

PAPER

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To cite this article: I Andrews and K Nikolopoulos 2018 *Phys. Educ.* **53** 054001

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# Introducing particle physics concepts through visual art

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## Abstract

The development of a workshop using the language, techniques, and processes of visual art to introduce particle physics concepts is described. Innovative delivery methods committed to the interaction and collaboration of different specialist areas are utilised, which—in curriculum terms—encourages connections to be made between separate subjects to the benefit of both. Beyond enhancing the understanding of the nature of the microcosm, this approach aims to stimulate a ‘creative curiosity’ about the world.

## 1. Introduction

The discovery of the electron by Thomson in 1897 [1] inaugurated an era of discoveries and ever deeper understanding of the inner workings of the microcosm. This culminated, 115 years later, in the Higgs boson discovery that completed the Standard Model of particle physics. Presently, as in the time of Thomson, there are several open questions that require an experimental breakthrough to be answered.

With this intellectually stimulating state of affairs the ability of visual arts to engage and express could ignite the curiosity of a younger audience in particle physics, independently of any studies they may pursue in the future. This was confirmed by the authors during an artistic collaboration culminating in the exhibition ‘The Sketchbook and the Collider’ [2], where it became apparent that despite obvious differences both specialisms are concerned with making the invisible, visible. Scientific developments have seen the ‘everyday’ dissolve into sub-atomic interactions only accessible by examining traces left in an enabling medium. A process mirrored by the artist expressing thoughts, emotions and insights through marks made and materials manipulated.

## 2. Workshop development

A main motivation for the workshop is to creatively embed scientific understanding, inspire interest in particle physics, and stimulate a ‘creative curiosity’ about the world. In parallel, it is important that the work produced and methods involved are artistically valid and that the workshops would prove beneficial for students studying art, providing potential coursework with only limited additions to the work produced during the day. Thus, connections between the separate subjects are encouraged and support is provided for innovative curriculum design, promoting inter-disciplinary collaborations. The experience comprises a range of methods and materials used in current fine art education at first-year degree level. The design was further informed by the creative pedagogical features [3] established within the CREATIONS project [4].

In terms of physics, the aspiration is for the students to understand basic concepts regarding research in particle physics and the structure of the microcosm. Specifically, that knowledge is acquired through experiments, where particles interact in the detector sensitive material and the information is used to construct images that are

interpreted as physics processes. For the structure of the microcosm, students explore the particle content of the Standard Model. They learn that matter particles make up the world around us, they are categorised as quarks and leptons, and are organised in to three families. The interactions are mediated via particles of different properties, e.g. the gluon, while the special role of the Higgs boson is also explained. Finally, students are introduced to the idea that our understanding is incomplete and ever evolving.

An initial range of drawing exercises, gradually developing from a traditional base to increasingly experimental, is followed by sculpture, photography and performance, as outlined in table 1. As the workshop unfolds, the placing of the outcomes onto a single A1-sized 'ideas' sheet leads the pupils to take greater ownership of the developing product, which is further enhanced by the annotation of the outcome with scientific explanations. Conveying concepts briefly in their own words offers another learning opportunity. The 'ideas' sheet then becomes the focus of a series of group critiques during the workshop.

In the following, the details of the workshop delivery are presented, also as a model for art and science teachers. The pilot implementation phase focused on students in Key Stage 4 (KS4), aged 14–16, in the British education system. Approximately 110 students, up to 16 per workshop, from schools in the West Midlands participated. Girls represented 60% of the participants.

### **3. Introducing particle physics concepts**

At the beginning of the workshop, the stage is set by introducing basic concepts of particle physics: the Standard Model particles and interactions. Following initial exercises, the students are exposed to major open questions, aiming to stimulate their imagination and underline science as an on-going effort beyond a textbook list of facts. During this discussion 'subatomic plushies' [5], a cloth model for each particle, are used to provide a visual anchor to the discussion.

#### *3.1. The Standard Model*

A video of an operating cloud chamber [6] with uranium mineral at its centre provides the opportunity to explain the basic operating principles of

the detector, along with some historic facts, and a connection to cloud formation in the atmosphere. The idea that we learn things about nature through experiments, and by 'visualising' the particles that are otherwise invisible, is introduced.

