Institution: University of York		
Unit of Assessment: 9 - Physics		
Title of case study: Binding Blocks: Inspiring young people through engagement with cutting-edge nuclear-physics research		
Period when the underpinning research was undertaken: 2013 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Christian Diget	Senior Lecturer	Jan 2008 – present
Alessandro Pastore	Lecturer	Sep 2015 – Present
Marina Petri	Senior Research Fellow	Mar 2016 – Present
Andrey Andreyev	Professor	Sep 2012 – Present
Alison Laird	Professor	Jan 2004 – Present
Kate Lancaster	Lecturer	Aug 2015 – Present
Period when the claimed impact occurred: September 2015 – September 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

York's cutting-edge research into nuclear physics has been translated into engaging learning activities, centred around interaction with an 8m-long nuclide chart constructed from LEGO®. Differentiated for age groups, the programme is designed to make concepts in nuclear physics accessible to diverse audiences and is delivered both face-to-face and, particularly post-Covid-19, online. CPD and training activities have also been developed to inspire teachers to teach physics in new ways and to educate a future generation of STEM practitioners. These activities collectively have engaged some 30,000 learners and teachers. Evaluation demonstrates participants are more likely to wish to study physics at university, with the effect on women and girls particularly strong. 100% of teachers stated that they felt better able to communicate physics concepts to their pupils. Participants in both curriculum-linked masterclasses and public exhibitions reported positive changes in their view of and attitudes towards nuclear physics.

2. Underpinning research (indicative maximum 500 words)

The York Nuclear Physics Group is firmly positioned as one of the leading nuclear physics groups worldwide, having recently expanded to a full complement of 14 academics with broad and interconnected research programmes encompassing hadron physics, nuclear structure, nuclear astrophysics, nuclear theory and applications-focussed nuclear technologies. Within the broader Department of Physics these research areas furthermore synergise with work from the York Plasma Institute, a leading group for research in nuclear fusion in the UK and worldwide. Through the construction of a nuclide chart using LEGO®, as well as through associated workshops and activities, the Binding Blocks programme engages participants with this body of research and demonstrates the interconnectedness of these different nuclear science research areas.

The project is led by Dr Christian Diget, researcher in nuclear astrophysics and nuclear technologies. His recent research on the impact of pre neutron-star merger systems on the Galactic Chemical Evolution [3.1] demonstrates that, prior to the neutron star merger, the binary stellar system may be a site for the production of rare isotopes, the so-called p-nuclei, the production of which is a hot topic in nuclear astrophysics. Secondly, Dr Diget has led technological advances in detector developments for nuclear astrophysics and beyond, including an advanced silicon detector array for nuclear reaction studies with radioactive ion beams (see [3.2] and citations thereof). A further 12 academics in the department have directly contributed to the underpinning body of research, five of whom are highlighted through the selected references below, with further contributions from early career researchers associated with their research programmes. Based around his personal research portfolio, Dr Diget has therefore drawn together a wider body of research which links the four areas of Fundamental Nuclear Science; Nuclear Astrophysics; Fusion Technologies; and Emerging Technologies for Nuclear Medicine. This body of research has served as the backbone of an extensive engagement programme: the Binding Blocks project.
The first focus area, on fundamental nuclear physics, is particularly underpinned by the work of

Dr M. Petri, whose studies of nuclear isotopes takes her to the most neutron-rich isotopes of these elements which can exist before neutrons start dripping off the nuclei spontaneously [3.3]. The research of Dr A. Pastore and Dr Diget [3.4] takes neutron-rich research from the so-called drip-line nuclei in Dr Petri's research way beyond the drip-line and right to the level of neutron stars in the nuclear astrophysics focus area, studying the properties of nuclear isotopes in the intense gravitational field of neutron stars; a prerequisite to a full understanding of the dynamics of neutron-star mergers. The research of Dr K. Lancaster takes the nuclear astrophysical reactions down to earth and considers the applications of such reactions—for example in nuclear energy research and the exploration of fusion technologies. Her own research in laser-induced fusion and the dynamics of extreme laser plasmas informs the Fusion Technologies focus area, as does the broader body of work carried out at the York Plasma Institute [3.5]. The nuclear technologies from the preceding sections are furthermore linked into their applications in nuclear medicine, such as for medical isotopes, both in terms of nuclear technologies, and in relation to specific nuclear isotope production. For example, building on and going beyond the exotic isotopes related to the research of Dr Petri, the research of Prof A. Andreyev [3.6] has measured the critical atomic binding energy of a novel medical isotope for cancer treatment, Astatine-211. This is an isotope for which the biochemical properties were previously unknown, but whose newfound properties are critical for the development of effective production processes for the medical isotope.

