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‘Playing with Protons’: a training course for primary school teachers at CERN

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Abstract

In recent years the realisation that children make decisions and choices about subjects they like in primary school became widely accepted. The role of the primary school teacher as the main ambassador for a subject is therefore crucial in inspiring and enthusing the younger generation towards STEM. However, in most European countries, primary school teachers do not necessarily have good content knowledge in STEM subjects including physics as this is not a requirement. Many teachers stopped studying physics at the core level in high school. This puts in perspective the problems a teacher might encounter when trying to share new physics ideas in the classroom. A new and innovative training course started at CERN in 2016 under the name ‘Playing with Protons’ with the aim to inspire, educate and empower primary school teachers towards modern physics, scientific discovery and innovation.

1. Introduction

There is widespread consensus amongst science education researchers and practitioners that learning science should begin early in every child’s schooling. There are many good reasons for this, but one stands out clearly: ‘Children naturally enjoy observing and thinking about nature’ [1]. Empirical research moreover suggests that students’ aspirations of pursuing a career in STEM, including physics, are likely to be shaped considerably by their experiences of and attitudes to school science at primary level [2]. Several studies have shown that the public also wants science to be taught early. For example, in a recent public opinion survey in the US, seven in ten Californians expressed the view that learning science in primary school is likely to increase the chances of students performing well in high school [3].

Yet the majority of interventions, at least in the UK, currently target secondary school settings [4]. One reason for this may lie in the fact that, unlike their secondary school colleagues, primary school teachers in most European countries do not specialize in specific subject areas and therefore may lack the subject knowledge, competence and confidence to teach science in general and physics in particular. This shortcoming is consistent with the results of research showing that primary teachers rate science among the least favourite and enjoyable subjects to teach [5]. In turn, as earlier research has demonstrated, poor teacher competence and attitude can have a negative effect on their students' attitudes towards science [6].

In light of the above, there have been several calls for universities and research institutes to invest further in primary science teacher education [7, 8]. 'Playing with Protons' [9] represents an effort towards this direction by enabling primary teachers to enhance their science teaching practice with creative, hands-on methodologies through which primary students can get engaged effectively with new physics ideas, scientific discovery and innovation.

2. The 'Playing with Protons' course at CERN

2.1. Background and development

One of CERN's strategic missions is to help train tomorrow's scientists, engineers and technologists, by providing support to schools, students, teachers and educators. Since 1998, CERN is home to a now extensive training programme specifically designed for high school physics teachers from member and associated member states as well as other countries [10]. The premise of this programme is that training teachers is an effective way of reaching many students, since the former can act as sustainable multiplicative factors by promoting science in general and particle physics within and beyond the classroom [11].

While several initiatives at or in collaboration with CERN have occurred over the past decade to bring the excitement of science in general and particle physics in particular to primary school students [12, 13], no primary teacher training had taken place at CERN until December 2015 [14]. 'Playing with Protons' aims to build on previous efforts in a systematic and consistent manner. As has been the case with CERN's many educational activities, the course emerged out of a bottom-up project that was first implemented in a Greek primary school in 2013–14 [15, 16]. With the support of members of the CERN community, including John Ellis, a well-known theoretical physicist and initiator of CERN's high school teacher programme, the project was extended to a pilot training course for 10 Greek primary teachers that took place at CERN in the summer of 2016 [17]. This course was initially supported by the CMS and subsequently by the ATLAS experiments at the large hadron collider (LHC) in the framework of the CREATIONS EU project [18].

The pilot course was followed up systematically for the next school year, during which nearly 900 Key Stage two students from 17 primary schools in Greece took part in hands-on particle physics activities for an average of 30 didactic hours. The positive results and feedback of this initial implementation [19, 20] encouraged the continuation and gradual expansion of the course, which up to September 2018 has trained 50 primary teachers from Greece and the UK. Details of the individual courses including the names and institutes of all contributors can be found in the programme agendas [21].

