in a satisfactory way, regardless of the outcome of that action. We aimed to analyse the influence of the participation of physics teachers in a scientific outreach event – the International Masterclasses Hands on Particle Physics, or simply Masterclass – and in a workshop on particle physics – a related event – on their self-efficacy beliefs, regarding the teaching of elementary particle physics in high school. To accomplish this objective, we applied questionnaires to all teachers and conducted semi-structured interviews with two selected teachers who had already attended the Masterclass and the workshop, both organized by the São Paulo Research and Analysis Center (SPRACE). Based on these questionnaires and interviews, we conducted an analysis to characterize the meanings attributed by them to the participation in both events. The analysis revealed that both teachers had high levels of self-efficacy beliefs and attributed educational, instrumental and motivational meanings to the participation in these events. Given that several aspects of teacher education (such as content learning and the theoretical assumptions in which this education relies) and the availability of pedagogical resources (like learning activities, experiments and examples to contextualize the content) can influence teachers' self-efficacy beliefs, this analysis has led us to conclude that attending such events has the potential to affect teachers' self-efficacy beliefs, influencing their decisions about whether accept or not the challenge of promoting curricular innovations.

1. Introduction

In the city of São Paulo, the SPRACE (São Paulo Research and Analysis Center) team organizes two scientific outreach events on high energy physics in one of the campi of the state university of São Paulo (Unesp). One of them is the International Physics Masterclasses - hands on particle physics and the other is the Particle Physics Workshop.

The Masterclass is an international event, promoted by IPPOG (International Particle Physics Outreach Group) in more than fifty countries, in which students and high school teachers visit universities and research centers where CERN collaborating scientists work, to learn about high energy physics, perform a data analysis activity and engage in a videoconference with students from other countries, simulating a participation in an international scientific collaboration. In the SPRACE particle physics workshop, teachers attend lectures on particle accelerators and the standard model, exchange experiences, discuss some didactic activities proposed by the textbook used in public schools in the state

of São Paulo and are presented to some activities related to teaching of particle physics, such as electronic and board games.

Our interest in these events is due to the fact that the subject addressed by them (particle physics) is part of the high school curriculum in the state schools of São Paulo but most teachers do not address this topic in their classes.

The teaching of topics of modern and contemporary physics (MCP) in secondary education has been discussed for a long time (at least since the 1990s) throughout the world. There is a wide variety of arguments to justify teaching these topics in high school: presenting to students the theories that underpin current technologies, awakening students' curiosity, attracting young people to the scientific career, presenting a new way of thinking, understanding the limitations of classical physics etc. [1-5]. Nevertheless, several obstacles in teaching MCP have also been listed by many researchers, such as teaching and learning its abstract ideas, the requirement of some advanced mathematical tools to solve some of its problems, the need to translate complex theories into something understandable by students, the lack of adequate textbooks [6]. In addition to the epistemological problems, each country or region faces specific problems related to teaching MCP. In Italy, for instance, many secondary school teachers are engineers or mathematicians and have no specific training to teach MCP topics. This has led several local universities to offer training courses for in-service teachers [7]. Nevertheless, despite all difficulties, some topics of MCP are being included in the secondary school curricula in many countries. Lobato and Greca [8] made a study about quantum theory issues in ten different curricula around the world (Portugal, Spain, France, United Kingdom, Canada, Australia, Italy, Denmark, Sweden and Finland) discussing how they address quantum theory. In this article we will focus on the Brazilian context, more specifically on the state of São Paulo.

