Scattering for STEM: Developing a Scattering Class with an Awareness of Barriers to Public Engagement

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Abstract.

Background: Public engagement (PE) is a long standing part of higher education, with a rapidly changing role. Increasingly, it is becoming integrated into the culture of research. Investigations of the barriers hindering this have identified key areas to be addressed. Communication of current research and the relationship between different research areas are key to policy in PE, to address the perception of areas such as nuclear physics, and improve PE impact. Purpose: To develop public engagement resources with consideration of these barriers, that enable integrated learning of both current research, curricula and science skills. Methods: The barriers identified are discussed in the context of how they have been targeted within UK nuclear PE. Kick-Start awards, providing dedicated time for PE for ECRs, were of significant support to this. A new class on the physics of scattering, has been developed. Scattering is relevant across not only nuclear physics but all STEM subjects and school curricula. Results: Clearly defining terminology, audience, the intended product of projects for PE and providing dedicated time through internships for early career researchers (ECRs) lowered the barriers into public engagement. The scattering class linked key STEM skills including abstract thinking and data analysis, suitable for a range of experience levels, to nuclear physics experiments. Conclusions: Recent PE within nuclear physics is developing methods to overcome barriers to PE, particularly for ECRs. A scattering class has been developed and distributed internationally, for exhibitions and school workshops.

1. Introduction

The concept of public engagement (PE) is one that is embedded in higher education (HE) institutions in the UK, present in the mission statements of an increasing number of institutions [1]. Engaging with the public has been identified as one of three core elements of national research strategy, influencing the development of UKRI. Ensuring an effective dialogue between the public, politicians and scientists has been highlighted as one of the key facets of the success of national research endeavours, therefore socio-economic and political changes must be reflected in the role PE plays within these institutions to ensure a credible dialogue is maintained [2].

A product of this funding has been the increased collaboration between UK nuclear groups, through enabling national training activities and funding for the development of classes and resource sharing. The creation of the Kick-Start scheme enabled the sharing of a graduate student between two or more nuclear physics research groups over a three month period. The methodology applied to PE and approach taken to overcoming identified barriers into PE in this period is discussed, alongside the product developed as part of the internship.
Scattering is a key process across STEM subjects, particularly in nuclear physics, where it led to the discovery of the nucleus by Rutherford in 1911 [3]. In modern day physics, Compton scattering is used to probe the internal structure of nucleons, which is one of the greatest outstanding problems in nuclear physics [4]. Recent advances in cancer treatment using proton beam therapy [5], and outside of physics using neutron scattering to provide information on the structure and dynamics of biological systems [6] are two of many current examples across STEM. Scattering is also the underlying process behind much of the energy and momentum transfer studied in schools. With such a strong relationship not only to nuclear physics but medicine and STEM subjects overall, a class has been developed to communicate the principles of scattering, ‘seeing’ the unseen and the scientific process. The key elements and equipment developed as part of this class are explained. The application of the class to schooling systems and communities, with an emphasis on accessibility is discussed.

2. UK Public Engagement of Science
The role of PE in STEM subjects has received significant support from research councils, with a major focus on investment, to create a culture of PE in research over the last decade [1]. However, it has been found that there has been a minimal increase in the levels of participation in PE from STEM researchers in that time. Reports from both the National Co-ordinating Centre for Public Engagement (NCCPE) and the Science and Technology Facilities Council (STFC), identified a set of key barriers and challenges to PE in HE. Across both reports, peer organisation and training, terminology, sustainability, time and feedback were broadly identified as the key areas needing development [7] [8].

3. Addressing the Barriers to Public Engagement in Higher Education
In response to the barriers defined in [7] and [8] the University of Glasgow’s Nuclear and Hadron physics group partnered with the Binding Blocks PE group at the University of York to work collaboratively. This involved the exchange of ideas, training, and resources with the goal of building a sustainable network of PE resources in nuclear physics. The Binding Blocks group have actively shared training and equipment resources with PE groups, however this further facilitated the hosting of equipment across the UK and aided the expansion and development of resources. Working collaboratively addressed many of the barriers to PE raised in [7], summarised here.

3.1. Kick-Start Awards
The key factor limiting researchers’ work in PE identified in [8] is time. Developing projects in public engagement and raising awareness of them requires regular development, review and use of these resources. A dedicated program for PhD students in nuclear physics has been developed to support research students with a passion for PE. Kick-Start awards fund a staff member within a research group to host a visiting student for three months to develop public engagement resources. The student should be based away from their home institution, working with at least one other research group during this time. Students accepted to this program will have a strong track record in PE and a key theme or idea they want to develop and build infrastructure for. During this time they will receive training and supervision surrounding the barriers to PE identified in [7], taking an active role in the development of these areas.