2.2. Motivation and aims

The 'Playing with Protons' course has been inspired by the vision to enhance the educational footprint created by large research infrastructures like CERN through the provision of tailor-made training for primary school teachers by using experienced physics educators mainly from their country of residence. This has the advantage that, once the course is over, teachers will continue receiving support from the trainers they met at the course. As the primary curriculum differs from country to country, it is crucial that the trainers are carefully chosen to have proven experience in primary school education and are still active educators themselves, but equally important that they have a strong background in physics (University degree or above).

The aims of the course are to help primary school teachers:

- Experience the unique culture of cutting-edge science, technology and innovation at the world's largest particle physics laboratory
- Try out new physics teaching approaches, especially hands-on activities and experiments with everyday materials, to increase their confidence when teaching physics and science in general

- Develop creative educational scenarios and lesson plans that build on and enrich their primary curriculum with modern physics ideas to increase the interest, motivation and wonder of students
- Get inspired and motivated to share their newly acquired subject knowledge with peers, parents and their local community

The development of the ‘Playing with Protons’ course is further informed by the creativity-based pedagogical framework [22] established within the CREATIONS project. Strong emphasis is placed on the features of dialogue, risk, immersion and play, and interdisciplinarity, the application of which can help make the science teaching and learning process inspiring and engaging both for teachers and students.

The advantage of running the course at CERN is that its programme is enriched with talks and Q&A sessions by members of the CERN scientific community and with visits to CERN’s experimental facilities and permanent exhibitions. The on-site venue chosen for the course is IdeaSquare [23] which provides a modern, collaborative and creative surrounding to the teachers who might feel slightly apprehensive about their visit to such an impressive establishment.

3. The structure of the course

Central to the ‘Playing with Protons’ course is the view that an inspiring and engaging primary science teacher training should not only be in line with the national curricula, but should also enrich teacher’s knowledge with current ideas, practices and reflections on science, technology and innovation. Equally important is designing the course in a way that its various parts fit together to provide participants with a flexible, multifaceted and integrated learning experience.

3.1. An integrated training approach

Due to the mathematical complexity of modern physics, the national curricula of primary and low secondary education are based on the physics of the 19th century. This gives an old-fashioned aura to the subject and inadvertently it loses out on image and attraction. Teachers who are unfamiliar with modern physics concepts, research and questions, are missing the tools to engage effectively their classes with the inspiring and creative world of cutting-edge physics. It is therefore crucial that any course that aims to help primary school teachers enthuse their students towards the subject must incorporate a level of specialisation. The teacher is brought in line with current developments in the field of physics, thus paying attention on how scientists, by using various research schemes, develop, evaluate and apply acquired knowledge [24]. In addition, this knowledge must be built slowly and in a conceptual way rather than a mathematical way that will be more challenging for primary teachers and their students. Concepts and ideas can be explained with simple demonstrations that go straight to the point and can be also understood by young students. For example, the process of science that involves observations, patterns, possible explanations, experiments, revisions and judgements is easily demonstrated using a ‘black box’ (figure 1); no one knows what is in the box but experiments on the box can lead to inferences and conclusions [25].

Moreover, the talks, visits and workshops of the course are structured in an integrated manner to offer teachers a diverse and holistic picture of the new physics ideas and concepts they are introduced to. This is crucial for the future use of the materials in the classroom. Students will pay more attention to the firsthand experiences of their teacher when he/she describes the visit to the LHC or shows them a photograph with one of the most famous theoretical physicists at CERN.

Finally, an equally important aspect of being at CERN is that the primary school teachers become part of a large international collaborative community. This is a cultural aspect that many teachers would not have come across on other training courses in their native country. The CERN culture of working together towards a common goal, irrespective of political affiliation of its member, associate and non-member states, is the ethical base that CERN was built on. This message is a powerful one and is certainly worth taking back into the classroom, as a teacher’s role is not only to educate students on subject knowledge but also to make responsible citizens in a diverse and global society.

Figure 1. Greg Dick (PI) explaining the 'black box' to 'Playing with Protons' trainees. Reproduced with permission from CERN.