In Brazil, some official documents such as PCN (National Curricular Parameters for Secondary Education) and PCN+ (complement of the National Curricular Parameters for nature sciences), which serve as guidelines for curriculum development in Brazilian schools, also highlight the importance of teaching MCP:

> Some aspects of the so-called Modern Physics will be indispensable in order to enable young people to acquire a more comprehensive understanding of the constitution of matter, so that they may come into contact with different new materials, liquid crystals and lasers present in technological devices or with the development of electronics, integrated circuits and microprocessors. The understanding of the models for the constitution of matter must also include the interactions in the nucleus of atoms and the models that science today proposes for a world populated by particles. But it will also be indispensable to go further, learning to identify, deal with and recognize the radiations and their different uses. That is, the study of matter and radiation indicates a theme capable of organizing the skills related to the understanding of the microscopic material world. [9, p.870]

This discussion is leading to a slow but steady renewal of the Physics curriculum and more and more MCP topics are being inserted into the high school physics courses. In the state of São Paulo, as we have already said, elementary particle physics appears as one of the topics to be taught in the third year of state high schools. This topic is inserted as part of the subject "matter and radiation", which include the study of

> [...] the microscopic organization of matter, as well as its relationship with known macroscopic properties, such as the thermal and electrical conductivities. Radiation and the ways of emitting and absorbing it are responsible for an important part of modern technologies and their benefits, as in certain lamps and in medical treatment and diagnostic equipment, without neglecting the dangers on which it is necessary to be aware. To these topics is added a relatively simple treatment of elementary particles - current and questionable version of the old dream of finding the fundamental blocks of matter - as well as the electronic components of information processing and storage, as subjects also appropriate to this theme. [10, pp.99-100]

In this way, it would be normal to expect elementary particle physics to be taught in the state schools and for students to leave school with some knowledge of the subject. However, this is not the case. Many teachers do not address this topic in their classes and the students finish their studies without having any contact with high energy physics. The main reasons pointed out by teachers and researchers are deficient teachers education (where particle physics is neglected or approached superficially and without concern for transposition to high school), the lack of time resulting from an extensive curriculum, the lack of educational and didactic materials and resources, the low incidence of this theme in admission tests in universities, and teachers' self-efficacy beliefs.

A subject's self-efficacy beliefs are related to the way he or she sees his or her own ability to put into practice certain behaviours in order to accomplish a task. The greater the self-efficacy beliefs of a subject in relation to a task, the greater will be the effort that he or she will employ in its execution, and the greater will be his or her resilience when facing difficulties. That is, the higher the self-efficacy beliefs of a subject in relation to a task, the more likely he or she will engage in it. Thus, teachers with weak self-efficacy beliefs are less likely to engage in new activities and to promote innovations in teaching.

This led us to think about the possible contributions of SPRACE's outreach events regarding the teaching of particle physics. More specifically, we ask ourselves what would be the potential of these events to influence teachers' self-efficacy beliefs. This is the question that guides this research.

2. The Masterclass and the Particle Physics Workshop

The International Physics Masterclass began in 1997 in the United Kingdom. In 2005, International Year of Physics, it was organized for the first time under the auspices of IPPOG, in 2006 it expanded research institutes in the United States and in 2008 it reached Brazil and South Africa. In 2018 the event was held in 52 countries and since 2016 is also held an exclusive edition for girls on the international day of women and girls in science.

The agenda proposed by IPPOG divides the event into three parts: lectures on elementary particles, an activity of real data analysis obtained in the LHC (or, in some cases, other particle accelerators) and a video-conference mediated by scientists at CERN, to discuss the results of the activity. Each venue can adapt the schedule to their needs or due to time zone differences.

Since 2014 SPRACE holds the Masterclass on two different dates each year for two distinct groups of students. The first group, called the advanced group, has students from schools that have participated in the Masterclass in previous years and whose teachers hold some of the lectures in the school itself, before the event. Thus, on the day of the event, students attend only a brief lecture on the data analysis activity before performing it and then discuss the results in the videoconference. Given the time difference between Brazil and CERN, these activities come to an end early in the afternoon. From the end of the videoconference to the end of the afternoon students participate in extra activities: guided tours to the GridUnesp central cluster, observation of a cloud chamber, card games, board and electronic theme games about particle physics and other topics of modern physics, games designed to develop reasoning and demonstrations of optical experiments. The second group, called the beginner group, is composed mostly by students from schools which have never participated in the Masterclass and who have not had any preparation prior to the event. In this way, the event for this group is divided into two days. On the first day students attend lectures on high-energy physics, on the standard model, the LHC and its detectors. In the afternoon, teachers also come together to conduct the data analysis activity that their students will perform the next day. The second day of this group has an agenda similar to that of the event for the advanced group.

