Institution: University of Northumbria at Newcastle		
Unit of Assessment: 12 (Engineering)		
Title of case study: Utilising engineering research to transform STEM aspirations and education-engagement strategies in North East England and Nigeria		
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:**
Vincent Barrioz	Associate Professor	01/09/2015 – present
Neil Beattie	Professor	01/06/2009 – present
Carol Davenport	Associate Professor	30/06/2014 – present
Rodrigo Ledesma-Aguilar	Associate Professor	01/10/2013 – 27/07/2020
Glen McHale	Professor	01/02/2012 – 27/07/2020
Gary Wells	Associate Professor	15/07/2013 – 27/07/2020
Guillaume Zoppi	Professor	27/06/2005 – present
Period when the claimed impact occurred: September 2014-December 2020		
Is this case study continued from a case study submitted in 2014? No		

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

Northumbria University's researchers and pedagogic experts co-created inclusive, interactive, public engagement workshops that bring together children, teachers, and families to experience engineering research first-hand. Between 2014-2020, these interactive workshops were delivered to 94,821 children and 17,974 families, carers, and teachers in 34 primary schools from less-affluent areas in the North East of England. The researchers tracked the specific effect on a sample size of 372 students by comparing 2017 data with a 2015 baseline. Data show children became more willing to pursue engineering careers (increasing from 25.6% to 33.1%) with the biggest effect on young girls (70.6% expressed an aversion to engineering careers before the interventions, 47.1% afterwards). Northumbria's specific public engagement approach has been adopted by Gateshead and Derby Further Education Colleges to increase women's enrolment on their construction apprenticeship programmes (from 8% to 23%, and from 0% to 39%, respectively); by North Tyneside Combined Authority to develop their Adult Education initiatives; by Museums Northumberland to enhance their community education and STEM participation in schools; and has expanded to 50 schools in Nigeria to improve learning and participation in science subjects, especially for young girls.

2. Underpinning research (indicative maximum 500 words)

The North East of England has a significant engineering-skills challenge with poor progression into Science, Technology, Engineering, and Mathematics (STEM) careers. Children from primary schools in less-affluent areas and/or with protected characteristics are especially disadvantaged and see limited routes into STEM-based careers and little use in studying STEM subjects. To address this, Northumbria University's Smart Materials and Surfaces Laboratory (SMSL) and Renewable Energy Technology and Materials (RETM) research groups delivered interactive workshops providing hands-on experience of their engineering research to excite interest and raise awareness of STEM opportunities and careers. This was funded using two approaches:

- **Start-up funding:** In 2014, Northumbria Engineering staff led a successful GBP1,200,000 bid to the Higher Education Funding Council for England which led to the creation of NUSTEM (Northumbria University: STEM) – a team of specialist public engagement staff who work with North East primary schools and other external partners to deliver a public engagement programme to support children's progression into STEM careers.
- **Long-term sustainability:** to support NUSTEM long-term, SMSL and RETM used funding from their EPSRC grants by designing suitable public engagement resources into their Pathways to Impact sections (see successful grant details in Section 3).

Over the REF2021 period, NUSTEM acted as a vehicle to deliver engineering research to a wide audience through a sustained public engagement programme. Since the funding to support

NUSTEM came, in part, from EPSRC grants, the proviso was that the public engagement had to be based on the funded research and draw materially and distinctly upon it. Thus, outreach materials – for example workshop demonstrations in schools to expose children to visually exciting, hands-on experiences of engineering research – were created and underpinned by specific examples of key research outputs produced within the Unit, and from the body of research carried out within the Unit. Exemplars of this underpinning research are:

- **Liquid droplet manipulation:** McHale and Ledesma-Aguilar used electrical fields to control liquids that can be manipulated from a droplet to spread into shaped films, such as a ring or a star shape, and then be retracted smoothly back into a droplet [**R1**]. McHale and Wells used smart super-heating arrays that part vaporise the droplet so that it 'levitates' fractionally above the surface to enhance control of the droplet's movement [**R2**]. Wells and Ledesma-Aguilar used oil-impregnated surfaces to create an 'ultra-smooth layer' to allow evaporation to be controlled and performed predictably [**R3**].
- **Cost-effective novel materials:** Barrioz's, Beattie's and Zoppi's work on nanoparticle ink-based solar cells has led to the development of efficient, cost-effective flexible solar cells [**R4**]. Identifying and addressing environmental and sustainability issues, such as solar power and the use of materials to increase energy-efficiency, are topics which young people engage with and identify as significant and ethical challenges for their lifetimes.