3.2. Introducing the new concepts

At the beginning of every workshop, an interactive talk provides the step-by-step ladder of knowledge that is needed to bring the trainees to the required level, equivalent to A level physics for UK trainees and of Lykeion for Greek trainees. The mathematical analysis behind the physics concepts is kept to a minimum as it is mostly important to understand the new concepts themselves and have the time to digest the newly acquired knowledge. Only when a mathematical analysis helps this process the equations and calculations are shared with and worked through.

Following the introductory talk, a series of hands-on activities are completed by the teachers. These activities use cheap everyday materials that can be easily replicated in the primary school classroom, either as they are or modified by the teacher [26]. As one of our primary aims is to empower the teachers themselves, we try to inspire them with these activities and to actively encourage them to come up with their own ideas and modifications to use in their classroom. Our hope is that some of the primary school teachers who participated in the course will return as trainers in future years, as has been the case for the Greek edition of the course.

Equally important is that we do not restrict the training to syllabus related topics only, but we give a wide overview of the current knowledge in physics, the current questions that are investigated at CERN, as well as the big unanswered questions. By providing opportunities for dialogue between teachers, scientists and science communicators, we also help teachers to understand that the evidence-based thinking and doing of science is one of the foundations of human creativity and that CERN works for humankind.

4. Implementation in schools and communities

Over the last two school years 'Playing with Protons' has reached out to schools and communities in Greece and the UK through many and diverse local activities and initiatives led by the 30 Greek and UK teachers/participants who took part in three training courses at CERN in the summer of 2016 and 2017.

Table 1 illustrates that the course participants have been involved not only in implementing activities in their own schools, but in activating their networks to engage colleagues from other schools, thereby helping increase the educational footprint of 'Playing with Protons'. On average, the multiplication ratio per course participant equals to 173 students, six teachers and three schools. This multiplication was possible mainly because of the organisation of local and regional

Table 1. Local implementation of ‘Playing with Protons’ in Greece and the UK.

School year	Country	Schools	Teachers	Students
2016–17	Greece	17	32	896
2017–18	Greece	43	97	1796
	UK	31	54	2492
Total	Greece, UK	91	183	5184

training seminars in which the course participants shared their learning experience at CERN with colleagues, school principals and advisors who, in turn, embraced the idea and decided to join the effort.

4.1. Diversity of activities

The diversity and breadth of the follow-up activities completed by the teachers was immense. As mentioned above, many teachers engaged with more schools in their area as well as with their local community. They have become ambassadors for science, physics, particle physics and CERN and continue to engage with larger audiences’ year after year. It is impossible to include in this paper the vast expansion of activities that continue to emerge. Table 2 gives a few examples of the subject areas, questions and type of activities that were used by the majority of teachers.

4.2. Awards and recognitions

While the impact of the aforementioned follow-up activities on students’ interest in science and creativity is currently under investigation, it may be worth noting that some of those activities have received awards and recognitions at national and international competitions. These are summarised in table 3.

5. Evaluation

Teacher evaluation is key to understanding effective teacher practice, identifying course strengths and weaknesses, and ensuring the continuous improvement of teacher professional development. Since its piloting, ‘Playing with Protons’ has been evaluated by its participants in two ways. First, at the end of each course, all teachers complete an evaluation questionnaire to assess the course’s quality and content. Second, a follow-up questionnaire is completed by those teachers who have already implemented activities in their schools and communities to assess the extent to which the course has delivered on its aims. Selected results of both evaluations are presented in the following subsections.

5.1. Course evaluation

In this subsection we present evaluation results based on quantitative and qualitative data collected with an online survey questionnaire from 30 teachers who participated in the following three courses: Greece 2016 ($n = 10$); Greece 2017 ($n = 10$); and UK 2018 ($n = 10$). The survey included single statements rated on five-item Likert-type scales ranging from strongly disagree (1) to strongly agree (5), or very poor (1) to very good (5), and open-ended questions to elicit richer feedback from the respondents.

In the first part of the questionnaire, teachers were asked to rate their agreement or disagreement with statements related to: (1) the relevance and usefulness of the course; (2) the organisation and running of the course; (3) whether the course met their expectations; and (4) whether they would recommend the course to colleagues.