The SPRACE Particle Physics Workshop arises from the Masterclass organizers' observation that the attendant teachers lacked knowledge of high-energy physics and claimed they did not know how to address this subject in high school. In addition, there was a demand from the teachers themselves for an

event aimed exclusively at them. So far, three editions of the workshop have been held: the first in 2012, the second in 2015 and a third in 2018. Here we will cover the 2015 edition, which we had the opportunity to follow. In this edition, the thirty professors and undergraduate students who met for three days at the Unesp Barra Funda campus (the same place where the SPRACE Masterclass is held) attended lectures on the standard model, accelerators and particle detectors (with a greater focus in the Compact Muon Solenoid – CMS), discussed the activities proposed by the textbook used in the state schools of São Paulo and were presented to games, activities and experiments focused on the teaching of particle physics.

3. Methodology

The research was divided into three main steps: initial surveys through open questionnaires, semi structured interviews and data analysis. The initial survey was conducted by applying questionnaires to teachers participating in the second edition of the particle physics workshop in 2015 and the 2016 edition of the Masterclass. The main objectives of these questionnaires was to know better the teachers who participated in these events, to know how many of them have ever addressed particle physics in their classes in high school and what were the difficulties (according to them) in teaching this topic, and to understand the importance of these events for them. Teachers answered about their prior education, how long they had taught physics, whether they had already addressed MCP topics in their classes, what they consider to be the main obstacles to the teach modern physics, how important was teaching MCP topics in high school in their opinions, what topics they thought were most important (and why), if they had any background on MCP topics, what expectations they had when they enrolled in that event and how they rate the contributions of events to the teaching of particle physics, among other personal questions. As the purpose of the questionnaire was only to collect basic information about teachers and the number of respondents was small (only forty-six questionnaires, including both events), we considered that the use of statistic methods to analyse the data would not be necessary or significative.

After analysing the answers to the questionnaires, we selected two teachers (who we will call Henrique and Valentina) for the interview stage, in order to better understand their life histories and teaching trajectories in order to better understand their relationships with both events. The interviews were conducted in two stages: the first one at the end of 2016 and the second one a year and a half later at the beginning of 2018. We chose the interviews as the main method of data collection since we wanted to understand more deeply the importance of the events for the teachers with the purpose of revealing what are the meanings attributed by them to their participation, and finally, how their beliefs of self-efficacy could be affected.

As a methodology of analysis, we have chosen the narrative analysis. From the transcriptions of the interviews, narratives of subjects' trajectories as students, teachers and participants of the studied events were elaborated. In this type of analysis, the researcher transforms the narratives into a new narrative, a plot that gives meaning to the data without seeking common categorizing elements, but rather unique, peculiar elements that configure the history. Unlike the paradigmatic analysis, for which the categorizations are fundamental, in the narrative analysis a generalization is not sought. Another important characteristic of this form of analysis is that, in it, subjectivity is not seen as a problem but as a fundamental part of the social phenomena studied. When a teacher talks about himself, he is recreating another “self” which is related to his beliefs about himself [11].

Based on the narratives produced from the transcripts of the interviews, we searched for elements that revealed the meanings attributed by the subjects to the Masterclass and to the Workshop of particle physics and that could exert some influence on their beliefs of self-efficacy. Moreover, from descriptors of high beliefs of teacher self-efficacy, found in a Bzuneck’s work [12], we searched for elements in the narrative that allowed us to qualitatively evaluate Henrique and Valentina's self-efficacy beliefs.

