Institution: University of Central Lancashire

Unit of Assessment: 10 - Mathematical Sciences

Title of case study: ***Mathematics Engagement: Shapes, Space, and Superheroes***

Period when the underpinning research was undertaken: 2007-Present

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:
Sylvy Anscombe	Lecturer in Mathematics	2015-2020
Kevin Bowman	Senior Lecturer in Mathematics	1990- Present

Period when the claimed impact occurred: 2014-2020

Is this case study continued from a case study submitted in 2014? N

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

By employing relatable and familiar topics such as cartoon animation, space travel and superheroes, we have engaged, informed and inspired children and adults with mathematics. Since 2014, mathematics researchers have run interactive workshops and presented talks at the annual Lancashire Science Festival, which has had over 65,000 visitors to date and focuses on familes from disadvanged backgrounds. Over 1,000 people have attended maths-based public engagement lectures at LSF and beyond, presenting mathematical research in an accessible and entertaining manner. A transdisciplinary popular science book, *Unmasked: The Science of Superheroes*, has been authored, applying mathematical theories to the concepts of change of size, time travel and super speeds as seen in the exploits of cinematic block-busting superheroes. Through STFC funding and in collaboration with the Reading Agency, over 5200 copies of the book have been delivered to libraries in the UK to optimise access and to get children interested in STEM subjects through reading.

2. Underpinning research (indicative maximum 500 words)

The Jeremiah Horrocks Institute (JHI) at the University of Central Lancashire brings together researchers from across mathematics, physics and astronomy. Within the JHI the Mathematics Research Group's expertise lies principally in Model Theory, Algebra, Functional Analysis, and Acoustics. Here, the work of Anscombe and Bowman are highlighted.

Anscombe's research features a mix of number theory and logic, concerning fields, especially those of positive characteristic, valued fields, and various notions of dimension and measure that arise in the study of measurable and generalised measurable structures.

Fields are mathematical structures which include addition, subtraction, multiplication, and division, all obeying the usual laws of arithmetic. Fields of positive characteristic (akin to modular arithmetic) suffer from the unhelpful phenomenon of inseparability, which causes a breakdown in the Galois-theoretic link between field extensions and groups of symmetries. This, in turn, creates challenges in the study of the theories of such fields. Developing techniques to overcome these challenges is the focus of some of Anscombe's work, especially [1], [2], and [3], and it may loosely be described as the study of arithmetic.

Bowman's research focuses on Lie algebras, deepening the understanding and classification of finite Lie algebras over a field by analysing the nature of chains of subalgebras [4]. Lie algebras are mathematical structures developed to understand and classify Lie groups, which, in turn, describe symmetries of geometric objects. The subalgebras are subsets of an original algebra with the same structures and this activity is akin to understanding a whole mathematical object by repeatedly breaking it in to self-similar components and observing how the process unfolds.

Both Anscombe's and Bowman's research help us understand further mathematical structures from their behaviours and by classifying their properties. These lessons have been taken forward into breaking down often difficult to understand mathematical concepts into simpler, more recognisable applications for a lay audience.

The themes developed from her work on model theory, and its applications in number theory and algebra, have underpinned and inspired Anscombe's work on the book *Unmasked: The Science of Superheroes*. Likewise, Bowman's expertise as a science communicator has also enabled him to contribute extensively to engaging the public with the research of the Mathematics Research Group and wider STEM research from across the University.

3. References to the research (indicative maximum of six references)

*Indicates peer reviewed journal

[1] Anscombe, S. and Fehm, A. *The existential theory of equicharacteristic henselian valued fields*. Algebra & Number Theory, 10-3:665--683, 2016. DOI: 10.2140/ant.2016.10.665 *

[2] Anscombe, S., Dittmann, P. and Fehm, A. *Approximation theorems for spaces of localities*. Mathematische Zeitschrift, 2020. DOI: 10.1007/s00209-020-02516-6 *

[3] Anscombe, S., Dittmann, P. and Fehm, A. *A p-adic analogue of Siegel's theorem on sums of squares*. Mathematische Nachrichten, 2020. DOI: 10.1002/mana.201900173 *

[4] Bowman, K., Towers, D.A. and Varea, V.R., 2007. *On flags and maximal chains of lower modular subalgebras of Lie algebras*. J. Lie Theory, 17(3), pp.605-616.*

All underpinning research available on request

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

The Mathematics Research Group (MRG) primarily through Anscombe and Bowman have helped to inform a wide range of public engagement (PE) activities aimed at improving levels of awareness of, and engagement with, mathematics. These targeted activities were undertaken as part of wider multidisciplinary ventures across associated STEM (science, technology, engineering as well as mathematics) subjects, part of a strategic decision to work alongside university colleagues in the Jeremiah Horrocks Institute and beyond to maximise PE opportunities both regionally and nationally. The two main approaches are outlined below.

Inspiring young people from disadvantaged backgrounds

The Lancashire Science Festival (LSF) has been run by the University of Central Lancashire since 2011, and from 2014, MRG researchers have annually contributed to public lectures and interactive hands-on stalls. The festival is a free event and aims to make STEM and Higher Education more accessible to a variety of audiences, with particular focus on primary-age children and their families, often from disadvantaged backgrounds.