As shown in figure 2, a staggering 100% of the teachers rated these questions with either ‘strongly agree’ or ‘agree’, demonstrating in a very clear manner the importance and value of this course. The only noticeable difference between the Greek and the UK teacher ratings was found in the relevance/usefulness parameter. This difference may be explained by cultural perceptions; for a UK teacher ‘relevant’ is understood as curriculum-relevant, where for a Greek teacher any knowledge that widens the horizons of their students is regarded as ‘relevant’.

The second part of the questionnaire allowed teachers to rate each activity individually. Yet as the UK and Greek programmes differed in the number and types of sessions, it was fairer to compare the overall rating given from each country

Table 2. Examples of the subject areas, questions and type of activities used by teachers.

Subject	Questions	Activities
CERN	• What happens at CERN? • What does the LHC do? • How do particle detectors work?	• Animated videos with photos of student's work • Group work—poster/model making • Video link session with CERN • Web page displaying student's research work • Immersion play activities (games using digital apps) • Creative story/comic writing
The scientific process	• Why and how did early man discover science? • How does science work (observations, patterns, possible explanations, testing experiments, revisions, judgements)? • How do we know what we know?	• 'Black box' activity • Immersion play activities (puzzles) • Simple class experiments • Animated videos
Famous scientists	• What did Newton believe about gravity? • What did Einstein believe about gravity? • What did the ancient Greeks know about science? • Who are the most important physicists of the 19th and 20th century and what did they discover?	• Group work—poster/model making • Immersion play activities (treasure hunt)
Fundamental particles	• What are the fundamental particles of matter? • How do particles interact with one another?	• Immersion play activities (dramatisation, quiz) • Group work—poster/model making • Creative story/comic writing
Fundamental forces	• What is gravity? • How do fundamental forces compare in strength?	• Immersion play activities (games) • Group work—poster/model making • Interactive talk with demos from teacher
Structure of matter	• What are atoms and molecules? • How did Rutherford discover the structure of the atom?	• Group work—poster/model making • Group work using phet simulations • Immersion play activities (dramatisation, cooking) • Interactive talk with demos from teacher
Matter and antimatter	• What is antimatter? • How does matter interact with antimatter?	• Group work—poster/model making • Immersion play activities (dramatisation)
Light	• How do the different colours of visible light combine?	• Simple class experiments
Cosmology	• How did the Universe begin? • What is in our solar system? • Why is the sky at night black? • What is the relative size of planets, stars, galaxies?	• Creative story writing • Sky observation using mobile phone apps • Group work—poster/model making • Creative story/comic writing

Table 3. List of awards won by 'Playing with Protons' teachers/participants.

Competition name	Organiser	Award type/category	Awarded school	Awarded project title	Awarded project description
Science communication awards ΕΠΙ[2]	Athens science festival	Best school demonstration at the Athens Science Festival 2018	Primary School of Vytina (Greece)	Colonizing Mars	A Scratch-programmed miniature colony on Mars made with LEGO bricks and Arduino hardware [27]
'Looking …Up! astronomy for ALL' global video competition	Office of Astronomy for Development (OAD)	Best educational video on astronomy	3rd Primary School of Chios (Greece)	Big Bang telling stones	A stop motion animation video on the Big Bang theory [20]
Particles4U competition	International Particle Physics Outreach Group (IPPOG)	Primary school (age 12 and under)	2nd and 6th Primary Schools of Artemida (Greece)	The quark show	Video on particle physics and quarks [19]

