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Particle physics for primary schools—enthusing future physicists

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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 understood. For this reason academic establishments focus some of their public engagement activities towards the younger ages. Taking advantage of Professor Lazzeroni's long-standing experience in particle physics research, during the last academic year we designed and trialled a particle physics workshop for primary schools. The workshop allows young children (ages 8–11) to learn the world of fundamental particles, use creative design to make particle models. The workshop has already been trialled in many primary schools, receiving very positive evaluation. The initial resources were reviewed and improved, based on the feedback received from school teachers and communicators.

1. Introduction

The fundamental particles of the standard model are grouped into three families: the quarks, the leptons and the bosons. Each particle has a distinctive name that often links to its behaviour or to a particular characteristic. The Birmingham group has a long standing tradition of studying the quark and gluon structure of the proton in fine detail [1] and the group's efforts are currently leading the top and heavy flavour physics and heavy quarkonia studies in the ATLAS experiment at the LHC [2]. Professor Lazzeroni has studied the behaviour of strange and beauty quarks throughout her career, in several experiments including the NA48 and LHCb experiments at CERN [3].

The world of fundamental particles is a topic that shares familiar trends with concepts that children are used to. The particle physics workshop explores the ability of young children to be imaginative and creative and exploits it to teach them the fundamentals of particle physics in a fun way.

2. The fundamental particles of the standard model

In primary schools students are familiar with the idea that everything around them is made out of small particles. In some cases students know the terms 'atom' and 'molecule'. At the start of the workshop these ideas are introduced by asking students to name the smallest thing they can think of; the terms 'cell' or 'bacteria' are the most commonly received answers. Students understand that it is possible to see small organisms using a microscope. A discussion follows where students learn that cells, microbes, bacteria etc are all made out of smaller particles which are called molecules and that these in turn are made out of even smaller particles, which are called atoms. The above concept can be demonstrated with a set of Russian dolls where inside one, a smaller one can be found. It is important to explain to the students that a school microscope is not powerful enough to show atoms; for this, scientists need a specialised microscope that is much larger than the ones used in schools, a lot more expensive and can be found in universities and research centres.

The idea introduced next is that scientists have discovered that atoms are made out of smaller particles, which we call protons and neutrons, and these in turn are made out of even smaller particles called quarks and gluons. No microscope can see inside an atom and students are bound to ask the obvious question: 'How do we know what is inside the atom if we cannot see it?'. Instead of giving a direct answer, a question can be posed here: 'What will you do if you want to find out how a toy works?'. The answer usually received is: 'you take it apart', or 'you smash it and you see what is inside'. This analogy introduces, in a very easy and simple to understand way, the reason why scientists accelerate particles and smash them together, so that they can break them apart and see what they are made out of. This is how scientists found the structure of the atom and the structures of protons and neutrons.

The above discussion introduces the concept of the particle accelerator as a complex machine able to smash particles together and break them apart in order to reveal what they are made out of. The discussion can be interactive and students can participate in a demonstration that shows Rutherford scattering using a muffin tray (for the unknown atomic structure), a football (for large particles) and ping-pong balls (for small particles). Firstly, the football is passed on from one student to another after it is bounced off the muffin tray. The observation is that the football always goes in the same direction, from one student to the other. Then the football is replaced by ping-pong balls. The ping-pong balls do not all bounce in the same direction; some fly off-side and a few bounce backwards. This is because they are small enough to hit the sides of the muffin-tray structure. The conclusion reached is that we can find out the structure of a small object if we hit it with small particles and observe where these particles go after the collision.

The location of CERN on a map of Europe and the size of the Large Hadron Collider (LHC) are also discussed with the students. Aerial views of the CERN location allow them to see Geneva and the borderline between Switzerland and France. The length and size of the LHC is compared to the M42 motorway around Birmingham or the M25 around London. Students are told that particles move very fast along the circular path of the LHC, almost as fast as light, and complete 10 000 rounds in the blink of an eye, i.e. in one second. The detectors of the LHC are compared to very fast digital cameras, able to take hundreds of thousands of pictures in one second, in order to capture the collisions between the fast moving particles [4].

In the next stage students are introduced to the three families of fundamental particles, the quarks, the leptons and the bosons. In this introduction we use the Particle Zoo soft toys [5] as a visual reference to the world of fundamental particles of matter and antimatter. Particular attention is paid to the strange, beauty and top quarks, given the Birmingham group specific research related to these particles. In the discussion that follows, students are told various fun stories about each and every particle [6] so that they can familiarise themselves with the names but also start forming in their minds a persona for each particle. Students are also introduced to the concept of 'charge' as a characteristic that can differ from one particle to another, in a similar way as two children can differ in the colour of their eyes, their height etc.