3. References to the research (indicative maximum of six references) (York research staff in bold, other York staff and students in italics)

3.1. Laird AM, Diget CA, *Keegans JD*. Nucleosynthetic Yields from Neutron Stars Accreting in Binary Common Envelopes. Monthly Notices of the Royal Astronomical Society. 2019 Feb 6;485(1):620-639. DOI: doi.org/10.1093/mnras/stz368.

3.2. Diget CA, Fox SP, **Fulton BR**, **Laird AM**, et al. SHARC: Silicon Highly-segmented Array for Reactions and Coulex used in conjunction with the TIGRESS gamma-ray spectrometer. Journal of Instrumentation. 2011 Feb;6(2). P02005. DOI: doi.org/10.1088/1748-0221/6/02/P02005.

3.3. Crawford, H. L., **Petri, M**, et al "First Spectroscopy of the Near Drip-line Nucleus Mg40." Physical Review Letters 122, no. 5 (2019): Physical Review Letters, 2019-02, Vol.122 (5) DOI: 10.1103/PhysRevLett.122.052501

3.4. Pastore A, **Diget CA**. A new statistical method for the structure of the inner crust of neutron stars. Journal of physics g-Nuclear and particle physics. 2017 Aug 11;44(9). 094003. DOI: doi.org/10.1088/1361-6471/aa8207.

3.5. Lancaster KL, Robinson APL, **Pasley J**, Hakel P, Ma T, Highbarger K et al. Observation of extremely strong shock waves in solids launched by petawatt laser heating. Physics of Plasmas. 2017 Aug 25;24(8). 083115. DOI: doi.org/10.1063/1.5000064.

3.6. Rothe S, **Andreyev A**, Antalic S, Borschevsky A, Capponi L, Cocolios TE et al. Measurement of the first ionization potential of astatine by laser ionization spectroscopy. Nature Communications. 2013;4:1-6. 1835. DOI: doi.org/10.1038/ncomms2819.

All of the above papers have been published in peer reviewed journals. [3.6] was submitted to REF 2014, and [3.3] is being submitted to REF 2021.

4. Details of the impact (indicative maximum 750 words)

In 2015, Dr Diget designed an innovative and engaging way of teaching school students concepts in nuclear physics through the use of LEGO® blocks to build a nuclide chart. The success of the Binding Blocks workshops led to a suite of exhibitions, learning materials, teacher CPD and masterclasses which to date (September 2020) have reached almost 30,000 participants across 78 events [5.1]. The events showcase elements of York nuclear physics research, which are translated into fun, interactive activities for all ages, accompanied by curriculum-linked materials for Key Stage 5.

"The Lego was memorable, but it was taking the time and figuring it out that made it stand out. As we didn't understand it, we had to really discuss it and think why we thought something was going on. Doing it physically helped it to stick. I remember it as the Lego day." (Undergraduate student who took part in a Binding Blocks event as an A Level student [5.2])

In June/July 2020, following the Covid-19 outbreak, Dr Diget and his team brought forward the development of a planned online nuclear masterclass, enabling young people to access a fully online, free of charge, four-week programme of research-led, curriculum-linked learning materials, with York physics staff giving talks on their research [5.3]. Evaluation responses indicated an outstanding experience and, of the 1144 people registered for the course, a total of 840 participants engaged with the materials and 34% completed the entire four-week programme and received a certificate [5.2]. This compares extremely favourably with average dropout rate of 96% for MOOCs [5.4].