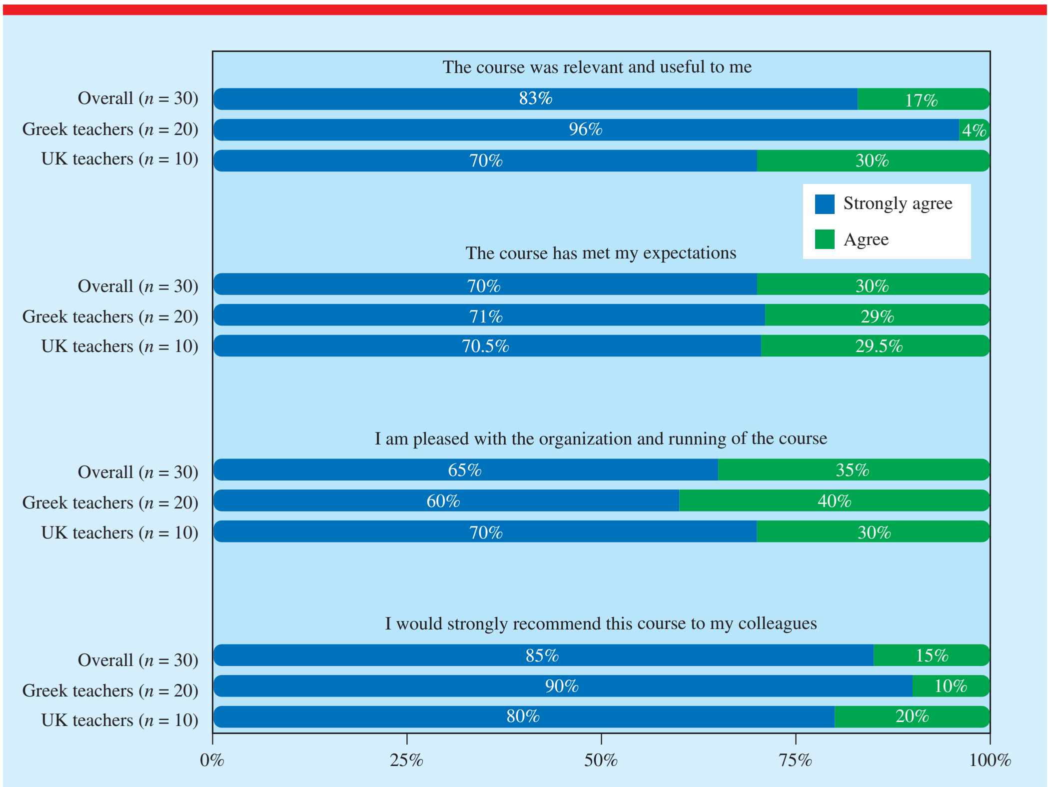

Figure 2. Greek and UK teachers' rating of the course's quality.

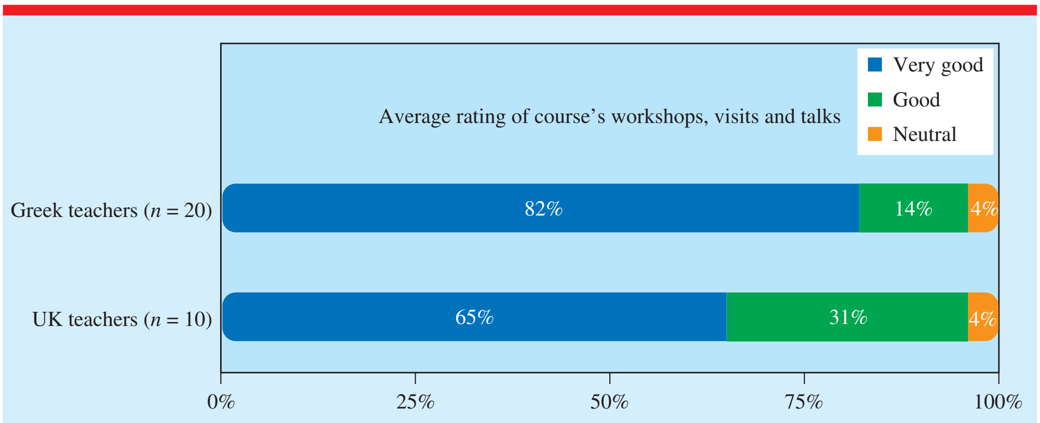

Figure 3. Greek and UK teachers' overall rating of the course's content.

rather than the individual ratings for workshops, visits and talks.

Figure 3 shows clearly that both UK and Greek versions of the course were an enormous success; % ratings for poor and very poor were zero while % ratings for neutral were very low in comparison. It is also clear that Greek teachers were more pleased with the course in comparison to their UK colleagues, perhaps because teacher training opportunities such as these could be less commonly available in Greece. It is therefore possible that the overall appreciation of the Greek teacher community was inflated for this reason.