In order for the students to familiarise themselves with the names of the fundamental particles and their characteristics, students can play the Happy Families game using trump cards (figure 1). The set contains one card for each fundamental particle, with the name and family name of the particle, its mass and its charge [7]. Each card also lists some general information about the particle as well as the names of the other particles it 'likes'. One card set consists of the thirty fundamental particles of matter and antimatter: six quarks (up, down, charm, strange, top, beauty), six anti-quarks (anti-up, anti-down, anti-charm, anti-strange, anti-top, anti-beauty), six leptons (electron, electron neutrino, muon,

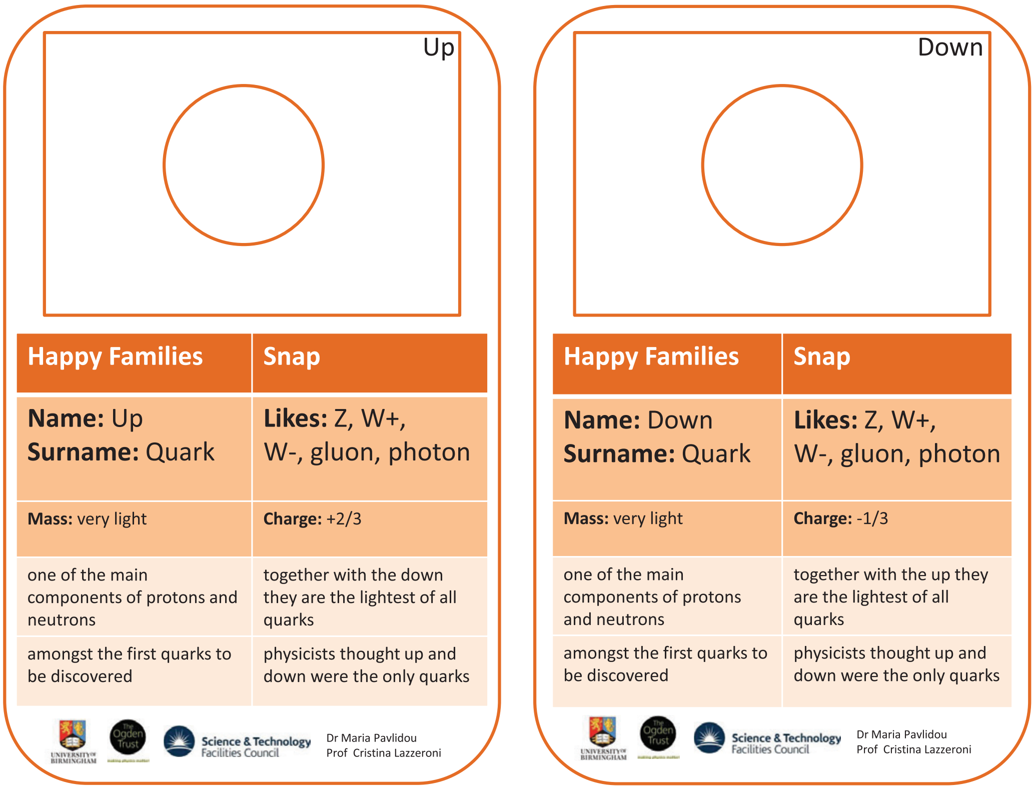

Figure 1. Trump cards, one per particle, showing name, surname, mass, charge, etc.

muon neutrino, tau, tau neutrino), six anti-leptons (anti-electron, electron anti-neutrino, anti-muon, muon anti-neutrino, anti-tau, tau anti-neutrino) and six bosons (gluon, photon, Z, W plus, W minus, Higgs).

3. Designing models for the fundamental particles

After playing the Happy Families game students are separated into five groups of six: quarks, anti-quarks, leptons, anti-leptons and bosons. Each student is assigned to one particle and is given the relevant trump card. The division is ideal for a class of thirty students. Students are asked to use their imagination and creativity to come up with a design for their particle in a way that it reflects its personality and properties.

Students working on matter–antimatter pairs are asked to work together because their particles have to be identical in every other way apart from the one feature which would correspond to charge. This feature will be coloured white for matter and black for antimatter. Throughout our workshops students have come up with a variety of choices on how to represent charge; by using a hat, moustache etc.