The first Kick-Start award centred around the collaboration of the University of Glasgow’s Nuclear and Hadron physics group with the Binding Blocks PE group at the University of York to develop and share a new PE class, alongside existing materials. The approach to overcoming barriers in PE was developed and shared between both institutions to facilitate their collaboration and implemented over a series of events during the internship. Finally, a new
PE class was developed as an ‘experiment in a box’ to be distributed across a variety of research institutions nationally.

3.2. Language and Definitions
Throughout both the PE delivered and the approach to internal engagement, language and definitions were identified as barriers to the dissemination of information [8]. This may be in the form of activities themselves, defining the role of researchers within PE or the advertisement of what PE the group provides. Defining what PE is was at the core of these issues [7].

Removing the emphasis on terminology to focus on who it is you want to engage with, why and your longer term goals of engagement was found to help clarify the roles required. When advertising PE opportunities to researchers across multiple institutions, working on multiple activities, advertising focussed on specific tasks to be completed. This was both to streamline development through the early identification of individual goals and to attract researchers who had not previously worked with PE. Equipment requiring development, workbooks needing review and the front-end demonstration were all advertised separately as individual projects to prevent presumptions about the role being made. Graphic design and digital development projects advertised across graduate and undergraduate students attracted people to working with PE for the first time.

3.3. Sustainability and Tracking Contributions
The high turnover of staff in HE limits the sustainability of PE where it is dependent on a subset of individuals. Resource sharing where a database of activities is maintained provides open access to these resources for all collaborators. This prevents documentation being lost and allows generations of documents to be stored as they are adapted so the evolution of the program can be followed. This also facilitates the tracking of contributions to the project across institutions. This helps ensure credit is given fairly, particularly to early career researchers (ECRs), while maintaining a contact list for project handover.

3.4. Training and Guidance
The Research Excellence Framework encourages researchers to submit impact case studies that feature PE, which has been emphasised by the Stern review, requesting ‘impacts on cultural life be specifically included’ [9].

Students working as part of a PE collaboration were sent to community and research groups, schools and labs across the UK to engage in learning. Understanding cultural impacts comes from understanding where research lies within these communities. Enabling ECRs to take their PE to a range of groups prepares them for the role the REF expects researchers to fulfil. This level of training develops a broader context for PE, as requested in [7].

Identifying the difference between quality and quantity was identified as an area needing work by [8]. Collecting large datasets of feedback from both those delivering and attending PE events identifies areas needing development. To ensure quality data is collected and General Data Protection Regulation (GDPR) rules are followed, expertise is required, found through collaboration. This is of particular importance for investigating long term impact where personal information may need to be recorded.

4. Scattering
The scattering class was the ongoing project brought into the first Kick-Start award. The purpose of the class is to teach participants about scattering, the scientific method and how we can ‘see’ the unseen.

The scattering class has several components and as such has elements that can be taught through developing in-class experiments using classroom equipment, working with a scattering
kit provided by a host institution for the class or ‘do it yourself’ guide to building the equipment used in the class. The scientific process is covered by each aspect of the class, challenging the participant to define the parameters of the experiments at each stage of the class by asking what question the experiment is answering, explaining their motivation, how they will make the measurements and what they expect to see, before analysing their data.

The concepts of scattering and the scientific method are combined with the theme of ‘seeing the unseen’. This is conceptually challenging and is helpful when teaching problem solving and logic skills. By the end of the class participants should be confident in understanding that through indirect methods (observing properties including the scattering pattern (angular distributions)), they can determine the characteristics of objects they cannot see. This can then be applied to other topics such as:

- The reflection of light from mirrors to identify the characteristics of plane shapes.
- Understanding the relationship between scattering and experiments performed by particle and nuclear physicists.
- How our understanding of fundamental particles has changed over the last 100 years.

The experiments within this class can be adapted to different ages and ability levels. Within the school system it can be used with key stage 1/First Level - A-levels/Advanced Highers. The class is intended to be ran primarily with pre-existing resources found within schools and households. Additional resources will be available to borrow (see section 4.1), however guides have been produced to facilitate the production on equipment in-house.