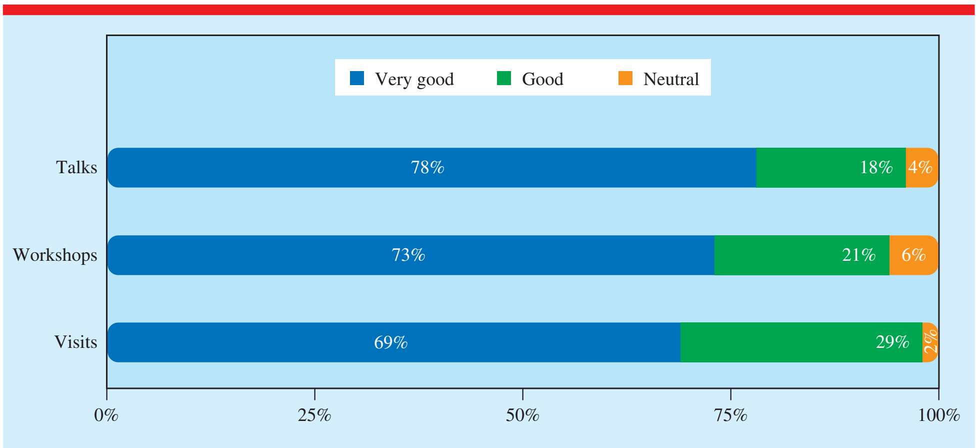

Figure 4. Overall teachers' rating for visits, workshops and talks.

When comparing the ratings teachers gave to visits, workshops and talks, it was clear that teachers liked the balance between the three types of activities. The high ratings 'talks' received (figure 4) show the value teachers placed in interacting with CERN staff and listening from the experts, even though most talks were not directly linked to the primary school curriculum but aimed at giving an overall view of the current research at CERN.

On the last part of the questionnaire teachers commented on: (1) the aspects they mostly/least enjoyed; (2) their plans to implement activities in their school community; and (3) ideas and suggestions for improving the course.

In the 'mostly enjoyed' aspects, comments included the good balance between theory and practice, the quality of the support given by the organisers, the visits, the quality of speakers, the change of role from teacher to student they experienced, meeting new people that are also passionate about science and recognise the importance of primary students and teachers, enhancing their subject knowledge, being in such an inspirational place, and many more.

In the 'least enjoyed' category, comments included the short duration of the course and the speed at which some concepts and discussions took place. Many teachers wanted the course to last at least 1–2 more days to give them the extra time needed to absorb the new material they were learning.

Finally, some very useful ideas for improvement were suggested that include: (1) the distribution of pre-reading material; (2) the set-up of a meeting prior to the trip to CERN so that team members have a chance to get to know each other before-hand; and (3) the possibility of including creative time-slots so that teachers have a chance to start putting their ideas into actions. The suggestion to make the programme longer and therefore less dense was again prominent in this part. Figure 5 shows the frequency of some of the words used by the teachers to describe the course.

Figure 5. Most frequently used words to describe the course.

Overall the organisers are very pleased with the evaluation they received and are currently taking steps to implement some of the above suggestions in their future plans.