4. Theoretical Framework

When verifying that some physics teachers avoid addressing particle physics in their classes because they do not feel sufficiently prepared for this task (due to their education, lack of knowledge, lack of examples to support themselves etc.), we realize that it would be interesting to look for a theoretical framework that would help us to understand the motivations of the teachers to adopt a behaviour change. This is how we found Albert Bandura's cognitive social theory and individuals' self-efficacy beliefs.

Bandura's cognitive social theory, originally called social learning theory, is opposed to the idea of the human being as a simply reactive organism (behavioural theories), as well as to the idea that his or her behaviour is shaped only by factors beyond his or her control. According to the author, "the human mind is productive, creative, proactive and reflective, and not only reactive." [13]

> In Bandura's (1986) social cognitive theory, individuals are self-organized, proactive, self-reflective, and self-regulated, rather than reactive organisms that are shaped and guided by environmental forces or driven by hidden inner impulses. Human thought and action are considered products of a dynamic interrelationship between personal, behavioural and environmental influences [14, p.98]

In his studies of human behaviour, Bandura concluded that humans are able to learn new behaviours from observation (or social modelling, in their words) without the need for direct reinforcement experience. However, the fact that a subject internalizes a particular behaviour does not necessarily mean that he will put it into practice. For a behaviour to be carried out, it is necessary for the subject to have a minimum of confidence in his ability to perform the necessary actions satisfactorily, thus avoiding feelings of frustration and self-censorship. These subjects' beliefs in their own ability to perform an action satisfactorily were called self-efficacy beliefs. According to Bandura, “efficacy beliefs are the basis of human agency. Unless people believe they can produce the results they want and prevent harmful outcomes through their actions, they will have little incentive to act or persevere in the face of difficulties” [15, p.78].

It is important to emphasize, however, that self-efficacy beliefs are always oriented to a specific task and can not be confused, for example, with self-esteem. In addition, it is related to an individual's view of their ability to perform that specific task regardless of their expectation that that action will generate the expected outcome. This second expectation, regarding the result of the action, is called outcome expectation by Bandura.

> An outcome expectancy is defined as a person's estimate that a given behaviour will lead to certain outcomes. An efficacy expectation is the conviction that one can successfully execute the behaviour required to produce the outcomes. Outcome and efficacy expectations are differentiated, because individuals can believe that a particular course of action will produce certain outcomes, but if they entertain serious doubts about whether they can perform the necessary activities such information does not influence their behaviour. [16, p.194]

An individual's self-efficacy beliefs are constructed throughout his life based on four factors. In order of importance, they are: direct (or domain) experiences, vicarious (third-party) experiences, social persuasion, and physiological states. Domain experiences are the most reliable source of information about a subject's abilities, for if he accumulates successful experiences in tasks similar to those he intends to accomplish, he is likely to believe that he can perform it satisfactorily. The opposite holds true when there is accumulation of unsuccessful experiences. Vicarious experiences do not exert so much influence on individuals' self-efficacy beliefs, but they are still an important source. The experiences of third parties with which an individual can compare may make him believe that his chances of success are as great or small as those of those who have already performed similar actions. Social persuasion and physiological states, which are due respectively to third-party opinions about an individual's capabilities

and the physical reactions experienced by the individual in planning and engaging in an activity, influence beliefs of self-efficacy very weakly and generally have a negative effect on it.

Cognitive social theory, more specifically self-efficacy beliefs, can be applied to the most diverse fields of study and has been applied to research in education since the 1980s. Bzuneck [12] conducted a literature review of research on self-efficacy beliefs of teachers. Among other results of these studies, Bzuneck pointed out some characteristics of teachers with strong self-efficacy beliefs, as well as others of teachers with weak self-efficacy beliefs. One of the main characteristics of teachers with strong self-efficacy beliefs is their willingness to develop innovative teaching activities. In the context of this research, we can affirm that the stronger are the self-efficacy beliefs of physics teachers, the more likely they are to address new topics in their classes, such as elementary particle physics. Rocha [17] corroborates this conclusion in a work with physics teachers in a context of curricular innovation aimed at teaching topics of modern and contemporary physics.