In addition to internal evaluation throughout the duration of the project, an independent external evaluator reviewed the Binding Blocks programme (September 2015 - September 2020), drawing on over 800 feedback forms from exhibition attendees, masterclass participants (both face-to-face and online), and teachers, and conducting in-depth interviews with participants, staff and collaborators. The evaluator's findings [5.2] highlight three key impacts of the Binding Blocks programme:

- Inspiring young people, and particularly women and girls, to study physics at university
- Supporting the teaching of nuclear physics, particularly at Key Stage 5
- Changing attitudes and views of nuclear physics

Inspiring young people, and particularly women and girls, to study physics at university
"The inspiring course offering really made me re-evaluate my options to consider studying physics" (Online masterclass participant [5.2]).
Between 2017 – 2020, 14 Nuclear Masterclasses were held reaching 845 Key Stage 5 students. Independent analysis of feedback following the workshops evidences the impact on participants: 58% considered the event inspiring, with 35% stating they were more likely to study physics in the future as a result of the workshop. 28% of pupils stated they were more likely to go to university (66% of participants were already 'definitely' going to university).

For the online Nuclear Physics Masterclass, prior to the event 91% were intending to go to university. Afterwards, 43% nevertheless agreed that the online masterclass made them more likely go to university. Over two-thirds of all students (68%) considered that, as a result of the online masterclass, they were more likely to study physics in the future, with females more likely to report this. Women and girls identifying as black or minority ethnic were particularly influenced, with 81% stating that they were more likely to study physics in the future as a consequence of the online masterclass. This is particularly significant at a time when the UK faces a significant shortfall of STEM graduates, and physics in particular does not attract many women to study at A level and at university [5.5].

Women and girls were more likely to strongly agree that they were inspired by the online Nuclear Physics Masterclass (63%) compared to their male peers (45%). Women and girls were also more likely to say that, in the absence of this online masterclass, they were unlikely or very unlikely to have found out about nuclear physics by some other means (37% compared to 28% of males).
The real-world applications explored in the masterclasses, and particularly the applications in medicine, were new for many and appealed:

"*I've always thought physics to be very theoretical and not have the practical aspects that I'm interested in. However, through this course, I've learnt so many thought-provoking and interesting things that have made me love the idea of studying and experimenting within nuclear physics."* (Feedback, female A Level student [5.2]).

Exhibition attendees make up the bulk of the 30,000 individuals engaged by Binding Blocks, primarily comprising family groups. They were also inspired by the Binding Blocks programme: at dedicated Binding Blocks exhibitions focussing on nuclear physics research, 84% of surveyed attendees 'agreed' or 'strongly agreed' that the exhibition was interesting, 86% of participants 'agreed' or 'strongly agreed' that they learnt something new, and 71% of participants 'agreed' or 'strongly agreed' that they would be interested in learning more about physics [5.2].
"[I] gained more interest and wanting to do further research myself" (Exhibition attendee [5.7]).

Supporting the teaching of nuclear physics, particularly at Key Stage 5
Jointly with the National STEM Learning Centre, Binding Blocks has implemented nine teacher training courses with a total attendance of 305 teachers across both primary and secondary schools.

"Teachers reported that the Binding Blocks programme training increased their confidence about nuclear physics. The training equipped them with new approaches to enhance their pedagogy that were engaging and interesting for their students. Teachers valued being able to access a fully formed methodology that could be adapted to meet the age, group size and interests of students." (Independent Evaluation [5.2])

100% of teachers surveyed 'strongly agreed' that the workshops had changed their view on how they could communicate nuclear physics. Teacher feedback highlighted that the training was engaging (95% 'agreed' or 'strongly agreed') and informative (41% 'strongly agreed' their knowledge of nuclear physics had improved, 96% 'agreed' to at least some extent). 77% of teachers 'agreed' or 'strongly agreed' that the Binding Blocks programme approach is relevant to the curriculum they teach; 59% 'agreed' or 'strongly agreed' that the Binding Blocks programme would be effective in delivering the concepts of nuclear physics to their students; and, on average, 7 in 10 teachers would be interested in delivering future sessions based on the Binding Blocks programme approach.