4.1. Scattering Experiment
The scattering experiment was initially developed as part of the University of Bonn physics show as a demonstration [10]. It has since been developed as a tabletop experiment to be used interactively as part of the scattering class, shown by Fig.1. Ball bearings are rolled down the ramp and scatter off the central target. Changing the target changes the distribution of ball bearings in the pockets. By hiding the target, the participant is challenged to determine which target matches which distribution, effectively ‘seeing’ the unseen. This is analogous to scattering experiments in nuclear physics, treating the ramp as the accelerator, the pockets as the probes/detectors and the central target as a nucleon.

The angle the projectile is deflected through, \( \theta \), can be calculated from the pocket the projectile scattered into, direction it travelled prior to scattering, and the target location. Following Eq.1, the incident angle, \( \alpha \) can be calculated.

\[
\theta = \pi - 2\alpha
\]

When using a circular target, an approximate cross section measurement can be made following Eq.2, where \( N_{\text{scattered}} \) = number of scattered ball bearings, \( N_{\text{total}} \) = total number of ball bearings, \( D_{\text{target}} \) = target diameter and \( w_{\text{ramp}} \) = ramp diameter.

\[
\frac{N_{\text{scattered}}}{N_{\text{total}}} = \frac{D_{\text{target}}}{w_{\text{ramp}}}
\]

The scatterer has been updated to allow additional measurements to be made. The angle of the ramp, distance along the ramp at which the ball bearings are released and release mechanism can all be changed as shown in Fig.2. This varies the energy of the ball bearings in two ways, providing two new variables. The effect of changing the energy with each variable can be investigated to demonstrate the dependence of the distribution on each respectively. The release mechanism allows the ball bearings to be released individually or simultaneously. When released simultaneously they interact and introduce noise to the distribution.

The number of pockets around the scattering disc is now variable. This is analogous to both the granularity of a detector and consequently the minimum increment of angular binning in...
histograms produced of the data. Plotting the counts in the pocket is equivalent to plotting the binned results where the angular coverage of the pocket is equal to the binning.

The target is still interchangeable, however there are a greater range of targets available. The shape can be changed to one with an undulating surface. Varying the range of the ramp used and energy of the ball bearings demonstrates the additional structure. Targets made from different materials can be used to demonstrate elastic and inelastic collisions. Finally, ‘3D’ targets can be used to show how resolvable features change with energy. A target comprising an outer ridge and an inner, larger, central ‘3D’ Gaussian will provide two different distributions dependant on whether the projectiles have enough energy to interact with both the primary, outer ridge and the inner peak. For higher energy projectiles an additional shape can be placed on the peak of the Gaussian. Different shapes being placed on this peak will produce different distributions for the highest energy projectiles that are able to interact with them.

Abstract thinking and the scientific method can be taught during the process of this experiment to predict how the distribution of projectiles will change with the target shape. Reinforcing and teaching scientific skills applies not only to this experiment but to problem solving overall. There is the potential for this to have a longer term impact on the participants due to the broad skill set discussed as part of the class, increasing science capital, which will be focussed on in future developments of the equipment and its use.

To ‘see’ the scattering ‘actively’ the ball bearings can be coated in paint and paper placed over the base of the scatterer to see how the scattering happened. This has also been used as an analogy for cloud chambers with advanced participants.

4.2. Simulations
An interactive simulation of the scatterer has been produced, using Blender [11]. Importing the files used to produce the scatterer described in section 4.1 from AutoCAD [12] into Blender, gravity, drag, mass and elasticity were modified to suit the environment and materials of the scattering class. The scattering simulation has the full functionality of the updated scatterer and as such can be used as visual support during exhibitions and workshops.

Having a simulation is beneficial for schools/community groups, where a scatterer has not yet
Figure 3. The simulated scatterer is shown in one of the optional simulated environments produced for its use. Its functionality is the same as the updated scatterer.

been procured, or where there is limited time, as the generation of results is faster. In addition, it can be used to discuss the limits of simulation when comparing simulated and experimental results.

4.3. Classroom Equipment for Scattering

Scattering, the scientific method and ‘seeing the unseen’ can be demonstrated using equipment found around schools and offices with little construction or cost. The initial concept of scattering can be introduced through the use of a football/basketball and a rugby ball, particularly with younger audiences. Asking the audience if they can predict where each ball will bounce and why introduces the concept of shape influencing scattering. This is a primer to introducing the scientific method asking the audience for predictions, reasoning and to explain the observed result.

Subsequent classroom experiments introduce the concept of resolution, scattering off an unknown target, and experimental design.