Overall we found that students who worked on matter–antimatter pairs collaborated very well with others from different schools. They were able to make suggestions, discuss their ideas and come to a common agreement. Collaborating with strangers introduces the idea that scientists work in teams, often from different countries, and that good communication and exchange of ideas is crucial in forming new scientific theories.

4. Making models for the fundamental particles

When introducing fundamental particles it is important to describe mass as one of the characteristics that differentiate particles from one another. The concept of mass relates to one of the foremost questions of current particle physics research, so it is important to give it the attention it deserves.

Table 1. How the fundamental particles of matter are grouped according to their mass.

Very light	Light	Heavy	Very heavy
Photon Gluon Up quark Down quark Electron Electron neutrino Muon neutrino Tau neutrino	Strange quark Muon	Charm quark Beauty quark Tau	Top quark Z boson W plus boson W minus boson Higgs boson

(a) (b)

Figure 2. (a) Particle model showing the anti-up quark; the indication of antimatter is given by the black star under the eye. (b) Particle models for the family of leptons.

Masses of fundamental particles differ vastly, with the 'lightest' being the photon with zero mass and the 'heaviest' being the top quark with its mass almost equivalent to that of a gold atom.

The mass differences described above makes it impossible to create a simple model where the relative masses of the particles are represented accurately. For this reason we decided to group the fundamental particles in four main categories: very light, light, heavy and very heavy (table 1). We also made a conscious decision to not worry about the terms 'heavy' and 'light' being linked to mass.

Once students completed the design of their particle, they were given a plastic coloured ball to make the particle model. Three different coloured sets were used, one for each of the families of quarks, leptons and bosons. Students were asked to fill in the plastic ball with a certain amount of plasticine so that it acquired mass. The rules we follow are: (i) for very light particles no plasticine is added in the ball, (ii) for light particles 5 g of plasticine are added, (iii) for heavy particles the ball is half-filled and (iv) for very heavy particles the ball is entirely filled with plasticine. Once the particles acquired mass the models were completed using coloured paper, googly eyes, feathers, pipe cleaners etc.

The imagination and creativity the students showed during the completion of particle models was impressive (figure 2). We fondly remember a little boy who stuck a lot of feathers on his gluon model and said to us 'I did this because gluons are sticky and this is why all the feathers are stuck!'

When evaluating the workshop students told us that this was the most enjoyable part of the day. They liked the freedom of choice they were given in making their particle model.

5. Evaluation

Although particle physics is not part of the primary school curriculum it offers knowledge of the current discoveries in physics and valuable skills in understanding how science works. We firmly believe that young children should not be kept away from challenging concepts because they have the ability to understand them as long as they can be related to their world.

During our workshops we evaluated the engaging strength of the activities, the enjoyment the students demonstrated and the short term learning of the students. Students were able to answer questions such as: ‘Where is CERN?’, ‘What does the LHC do?’, ‘How do scientists find out about the structure of small things such as atoms?’, ‘How many particle families do we have and what are their names?’, ‘How many quarks/leptons/bosons can you name?’, ‘Do you remember any special features of a particle?’. The short term learning was very high. A class of 30 students was able to answer all these questions easily.

In order to evaluate if students understood the idea that science is progressing and that what we know evolves with time we also asked the question: ‘Can you tell us something about how science works?’. The student comments included: ‘we might find in a few years that there are smaller particles inside quarks’ or ‘maybe there are more particles we have not discovered yet’ and finally, from a young girl who was adamant that anti-bosons exist, ‘I will become a particle physicist to find the anti-bosons!’. These comments made it clear that the workshop fulfilled its aims: to teach, to enthuse and to give a wider understanding of how science works.

Looking ahead, we plan to evaluate the long term learning of the students. Our next step is to offer training to school teachers, so that they can use this workshop in their classroom as and when they choose and therefore have the means to complete a long-term evaluation on the learning of the students. We hope that this workshop will provide inspiration for teachers and will be used as a cross-curricular project within schools.

The resources of this workshop, together with detailed teacher guidelines, can be downloaded for free from http://birmingham.ac.uk/schools/physics/outreach/MiniParticlePhysicsWorkshops.aspx. The authors are considering adapting the resources also for a young secondary school audience.

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Maria Pavlidou graduated in 1988 from the National and Kapodistrian University of Athens in Greece with a research in space physics. She did a PhD at Cardiff University on the acoustics of the classical guitar. She has been a secondary school teacher in Greece and in UK for 26 years. In 2013 she joined the University of Birmingham as a Teacher Fellow funded by The Ogden Trust focussing on outreach and public engagement. Since 2015 she is the School of Physics and Astronomy Liaison Officer.