Alongside development of the interactive activities, beginning in 2014, SMSL, RETM, and NUSTEM co-designed a unique public engagement approach: the engineering-based 'Theory of Change', which is designed to inspire children's engagement with STEM education and careers [**R5**]. The Theory of Change approach acknowledged and addressed the issue that children's confidence and interest in STEM is influenced by their experiences of STEM from an early age (primary education level) and the perspectives of people around them (teachers, parents). The public engagement programme was delivered in partnership with schools and parents to inspire children to see different possibilities in STEM and new potential in themselves [**R5**, **R6**]. The workshops revealed how exposing young people to the creativity, variety and application of engineering research expands their awareness of the opportunities available and the importance of delivering these interventions at a key age (primary-level) to maximise STEM aspirations [**R5**, **R6**]. The integration of disciplinary and pedagogic research led to the formal Theory of Change model, providing the theoretical underpinnings and context for the complex mix of interventions necessary to lead to a significant change in the number and diversity of those choosing STEM careers. The Theory of Change demonstrates the potential of making engineering accessible, interactive, and exciting to kindle and catalyse children's interest in STEM subjects and careers.

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

R1. Edwards, A.M.J., **Rodrigo Ledesma-Aguilar**, Newton, M.I., Brown, C.V., and **Glen McHale** (**2016**) 'Not spreading in reverse: The dewetting of a liquid film into a single drop' *Science Advances* **2**: e1600183 https://doi.org/10.1126/sciadv.1600183

R2. Dodd, L.E., Wood, D., Geraldi, N.R., **Gary Wells**, **Glen McHale**, et al. (**2016**) 'Low Friction Droplet Transportation on a Substrate with a Selective Leidenfrost Effect' *ACS Applied Materials & Interfaces* **8**(34**)**: 22658-22663 https://doi.org/10.1021/acsami.6b06738

R3. **Gary Wells**, Ruiz-Gutiérrez, É., Lirzin, Y.L., Nourry, A., Orme, B.V., Pradas, M., and **Rodrigo Ledesma-Aguilar** (**2018**) 'Snap evaporation of droplets on smooth topographies' *Nature Communications* **9**(1): 1-7 https://doi.org/10.1038/s41467-018-03840-6

R4. Xu, X., Qu, Y., **Vincent Barrioz**, **Guillaume Zoppi**, and **Neil Beattie** (**2018**) 'Reducing series resistance in $Cu_2ZnSn(S, Se)_4$ nanoparticle ink solar cells on flexible molybdenum foil substrates' *RSC Advances* **8**: 3470-3476 https://doi.org/10.1039/C7RA13336G

R5. **Carol Davenport**, Opeyemi, D, …, **Gary Wells**, and Woodward, J. (**2020**) 'A Theory of Change for improving children's perceptions, aspirations and uptake of STEM careers' *Research in Science Education* https://doi.org/10.1007/s11165-019-09909-6

R6. Emembolu, I.*, Padwick, A.*, Shimwell, J.*, Sanderson, J.*, **Carol Davenport**, and Strachan*, R. (**2020**) 'Using action research to design and evaluate sustained and inclusive engagement to improve children's knowledge and perception of STEM careers' *International Journal of Science Education* **42**(5): 764, https://doi.org/10.1080/09500693.2020.1729442

* Members of the NUSTEM project team
Relevant successful grants include: EP/K014803/1, EP/L026899/1, EP/N007921/1, EP/P005896/1, EP/P018998/1, EP/P024408/1, EP/P026613/1, EP/P019889/1, EP/S036857/1, EP/R036837/1, EP/N024389/1, EP/T005491/1, EP/R021503/1, EP/S023836/1

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

NUSTEM provided a vehicle to engage the public with Northumbria's engineering research. Hands on workshops underpinned by engineering research were created to inspire children's interest in STEM careers. The programme's success led to increased interest in STEM careers among primary school children, modified teacher training, and revised curriculum in schools attended by some of the least-affluent children in the UK. The Theory of Change approach was adopted by organisations from across North East England and primary schools in Nigeria as part of their efforts to enhance diversity in STEM education and inspire STEM-led economic development, underpinning improved learning and participation for enhanced social welfare.