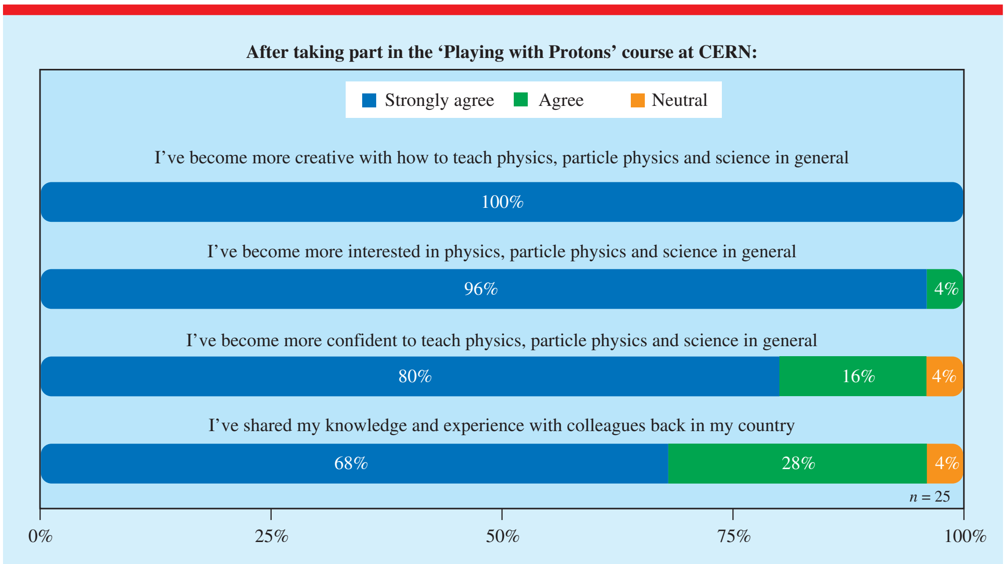

Figure 6. Teacher follow-up quantitative evaluation.

5.2. Follow-up evaluation

In August 2018 an invitation to a follow-up online survey was sent to 30 primary teachers from Greece ($n = 20$) and the UK ($n = 10$) who participated in ‘Playing with Protons’ courses at CERN in August 2016 and 2017. The aim of this survey was to measure changes over time in teachers’ interest, confidence, creativity and knowledge sharing as well as to gather information on changes in their professional and self-development as a direct consequence of their participation in the course. The survey employed single statements rated on five-item Likert-type scales ranging from strongly disagree (1) to strongly agree (5), and open-ended questions to elicit more details from the respondents. Surveys were fully completed by 25 teachers, with a response rate of 82.5%.

As shown in figure 6, the results indicate that the course not only increased teachers’ interest in physics, particle physics and more generally in science, but also boosted their science teaching confidence. Importantly, as shown in the same figure, all respondents agreed strongly that they became more creative primary science teachers because of their participation in the course. In addition, 68% of teachers agreed strongly and 28% agreed that they shared what they learnt during the course and implemented in their schools with colleagues from their home country.

Teachers’ follow-up comments complement the above picture by illustrating the positive and, in some cases, transformative role the course has had on their teaching practice, professional development and even personal outlook. First, in table 4, we present selected teachers’ qualitative feedback categorised along the evaluation dimensions of interest, confidence, creativity and knowledge sharing. To note that these dimensions are linked directly to the four core aims of the ‘Playing with Protons’ course. Second, table 5 presents additional quotes that depict the impact the course has had on teachers’ professional development and personal outlook.

6. Discussion

Recent years have witnessed the realisation that primary science education matters. As research has shown that ‘by age 14, most young people’s attitudes to science are fairly fixed’ [4], broadening the scope and focus of science education programs and interventions, offered by universities and research institutes to effectively include primary school teachers and students, becomes imperative. It is this premise that largely guided the decision to establish in a consistent and reproducible manner a training course for primary school teachers at CERN.

Table 4. Impact on teachers' interest, confidence, creativity and knowledge sharing.

Course aim	Evaluation dimension	Teachers' quotes
Experience the unique culture of cutting-edge science, technology and innovation at CERN	Interest in particle physics, physics and science	'I became more interested in particle physics and have used this in my own teaching. I have read around the subject and sought out articles and books on the subject'. 'I felt my brain gradually come alive! I now search out news and books on anything to do with particle physics and was delighted to be able to understand a presentation on antimatter at the Cheltenham science festival (and the accompanying book)'.
Try out new teaching approaches, to increase confidence when teaching physics and science in general	Confidence to teach particle physics, physics and science	'[I developed] better confidence because of better subject knowledge and proven tools to deliver successful lessons'. 'I became much more fluent and confident in teaching and inspiring next generations about particle physics and science in general'.
Develop creative educational scenarios and lesson plans to increase the interest, motivation and wonder of students	Creativity with how to teach particle physics, physics and science	'I developed play-based educational material for making the teaching of physics more attractive to my students'. 'I indulged in the breathtaking world of physics and although I have always liked it, I think that I found a way to make my students also love it'.
Get inspired and motivated to share their newly acquired subject knowledge with peers, parents and their local community	Knowledge sharing with colleagues etc.	'Many colleagues showed great interest in introducing parts of this innovative course in their classroom. The web site I developed gave them support and a variety of ideas how to start something new and fresh in STEM. The local media asked more info for the general public'. 'The course gave me the opportunity to interact and share ideas with colleagues in ways and aspects I had not thought of'.