We believe that this outlook on Bandura's cognitive social theory and self-efficacy beliefs is sufficient to justify our interest in this theoretical framework and to sustain the pertinence of the guiding question of the research. After all, if the participation of physics teachers in scientific outreach events such as those promoted by SPRACE may exert any influence on their self-efficacy beliefs regarding to the teaching of elementary particle physics, these teachers will have a better chance of engaging in this work or persist when they face adversity.

5. Analysis and Conclusion

As already mentioned, the first stage of data collection took place through two questionnaires: one answered by the 2015 Workshop and another by 2016 Masterclass attendants. These questionnaires served mainly to confirm what previous researches had already exposed and to select the research subjects for the interviews phase. The answers showed, first of all, that most of the participating teachers had never had any contact with elementary particle physics as students nor addressed this or other MCP topics in their classes. This result was already expected, but we believe that it gains relevance in this context in which the universe of the subjects studied is small and contains only teachers who were participating in an event focused on particle physics, that is, subjects that somehow show interest on the subject.

Another question raised by the questionnaires was about the obstacles that teachers see for the teaching of particle physics. Once again the answers confirmed the results of previous researches: deficiencies in teacher education, an excessive quantity of topics to be addressed in a reduced time, lack of quality teaching materials (including for teachers' study), the low incidence of the subject in the admission exams and beliefs that this is a difficult subject for students' understanding and that teachers are not prepared to teach it.

Finally, the most important question for this research asked the teachers to point out the main contributions of the two events to their participants. The most mentioned contributions were the acquisition of knowledge about particle physics, the discovery of new methodologies and didactic materials to teach MCP topics, the exchange of experiences with other teachers, the increase of the motivation to teach elementary particles physics and other MCP topics besides the opportunity to get in touch with scientists and cutting-edge researches.

The analysis of the answers to this last question showed that most of the teachers considered the participation in these events as an additional training or a form of professional qualification, where they had the opportunity to learn more about the subjects covered. That is, the teachers attributed a formative meaning to the events. The fact that many of them point out the discussions of methodologies and the presentation of didactic activities that they could use in their classes among the main contributions of the events shows us that another meaning attributed by the teachers to the events is that of instrumentalization (acquisition of resources and repertoire). In addition, statements that participation in

such events could serve as a first step or at least a motivation for the teaching of particle physics in high school points to the attribution of a motivational meaning to events.

From the point of view of teachers' self-efficacy beliefs regarding the teaching of particle physics, the attribution of such meanings to events seemed relevant to us, since they are directly related to the obstacles pointed out by the same teachers in the previous question. We consider it coherent to consider that by attributing the formative, instrumental and motivational meanings to the events, teachers are indicating that attending the Masterclass and the Workshop can help them overcome some obstacles to the teaching of particle physics, making them more prepared and motivated for this task. Consequently, it is possible to infer that participation in these events has the potential to affect their self-efficacy beliefs.

The next stage of the research, which aimed to better understand the teachers' relationship with the events studied and to report successful experiences, pointing out ways to change practices, was composed by interviews with two subjects selected from those who answered the questionnaires and the narrative analysis of the transcriptions of these interviews.

Henrique, the first subject to be interviewed is an experienced physics and chemistry teacher, who has taught at different public schools, worked on teacher education, and since 2012 teaches at a fulltime state school. He is the teacher who most attended the Masterclass organized by SPRACE (since 2012) and also attended the second edition of the Particle Physics Workshop. Since the beginning of his career, Henrique tries to insert topics of modern physics in his classes, even when they are not predicted in the curriculum. Teaching in a full-time school, he had the opportunity to teach elective subjects in the counter period. One of the elective courses chosen by Henrique to teach is astronomy, a subject for which he shows great interest. Within this discipline he is able to address some topics of modern physics such as nuclear physics when speaking of nucleogenesis in stars.