There are high levels of deprivation across Preston and the North West; according to the English Indices of Deprivation 2019, approximately 18% of the city's population live in the most deprived 10% of local authority areas in the country. Since 2014, 65,055 people have attended the Festival [A1], and an audience analysis conducted by the UK Science Festival Network in 2017 and 2018 showed that attendees with limited budgets or living in rented accommodation were overrepresented at the LSF when compared to national averages [D]. Low socioeconomic status, such as those seen in Preston and the surrounding region, has an established link with poor educational attainment. Research on the LSF found that 70% of parents attending the Festival reported a positive impact on their perception of STEM with this proportion increasing among parents from more deprived areas [B]. The MRG plays an important role in the festival offering and we would highlight the following two activities:

Experiment Packs

As part of the 2019 Festival activites, Anscombe contributed to an 'Experiment Pack' which was available for free to children from disadvantaged backgrounds who attended the festival with

their schools or their families. Informed by her research, Anscombe developed a series of engaging logic puzzles suitable for primary school children. In total, 755 packs were sent to nineteen schools in the surrounding region. Positive feedback from teachers noted that the packs would **"Allow the parents to see what they can do [to] support their child's learning"** and **"Inspire them and show them how accessible science is to do at home"** [E].

Rocket to the Moon

As part of a series of celebratory events centred around the 50th anniversary of the Moon landings, Bowman developed and delivered 'Rocket to the Moon', a PE cinematic experience which broke down the mathematical challenges faced and solved in the effort to land humans on the moon. The political, economic, ground breaking engineering and hitherto unexplored scientific challenges faced by the Apollo missions all involved the solving of related mathematical problems.

Presented at the Lancashire Science Festival as well as at the Harris Museum, Preston, and World Museum, Liverpool, the events were attended by over 500 members of the public, ranging from primary school children experiencing the story for the first time to adults reliving their memories of the momentous occasion [C1]. The event was praised for how it engaged members of the public with the mathematical science involved, with many commenting how inspiring and informative the talk was. One, initially reluctant, attendee commented **"I will confess that I was almost dragged there, like a reluctant teenager, with just the promise of lunch afterwards as a way to keep me looking forward. I have to say that within seconds you had me hooked. From the warm up screen presence of the TV and film related space characters to you finishing to both canned and in-house cheering I was intrigued and I learned so much."** Another attendee praised the use of mathematics to provide context: **"I liked the maths calculations to explain things more in context, even though I am not a Maths person."**[C2]

Engaging audiences with Mathematics through thrills, movies and superheroes

From the perspective of a lay audience, mathematics and other related science subjects are intimidating topics that are often difficult to grasp. However, placing them in the context of something more familiar and relatable can break down pre-conceived barriers and anxieties to learning, enhancing the appreciation of how vital yet enjoyable mathematics can be.

In this context, Bowman regularly delivers popular maths-focused talks at festivals and public venues designed to engage the younger audience members. His session 'Maths, Disney and Pixar' and subsequent sequels showed the audience how mathematics plays an integral role in the design and production of our most beloved animated characters. Other related sessions target how maths is employed in the construction of rollercoasters and in robotic design. Using these appealing themes, Bowman introduced attendees not just to the basic mathematics of gravity and speed but also those of shapes integral to the creation of thrill rides as well as use in animation techniques. Over 700 people attended the public talks in 2018 and 2019, with 90% of feedback respondents praising the presentations and its application of mathematics in an unusal yet accessible manner [A2]. The feedback for these events has highlighted the successes that have been achieved in engaging with audiences. One attendee commented on Twitter **"Dr. Kevin Bowman Maths, Disney and Pixar lecture -best I've ever seen."** [A3]

In a similar fashion, Anscombe was part of a transdisciplinary project that built on the surging popularity of the superhero genre. *Unmasked: The Science of Superheroes* is a popular science book (ISBN 978-1912979080) authored by seven UCLan researchers to explore the scientific realities behind famous comic book legends and blockbusting movie icons. Launched on World Book Day in February 2020, the book draws on Mathematics alongside Computing, Engineering, Physics, Biology and Psychology to examine how real-world research can be just as wondrous and intriguing as the explosive events presented on our cinema screens. As part of the project, each of the authors were spectacularly turned into superheroes themselves across the pages of the book, with each character reflecting different types of superpowers and their scientific basis. Anscombe played a central role in the project team including writing a book chapter on "Superhero Mathematics". As of end of 2020, 191 books had been sold online via the usual booksellers with a rating of 4.7/5 on Amazon [H1, H2].