Subsequently, a model of the atom, consisting of 'subatomic plushies', is provided. Students at KS4 are familiar with the idea that matter consists of atoms, with a dense nucleus made of protons and neutrons, and electrons around them. It is found that very few students are aware of the term 'quark'. Students are invited to 'open' the proton and the neutron to find that they consist of up- and down-quarks, along with gluons keeping them together. The electromagnetic force and its carrier, the photon, are explained in terms of what keeps the electron orbiting around the nucleus. The weak interactions are introduced, by connecting to the video and discussing what leads to uranium decay. The opportunity is also taken to discuss neutrinos, which are intimately connected to the weak interaction.

Having introduced most of the first generation particles along with the force carriers, the discussion expands to the three generations of matter, essentially heavier replicas of the first generation. Students are confronted with the open questions: 'Why three generations? Are there more?'. Finally, the Higgs boson and its special role in the Standard Model is introduced.

#### *3.2. Beyond the standard model*

Following the drawing exercises, students are confronted with the idea that the Standard Model particles account for less than 5% of the matter-energy content of the universe. Some of the evidence for the existence of dark matter and dark energy are presented. It is pointed out that intensive current research attempts to answer these questions, and that younger people, like themselves, will contribute in the future. Usually, there are several questions during this part of the workshop. Often students find it fascinating and intriguing that one could know something exists despite not knowing much about its nature.

### **4. Drawing**

Following the introduction to the world of particle physics and armed with the imagery of cloud

and bubble chamber images, showing the trails of particles and the debris of particle interactions, students embark on visualisation drawing exercises. These have a traditional starting point, and gradually become experimental.

#### 4.1. Charcoal

A charcoal ground is laid across the surface of a sheet of paper, as shown in figure 1. Putty rubbers are then used to draw into the charcoal ground removing the charcoal and creating white marks on the dark paper surface. In this context it represents the particle interaction with the substance of the detector through which the particle traces become visible. The idea of using interaction to make visible the invisible is fundamental.

This is a traditional technique, encouraging consideration of the whole visual field when working on a composition. Students are encouraged to consider overlapping the trails to enhance the understanding that particles move and interact in all three spatial dimensions, while the obtained images show a two-dimensional projection of these events.

The laying down of the charcoal ground can also be used, depending on the scientific level of the students involved, as a reference to the Higgs field that is present everywhere in the universe, even in empty space: the zero of white paper replaced with a surface of grey charcoal.

This exercise is followed by a critique where students are encouraged to discuss the artistic choices made in relation to the scientific context. This is an opportunity to point out marks that may closely resemble specific events as if they were actual bubble or cloud chamber images [7]: (a) an incoming beam of particles; (b) ‘vees’ from the decay of a neutral massive particle; (c) ‘kinks’ when a charged particle decays; (d) electron-positron pair production from a high energy photon; (e) production of  $\delta$ -electrons, seen as trails perpendicular to a main track; (f) inferring the direction of particles from the changing radius of repeated circles, as the particle loses energy; and (g) ‘fiducial’ marks on the chamber walls, with accurately known positions, that are essential for event reconstruction. Depictions that would lead to violation of fundamental physics laws, e.g. conservation of the electric charge, are identified and discussed. This enhances the visual

**Table 1.** Physics and visual art workshop lesson plan.

| Activity    | Description                                      | Duration (min) |
|-------------|--|----------------|
| Discussion  | Standard Model particles and interactions        | 20             |
| Discussion  | Art-science collaborative examples               | 10             |
| Drawing     | Charcoal and putty rubber exercise               | 45             |
| Critique    | Reviewing the ‘ideas’ sheet                      | 15             |
| Drawing     | Pen and pencil exercise                          | 20             |
| Drawing     | Experimental mark making exercise                | 15             |
| Break       |  |                |
| Discussion  | Open questions: dark matter and dark energy      | 15             |
| Sculpture   | Materials manipulation and light-box experiments | 30             |
| Performance | Devise and film shadow screen performance        | 30             |
| Critique    | Reviewing the completed ‘ideas’ sheet and films  | 15             |

equivalence between the artistic outcome and particle physics experiment.

#### 4.2. Pen and pencil

The next set of exercises are more demanding artistically because they relinquish traditional skills, move towards abstract thinking, and require greater contextualisation.