4.3.1. Muffin Tray Experiment

The muffin tray experiment demonstrated both scattering and resolution. Taking a muffin tray, position it in an open space such that the base of the tray faces the ceiling, and attach it to a weighted object such as a box file filled with paper. A football, tennis balls and a range of smaller rubber balls are required. Taking the football, the audience is challenged to consider what happens if it is thrown at the muffin tray and why. Repeat this with increasingly smaller balls to demonstrate the tray acting as a flat surface until a ball smaller than the spaces between the individual sections is used. To further challenge the students ask them how they would estimate the spacing between the muffin trays from considering the projectiles alone, connecting the scattering angle with projectile size.

4.3.2. Hidden Shapes

The scattering experiment can be demonstrated with a larger group using a weighted object that can be covered with a large piece of card. This can be, for example, a box or a bin. Sitting in a circle, participants take it in turns to roll balls at the shape. Each participant draws the surface they believe their projectile collided with- for example a curved or flat surface. The participants work together to decide what they believe the initial hidden shape was.

5. Implementing the Scattering Class

Each element of the class has elements that require different levels of expertise. A brief explanation of which concepts would be taught for different school systems at exhibitions where a range of expertise is encountered is given.
5.1. **Primary to High School**
While students are not taught the terms 'elastic' and 'inelastic' scattering until high school in the UK, they are key concepts in science and the students' introduction to scattering. Having an early understanding of these concepts, regardless of terminology, will lend a familiarity when being taught more challenging ideas later.

The scientific process can be taught at this stage for all the experiments. Understanding the logical process of what they are seeing is beneficial to their understanding of how we think about science and solve problems. This includes the concept of control variables.

5.2. **GCSE and National Qualifications**
Building on the previous work where necessary, data produced from the scatterer can now also be plotted as a histogram rather than observing where the projectiles land. The scatterer is used to describe Rutherford scattering and perform cross-section and deflection and incident angle calculations. The information the experiment tells us about the target is investigated (material type, shape, size etc.). Identifying the control variables and how to optimise their values is discussed, with how the experiment can be improved, adapted and extended.

The muffin tray experiment is used to describe resolution, which can also be demonstrated with the scatterer targets with varying surface shape.

5.3. **A-level and Highers**
Following on from the previously covered sections where applicable, the type of statistics the data follows is discussed. A python programming class has been implemented. Participants plot their data as histograms, considering the effect of binning. The data is fit to and the resulting chi-squared value calculated. Python programming is used because of its links to both data science and education. Any of the data analysis tasks involving varying the experimental conditions, identifying the experimental limits and comparing simulated and real data can be repeated here.

Participants relate how the scatterer and analysis works to a real experiment, describing the analogous components, limitations and results. This can be as part of a larger research project.

5.4. **Community Exhibitions**
At exhibitions and community events where a range of expertise is involved, each part of the class is set up with a demonstrator. Posters surround the set up describing key concepts, current (related) research and background (e.g. Rutherford scattering). The demonstrators are trained on each element of the class and give a general introduction to the topic, however the emphasis is placed on listening to the participant and finding out what they want to know as a form of community led engagement. Placing a rigid order on the demonstrations is avoided. Where there are a broad range of publics present, marketing the environment as being both demonstration and conversation improves the quality of the engagement by treating each member of the public as one of many 'publics' rather than part of one body [13].

5.5. **Accessibility**
The development of this class was driven by the intention of reaching a broad set of demographics/publics [13]. The only element requiring equipment found outside the home is the scatterer. A national lending scheme is being developed to allow schools and communities to borrow all the scattering resources from a local hub. This will be distributed as a 'class in a box'. For groups wishing to make their own scatterer the instructions, CAD files, material lists and costings will all be placed online for both the original and modified scatterers.
The remaining resources for the scattering class will be made openly available with the construction information for the scatterer. Where not everyone will have the resources to download large files, the option to be sent the resources using a memory stick will be given.

This supports both UK and Scottish parliament initiatives regarding computer skills support, combining critical thinking and STEM subjects and the interrelation of areas e.g. maths, computer science and physics [14] [15]. In the interests of financial support, all the booklets are designed to be clear when printed in greyscale.

6. Conclusions
In this proceeding, the key barriers to PE addressed while working collaboratively with HE groups was discussed and its future discussed. The main features of the scattering class developed while working collaboratively and during a Kick-Start award were presented. The scattering class has at the point of writing been presented at a range of events, including teacher training, school and community exhibitions in the USA, South Africa and the UK. The material required to run the scattering class will be documented on the Binding Blocks website [16].

The scattering class is still under development. Ideas for expansion include the calculation of energies and momenta of projectiles at different points in the scattering experiment, the class’ application to medical physics and the expansion of programming and data analysis tools for simulation.

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