During 2020, a series of schools outreach events was planned to coincide with the publication in addition to an extensive engagement programme at science, literary and comic festivals across the UK. This included author talks with demos, reading sessions, panel discussions and interactive stands; however, the COVID-19 pandemic halted all this activity. Instead the authors sought other possible avenues for engagement. In particular, the Science and Technology Facilities Council Public Engagement Team saw the opportunity for a unique approach to interdisciplinary outreach provided by the book and the UCLan team; so much so that STFC invested almost GBP23,000 in the printing of 12,000 copies to be used for their national activites.[G]

Unforunately once again, the rolling national lockdowns prevented any STFC school and science centre engagements from taking place. However, it was possible (i) to create an "Unmasked Science" website [H3] containing national curriculum lesson plans on elements from each book chapter as well as some online games ("Density Matters" and "Super Maths" respectively for mathematics); and (ii) in conjunction with the Reading Agency, distribute approximately 5,200 copies of the book to libraries right across the UK.

Debbie Hicks, Creative Director at The Reading Agency, commented, **"Research and experience show that children learn by incorporating reading into play. Developing science knowledge through superheroes is a brilliant way to get children interested and engaged in STEM subjects. We know children and families will love unmasking the astounding world of science and superheroes by borrowing the book from their local library."** [G] Similarly, Carol Stump, Chief Librarian at Kirklees Council and President of Libraries Connected, stated: "**The book will definitely engage children with STEM, using superheroes and the comic book legends to explore and understand science. A brilliant concept and way of getting children interested in STEM subjects through reading**!" [G]

The team also worked with the STFC on sending copies of the book to a number of targeted groups or organisations. In particular, Anscombe led on the engagement with STEAM Packs, a small local charity based in Kent. Knowing from their own experience that life in hospital can sometimes be "boring, painful and a little scary", STEAM Packs create and distribute educational science, technology, engineering, art and maths packs to chronically sick children in hospital. As well as planning the production of additional mathematical puzzle sheets for these packs, in late November 2020 over 600 books were sent to specialist play teams in Darent Valley Hospital, Kent and the Royal National Orthopaedic Hospital, Middlesex as well as three specialist children's cancer wards with support from the Chartwell Children's Cancer Trust (Croydon University Hospital; Kings College Hospital, London; Queen Elizabeth Hospital, Woolwich). The

books, which were given to both paediatric patients and their siblings, helped the children feel **"…valued and cared for"** and gave the staff **"…a positive boost"** [F].

Also in collaboration with the Public Engagement Team at the STFC Daresbury Laboratory in Warrington, 100 books were received by the specialist play team at Liverpool's Alder Hey Children's Hospital. Hayley Thomas, Head of Corporate Fundraising at Alder Hey Children's Charity, commented: "**Thank you for generously donating the Unmasked: The Science of Superheroes books for our patients. Our Play Team was delighted to receive them. New books are a great way to entertain patients during their hospital stay so your donation is really appreciated**."[I]

Follow-up contacts with all the aforementioned organisations will take place from early 2021 onwards.

Effect of COVID-19

Due to the COVID-19 restrictions a considerable number of impact activities have been adversely affected. The 2020 Lancashire Science Festival and a wide range of associated regional school engagement activities were cancelled; hence no PE maths lectures have taken place. In particular, the launch of the "*Unmasked: the Science of Superheroes"* book just four weeks before the first lockdown resulted in a loss of critical time and severely inhibited the plans for promotion of the book in schools. Major events where the book had been due to be promoted were cancelled including for example, the Northern Young Adult Literary Festival and the Blue Dot Festival, Manchester. Although in collaboration with STFC and the Reading Agency, copies of the book have reached the vast majority of libraries across the UK, all in-library activites (eg. author readings, science clubs) cannot be undertaken. Visits to support the STEM activity in children's wards was just not possible. Combined, this had a significant impact on the uptake and engagement possible for the use of the superhero book.

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

[A] Lancashire Science Festival
- [A1] Lancashire Science Festival Attendance
- [A2] Lancashire Science Festival Feedback
- [A3] Lancashire Science Festival Social Media

[B] Canovan, Cherry (2019) "Going to these events truly opens your eyes". Perceptions of science and science careers following a family visit to a science festival. Journal of Science Communication, 18 (02).

[C] Rocket to the Moon public engagement
- [C1] Rocket to the Moon Feedback data
- [C2] Rocket to the Moon emails

[D] UK Science Festival Network Audience Analysis

[E] Lancashire Science Festival Experiment Pack & schools feedback

[F] Testimonial from STEAM Packs

[G] Press release with Reading Agency URL: https://readingagency.org.uk/news/media/scientists-divulge-superhero-secrets-with-childrens-wards-and-libraries-this-christmas.html [Accessed 9 March 2021]

[H] Unmasked: the Science of Superheroes popular science book
- [H1] UCLan Publishing: online sales of "Unmasked: the Science of Superheroes"
- [H2] Amazon reviews of "Unmasked: the Science of Superheroes" URL: https://www.amazon.co.uk/Unmasked-Science-Superheroes-Robert-Walsh/product-reviews/191297908X/ref=cm_cr_othr_d_show_all_btm?ie=UTF8&reviewerType=all_reviews [Accessed 16 February 2021]
- [H3] Unmasked: the Science of Superheroes website – www.unmaskedscience.com [Accessed 16 February 2021]

[I] Letter from Head of Corporate Funding at Alder Hey Children's NHS Foundation Trust