The increase in attractive force between two quarks as they are separated is explored by drawing against the restrictive properties of an elastic band wound around the pencil and other hand. This exercise is expanded by students using different colours to further express the increase in attraction and the use of more than one pen gripped in the hand whilst drawing. Discussion takes place regarding ‘colour’ as the property, charge, that makes particles interact through the strong interaction. Pencils, coloured pencils, and felt tip pens are the most appropriate media in this case. Examples of the work produced are shown in figure 2.

A collaborative approach to drawing is employed in this next exercise, exploring the idea of particles interacting, decaying, and transforming. Students create a drawing in a short time, 30 s or less, and then pass it to a neighbour who must respond in an equally short time period. The stipulation is that each participant must begin their

drawing by working into the marks already on the page. The drawing is continuously passed around the group until all have added a transformative series of marks to the overall composition. Media used in experimentation so far have been pencils, coloured pencils, and felt tip pens as the speed of the exercise makes any messier materials counter-productive. The time period depends on the size of the group but the activity is designed to be fast to reinforce the idea of the short lifespan of some of the particles involved. This exercise is inspired from the 'exquisite corpse' collaborative drawings of the Surrealists.

The students can dislike the idea of another person intervening on their art work. In a scientific context this is used to explain that particle physicists work collaboratively, nowadays in very large teams from different countries, and that collaboration, and the ability to communicate and exchange ideas, is crucial for progress.

#### 4.3. Experimental mark making methods

Continuing into the workshop, the use of glue guns as a drawing tool takes the definition of drawing to an extreme that mirrors the experimental nature of much of current visual art practice. It also enables the creation of work on a range of surfaces which if transparent, like polythene or plastic sheet, can be placed upon a light-box and projected. The transformation of a small drawn starting point that becomes a large light piece, that can be further changed by distortions caused by the surface on which it is projected, as shown in figure 3, is used for the development of ideas regarding the transformation and interaction of particles.

### 5. Sculpture

In this section pupils explore the sculpture techniques with simple materials in three dimensions to re-emphasise some of the particle physics concepts introduced and potentially explore new ones. Materials have been restricted to various forms of wire, string, tape, cocktail sticks and air-drying clay.

The drawn starting points transform from two dimensions into three dimensions, with various forms of wire taking the place of drawn lines and air-drying clay enabling drawn shapes to be



**Figure 1.** Paper prepared with charcoal ground for first exercise with putty rubber.

translated into form. The transformation of particles is discussed and when the sculptural form is placed on the light-box and taken back into two dimensions via projected light and shadow, the nature of transformation and elements changing state can be introduced or reinforced. The making of sculptures from some of the earlier drawings re-iterated that particle traces are being created in a three-dimensional space. An example of a sculpture is shown in figure 4(a) and its projection in two dimensions in figure 4(b).

### 6. Shadow screen performance

Ideas that would be challenging to include in a drawing can be explored in a performance, by using the movement and interaction to express and discuss activity in the particle world. The students, divided in two smaller groups, devise, perform, and film a short performance piece using the movement and interaction of their own bodies. Following discussion, the students allocate



Figure 2. Examples of developing ideas sheet.

roles: direction, sound, performance, camera etc. To avoid self-consciousness the performance is behind a paper screen with an overhead projector casting their shadows onto the screen.

Students consider the different particle physics concepts to which they have been introduced. New concepts can be introduced at this point to particularly able groups or older participants. The concept is expressed through choreography with the students deciding on the props and sounds that would reinforce the content, and whether a background image can be produced, projected and moved on the overhead projector in addition to the movement of the participants themselves.