Since particle physics became part of the high school curriculum, Henrique addresses this issue and, to make the transition between classical physics and quantum physics smoother for students, he claims to have rewritten one of the proposed learning situations proposed by textbook. Another initiative was the use of a game for students to improve their understanding of the phenomena of the microscopic world. That is, he is a teacher who feels capable of teaching MCP topics in his classes and has been doing this for some time.

For him, the Masterclass "is a supplementary training" offered to teachers every year and "this is very good for teachers because many of them did not had this opportunity during their undergraduate courses." About the Workshop, Henrique tells how this event was important for a colleague who felt insecure to address MCP in her classes:

> For me, what was pretty cool [at the Workshop] is that I was able to invite another teacher from my school. (...) In the previous year's Masterclass, I had invited her to go and she refused. I think it was a bit of insecurity, that she thought "I'll be together with the students. What if a student asks me something that I don't know how to answer?". There was this difficulty. As we went to the Workshop and it was a group of teachers only, she felt more confident so that she could go later in the Masterclass. That was nice. (...) I think it gave her more confidence to talk about this subject [at school]. (...) When students ask, she already has more autonomy to speak, so I think it helped her.

Henrique's view of both events can be further supplemented by one of his responses to the questionnaires. In the question about the benefits of these events for teachers, Henrique answered: "it can broaden our knowledge, present new didactic proposals, motivate [...]".

Valentina, the second interviewed teacher, is younger than Henrique. She teaches physics at three different private schools, participates in the Masterclass since 2016 and has also attended the 2017 and 2018 editions of women's and girls' day in science and the second edition of the Workshop. Graduated in a degree in physics, Valentina was finishing her master's degree in sciences education at the time of the first interview, and by 2018, when we conducted the second interview, she had already started her doctorate studies in the same field. In addition, in 2016, despite reporting her desire to teach modern

physics topics and feel empowered to do so, she had not yet inserted any topic into her regular classes. However, by 2018, she had already managed to organize extra classes in one of the schools to address elementary particle physics.

According to Valentina, attending the Workshop is important for teachers because they feel unprepared, so "the workshop is a training that complements" and can help them. She believes the workshop is a very interesting professional growth opportunity for the high school teachers. Her judgment of Masterclass is similar:

> It is an opportunity for teachers to improve their knowledge about this content and, in addition, it is an opportunity that the teacher does not have to face alone, because in Masterclass he does not have to give any lecture, he does not have to give any previous classes to the students. He will experience the Masterclass together with the students. So, he will be able to learn. Hopefully it will not be the first time he will get in contact with that subject and then he will be able to assimilate things that he has not assimilated previously [...]

Finally, Valentina claims to believe that after participating in the Masterclass it is easier for teachers to break down barriers and approach particle physics in high school, that participation in the Masterclass can be seen as a kick-start for teaching this and other topics of MCP.

The analysis of the interviews leads us to conclude, firstly, that the formative, instrumental and motivational meanings are present in their discourses. In a second analysis, based on the results of previous research that show the behavioural characteristics of teachers according to their beliefs of self-efficacy, we conclude that Henrique and Valentina have high self-efficacy beliefs regarding the teaching of particle physics and other topics of MCP [18]. Based on these two conclusions and the arguments already discussed above, we believe that it is consistent to infer that participation in those events can help teachers to overcome obstacles that prevent them from promoting innovations in their teaching practices and may have exerted some influence on the construction of Henrique's and Valentina's self-efficacy beliefs, something that we suppose could happen to other teachers as well.

We are not asserting here that attending these events is enough for a teacher who does not address particle physics in his classes to do so, but we feel safe to say that such participation has the potential to affect the self-efficacy beliefs of teachers, and consequently can serve at least as a trigger for a sequence of investments to be made by the participants in that sense. This conclusion cannot be generalized because of the small number of teachers who answered the questionnaires and were interviewed (what is a limitation of this study). Furthermore, improving the research design and analysis methods (such as the development of the questionnaires and the statistical analysis of the data) could strengthen the reliability of the results. Nevertheless, this work points out to new research questions and is bound to serve as a starting point for more comprehensive studies about this topic.

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