In addition to bespoke teacher CPD courses, 88 teachers also registered to take part in the online Nuclear Physics Masterclass. The content was tailored to the Key Stage 5 curriculum covering all of the Department for Education required nuclear physics content for A level [5.6] - which makes up 60% of all exam board specifications - and also encompassing material specific to each exam board, including for optional modules such as Astrophysics and Medical Physics. This alignment with the curriculum was recognised by the teacher participants: 60% of those responding to the survey said the content supported the curriculum 'very well', with 40% stating it supported the curriculum 'a fair amount'. 67% of teacher participants reported that the online masterclass improved their confidence in teaching nuclear physics 'a lot', with the remaining 33% stating that it had improved their confidence 'a little' and the masterclass also informed the teacher's pedagogy – helping them to connect the curriculum to real life applications:
"I loved watching the presentations during the webinars and seeing how GCSE and A-level physics is applied in research and the wider world. The topics became very real and gave me a lot more to talk about when I teach it." (Online masterclass, teacher participant [5.2]).

Changing attitudes and views of nuclear physics
Nuclear Physics is often perceived by a non-specialist audience as only relating to nuclear power and nuclear weapons. The Binding Blocks programme highlights the many different faces of this diverse discipline and participants realise that nuclear physics is *"not just about bombs and radiation."* (online Nuclear Physics Masterclass participant [5.2]).
65% of those surveyed at an exhibition at the Institute of Physics (IoP) in 2020 agreed that it had changed their views about nuclear physics. All reasons stated were positive, with most comments around gaining greater knowledge (58% of comments) and finding it more interesting

or exciting (27% of comments) [5.7].
"I learned things about nuclear physics in a fun way which made nuclear physics more fun and interesting" (IoP exhibition attendee [5.7]).
While A-level students are already positively disposed towards physics, their opinions and views on nuclear physics are also being positively influenced by the Binding Blocks programme [5.2]. Over a third of masterclass participants (both face-to-face and online) stated that the Binding Blocks programme changed their views on nuclear physics either 'a lot' or 'a great deal', with a further 40% stating that their views had changed 'to some extent'. Where opinions and mindsets had changed, it was apparent that the breadth of the subject, the range of applications, and the opportunity to get into detail were important. The findings also show that students can gain benefits; either cognitive (knowledge), or affective (attitude shift) regardless of their views going into the event. [5.2]
"While I already loved physics, the course deepened my understanding of the field, giving me some of the tools needed to work with the kind of figures used. It was as though I had a 2D picture of nuclear physics, and the Nuclear Masterclass made it 3D." (Online masterclass participant [5.2]).

Summary
This wide-reaching project has demonstrated significant impact across a range of audiences. Funded by STFC because of the strong links with their nuclear physics research portfolio, the programme has been reviewed by experienced public engagement professionals who have directly observed the project. The STFC Public Engagement Manager and Particle and Nuclear Physics Outreach Officer states:
"The Binding Blocks project has reinvigorated public engagement (PE) in the UK nuclear physics community, providing a range of activities that different groups can easily utilise for their own PE programmes. The active participation of undergraduate and post-graduate students with the project and the training they receive gives them the skills they need to talk with confidence and clarity about their research to all audiences both public and scientific. During an event people are naturally drawn to the Binding Blocks activities and using Lego as a gateway the Binding Blocks team have developed an effective and unique way of engaging school students, teachers and the public with the wonders of nuclear physics." [5.8]

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1. University of York Department of Physics Data Table (September 2020)
5.2. Independent Evaluation report by Paul Rhodes Consulting (December 2020); this report drew on:
Evaluation feedback forms from a sample of 209 young people attending 5 masterclass events; 388 young people taking part in the 2020 online masterclass; 18 student volunteers, 22 teachers (from 19 schools) taking part in face to face masterclasses, and a further 16 providing feedback on the online masterclass; and 187 members of the public who attended exhibitions. In-depth interviews were conducted with: Binding Blocks staff (2), Collaborators (2), HEIs (12), Kick-Starter interns (2), Secondary School (1), the Science Technologies Facilities Council (STFC), and the Institute of Physics (IoP). The evaluator also carried out observation of live and asynchronous aspects of the online masterclass.
5.3. Copy of online Nuclear Physics Masterclass webpages
5.4. *Financial Times*, March 2019, *Moocs struggle to lift rock-bottom completion rates*
5.5. IoP Report, May 2018, *Why not physics? A snapshot of girls' uptake at A-level*
5.6. GCE AS and A level subject content
5.7. Review of IoP Exhibition, February 2020
5.8. Letters of support from the Science and Technology Facilities Council (STFC) Public Engagement team, January 2021