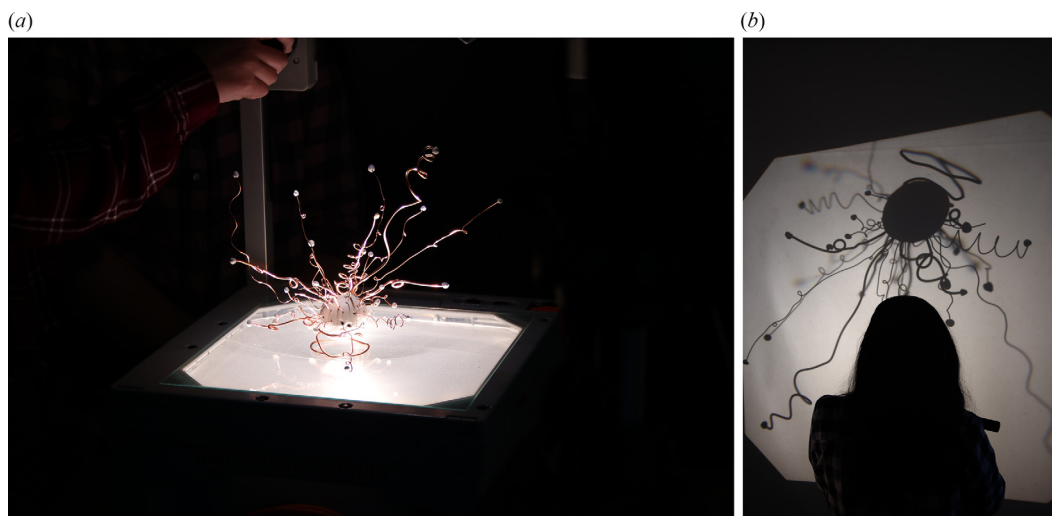
As an example, a performance designed to show the increasing attraction when quark pairs are separated, involved two students pulling on a binding wrapped around them in an increasingly agitated fashion as the distance between them grew. The concept was reinforced by the background image, produced during the glue gun experimentation, also moving in an increasingly agitated fashion out of sync with the movement of the performers. Combined with a soundtrack of rustling paper becoming increasingly loud and frantic. The combination produced a memorable



Figure 3. Example of experimental mark making on transparent surface and projection.

sequence that made an impression to the students involved.

Depending on the abilities of the group it is often possible to edit the footage produced to obtain a more resolved film. Examples of simple interventions that can be applied are: (a) reversing the tones, with light areas becoming dark and vice-versa, enabling the reinforcement of the idea of antimatter if relevant; (b) heightening the colour, making the footage very hot, can reinforce the idea of energy concentrating and dissipating; and (c) changing the colour entirely, reinforcing the idea of the transformation of particles. An example still image is shown in figure 5.



**Figure 4.** Example of (a) sculptural exercise and (b) resultant projection. Reproduced with permission from D Spathara.

## 7. Critique

The workshops conclude with a group critique of the ‘ideas’ sheet. An example of the drawing exercises, the photographic evidence of the light projections, the sculptures, and a viewing of the films produced, is presented in figure 6.

This final discussion session is used to further reinforce key concepts and to check for and dispel any misconceptions that may have developed. This activity is also linked to the scientific seminar and the idea that progress relies on scientists presenting their results, discussing them, and potentially changing or improving them following suggestions.

The full ‘art school’ experience using the range of activities enables cross connections to be made and scientific concepts to be reinforced from one activity to another. For example the attraction between quarks may be remembered by the use of the elastic band exercise but also as the subject of a shadow screen performance.

## 8. Evaluation and feedback

During the workshop learning was evaluated informally through one-to-one discussions. Students have shown growing understanding regarding detector operation, the families of particles, and the properties of the force carriers. They also discussed the concept that had the largest



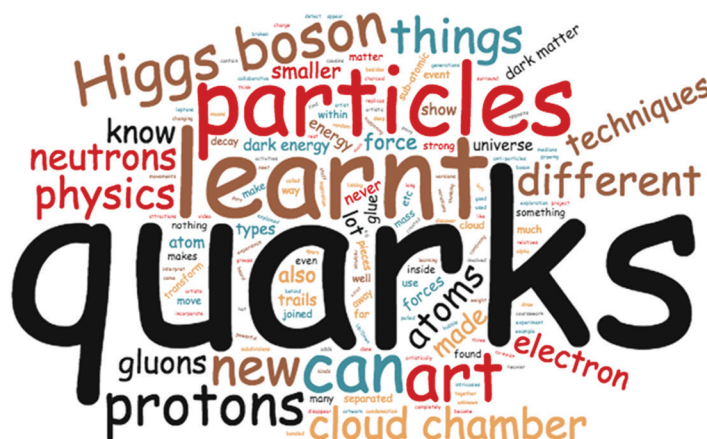
**Figure 5.** Example of a still image from performance, following preliminary editing with students.



**Figure 6.** The ‘ideas’ sheets, sculptures, and films exhibited for discussion at group critique. Reproduced with permission from D Spathara.

impact on them, as shown in figure 7, with the term quark appearing prominently.