Although at its early stage of development, it is evident that 'Playing with Protons' has created a non-negligible impact on primary science teacher communities in Greece and the UK. This impact may be best considered not only in terms of numbers of involved schools, teachers and students, but also in terms of the positive and in cases transformative changes the course triggered to teacher attitudes, by increasing their interest in physics and, most importantly, by boosting their creative confidence to introduce primary students to various scientific processes and discovery endeavours into the microcosmic world of particles as well as the macrocosmic universe. This creative confidence is reflected both in the follow-up evaluation and the diversity of activities implemented in schools and local communities, some which received awards at national and international level.

A closer look at the implemented activities also shows that the ways in which 'Playing with Protons' teachers approached their teaching, aimed not only at enthusing students about physics and science but also at providing them with opportunities to develop general skills including collaboration, problem-solving, creativity, and presentation and communication. The CREATIONS pedagogical features around which the activities were structured also allowed space for pupils of various abilities to participate and contribute their distinct skills to interdisciplinary inquiry- and creativity-based learning episodes that promoted diversity and the breaking of cultural stereotypes associated with science and scientists. In doing so, the activities implemented in the context of the course aspired to enrich the primary curriculum by demonstrating the value and thrill of learning modern physics and science at an early age.

Finally, an important parameter in the development of 'Playing with Protons' has been its inclusion under the umbrella of the CREATIONS project. This has enabled the deployment and evaluation of follow-up activities in collaboration with experienced partners in science education research and practice across Europe. It has also helped build teacher online communities of interest in Greece and the UK that currently number more than 170 members and contain over 20 learning resources, such as educational scenarios and lesson plans developed by teachers, which are available freely to anyone interested in primary physics.

Table 5. Impact on teachers' professional development and personal outlook.

Impact on teachers' professional development	Impact on teachers' personal outlook
'I have applied to and taken part in similar training courses in other European organisations. This would not be possible if I had not taken this course'.	'It opened up a new way of perceiving nature'.
'I have taken part in several seminars and presented ways to teach physics with everyday materials. Many schools have invited me to present what I did during the summer course at CERN'.	'The fact that I met and kept contact with great scientists gave me self-esteem, knowledge and confidence'.
'In the next school year, I will lead a new regional network of schools and teachers inspired by Playing with Protons'.	'I became more positive and patient as a person. Maybe more mature...'
'The course triggered my involvement in interdisciplinary STEM projects but also my development as a Scientix ambassador'.	'New horizons, new knowledge, new friendships'.
'I have had the confidence and enthusiasm to share ideas and concepts from the course at our county conference to over 100 teachers'.	'Personally speaking, there was a positive impact on my views and also my knowledge related to physics, cosmology, CERN and more generally of science'.
'I collaborated with other teachers, school advisors and I helped my school secure a grant from a foundation'.	'My professional and also my recreational choices are more closely related to science. Even my relationships with my students, both professionally and personally, have been improved as a result of my involvement with this course'.

7. Concluding remarks

The two most frequent words teachers used to describe the 'Playing with Protons' course were 'innovative' and 'inspiring'. While this is certainly a positive sign of the course's current impact and future potential, we argue that, from an organizational point of view, what makes the course exciting and promising is its ability to generate synergies across a set of key actors willing to exchange knowledge and expertise, and to combine human and other resources to achieve common goals. In this sense, 'Playing with Protons' is more than a training course; it is an emerging collaborative community governed by an ethic of interdependent contribution to a shared purpose, that is the effective engagement of all primary students with modern physics, scientific discovery and innovation.

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