At the end of each workshop students were invited to comment on areas of particular success and areas for improvement. At the same time



**Figure 7.** Word cloud of the students' response to the question: 'Describe one thing that you learnt today'.

feedback was requested from the teachers accompanying the students. Discussing physics through visual arts, led to an increased interest in physics for four out of five students. Approximately 35% of the students found it more likely to study physics at university after this event, while this fraction was 20% among students that were not originally inclined to study physics. Finally, after the workshop three quarters of the students considered physics to be a more accessible subject, including 65% of students that initially did not consider physics an accessible subject.

### 9. Discussion and future directions

The experience and feedback acquired during the pilot implementation phase is being reflected upon to improve the workshop and plan the roll-out of a streamlined version aiming to reach a larger audience. This could be achieved by implementation at schools through collaboration of science and art teachers, potentially through teacher training sessions.

The materials used are readily available, with the crucial point being the imagination with which the materials are used, while the use of more complex, expensive, and difficult to obtain materials is likely to reduce the effectiveness of the workshop, as the cost becomes a prohibiting factor. A possible exception is the film editing which was done by the artist, and in the future by the art teacher, involved, with the students advising on what filters and effects they think are most appropriate. All of these activities require the

participants to use the clues given by the exercise, e.g. the restrictive nature of the elastic band, and to make marks suggested by the forces involved.

The workshop includes several strands of visual arts to maximise the probability that each student will find inspiration. However, each of these activities, appropriately expanded, could form a separate workshop. This preserves the art school experience and has the added benefits of increasing the involvement of each student with a given art form, deploying more advanced techniques, maximising learning time, and allowing for the creation of more complete artworks. For example the sculpture activity could be expanded by introducing additional materials and using larger areas, while keeping some links to drawing through a preceding activity, as initial exploration and design thinking prior to making. The shadow screen performance activity could be extended by involving design drawing and storyboarding prior to the production of the performance itself. Provided sufficient resources are available, the editing could become a significant feature, done by the students themselves.

Although the workshop was initially focused on KS4 students, with minimal changes it can be addressed to older or younger students, and to larger class sizes without loss of its distinctive features. For younger participants, for example, developing the sculptural unpacking into a form of 'pass the parcel' could be used as an interactive, fun element whilst emphasising the unwrapping or splitting of the particles down to their elementary constituents. At the same time a

sitting configuration of participants, rather than the usual circular, could be established in advance representing a specific particle interaction, while, depending on age, Feynman diagrams could also provide teaching aids and introduce specific scientific visualisations.

## 10. Summary

An ‘art school in a day’ workshop has been developed and implemented, aspiring to introduce particle physics concepts to students through the use of visual art, while stimulating a ‘creative curiosity’ towards the world. The workshop consists of drawing, sculpture, and shadow screen performance. The students are introduced to particle physics concepts new to them, and the art outcomes are discussed both in relation to the scientific concepts and aesthetics. Building on the promising evaluation of the pilot phase, future steps involve focused implementation and expansion to different ages to allow for larger classrooms, and the training of science and art teachers so that they can deliver the workshop in their local schools.

## Acknowledgments

The authors would like to thank Sarah Fortes-Mayer, co-founder of In-Public, and Dr Paul Thompson for their participation in the implementation phase of the workshop. We thank Dr Maria Pavlidou for her support as the University of Birmingham School of Physics and Astronomy Liaison Officer and Dimitra Spathara for documenting photographically the workshops. Feedback and suggestions of Dr Maria Pavlidou and Dr Elizabeth Cunningham on the manuscript are gratefully acknowledged. This work has been supported by the European Commission as part of the ‘CREATIONS—Developing an engaging science classroom’ support and coordination action (CREATIONS-665917).

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Received 1 May 2018, in final form 6 June 2018

Accepted for publication 10 July 2018

<https://doi.org/10.1088/1361-6552/aad276>

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library of Birmingham in 2019.

**Ian Andrews** is artist in residence at the University of Birmingham exploring the connections between fine art and particle physics. The initial work entitled “The sketchbook and the Collider” was shown recently at the University’s Rotunda Gallery and new developments will be exhibited at the



**Kostas Nikolopoulos** is a particle physicist who was strongly involved in the Higgs boson discovery and now tries to complete our understanding of mass generation for matter. He is also interested in inspiring the new generations of scientists and citizens.