4.1 Improved STEM learning and participation in primary school children from less-affluent areas in the North East of England

Between 2014 and 2020, interactive workshops used the Theory of Change model to showcase engineering research. They were delivered to 94,821 children in 34 partner primary schools from groups under-represented in STEM education and careers, such as girls and children from less-affluent areas in North East England (primary schools were recruited on the percentage of children that received free school meals; a widely used proxy for identifying schools in areas with low socioeconomic status). These workshops included participation from 17,947 families, carers, and teachers in the partner primary schools [**E1**, p4, p7]. Demonstration kits (developed from EPSRC-funded projects) for use with primary school children, delivered by engineering researchers and the NUSTEM team, were utilised to explain concepts such as smart materials, surfaces, shape memory materials, levitation, nanoparticle inks, and solar energy. Supplemented by university visits, work-experience week, and Scientist of the Week activities, NUSTEM research-led workshops broadened children's understanding of STEM careers.

The researchers tracked the specific effect on a sample size of 372 students by gathering baseline data in 2015 and, after benefiting from sustained engagement through 'Theory of Change' workshops, compared it to data in 2017. The data show that engineering careers had the largest increase in the response '*would like to do*' from **25.6% to 33.1%** in comparison with other STEM options such as 'astronaut' and 'games tester' [**E2**, p11]. Furthermore, examining preferences by gender revealed that boys' responses to '*would like to do'* engineering rose from 32.1% (in 2015) to 59.0% (in 2017), boys' responses to '*would NOT like to do*' engineering fell from 55.6% (in 2015) to 25.3% (in 2017) and the responses to '*Not sure*' were 12.3% (in 2015) and 15.7% (in 2017) [**E2**, p13]. For girls, the '*would like to do'* engineering response rose from 20.0% (in 2015) to 21.8% (in 2017). However, girls' responses to '*would NOT like to do*' engineering fell from **70.6% (in 2015) to 47.1% (in 2017)**, and responses to '*Not sure*' increased from 9.4% (in 2015) to 31.0% (2017). This demonstrated that the engineering workshops have a more pronounced effect on young girls and showed a clear shift away from closing off the option of an engineering career [**E2**, p13]. Indicative quotes from follow-up evaluations include Julia Bourne, STEM coordinator at New York Primary School (North Shields) who states: '*NUSTEM has helped us hugely in raising aspirations in science and STEM … Because of the effect of NUSTEM we are seeing more and more boys' and girls' aspirations heading towards STEM careers'* [**E1**, p18; **E3**].

4.2 Revised curriculum and teaching practice in primary schools in North East of England

The use of engineering research illustrated and enlivened the imaginations of children, enabling them to express and explore their interest in their own way [**E1**, p23]. Incorporating parents and

active collaboration in hands-on experiences with teachers fostered a supportive environment where children feel empowered to state and pursue interest in STEM subjects [**E1**, p17]. Building on this, schools have revised their curricula to adopt the Theory of Change approach of using '*family workshops*' and '*more practical teaching of science*' to stimulate and sustain interest in STEM subjects and careers [**E1**, p17-20]. The curriculum changes have been focused on linking STEM subjects to career opportunities through NUSTEM's Primary Careers Tool, an online STEM jobs database where jobs are linked to science subjects and designed to support primary school teachers to easily embed relevant careers as part of their regular classroom teaching [**E1**, p20]. Indicative quotes from follow-up evaluations explain that the '*tool gives me exactly what I need, in the most straightforward way possible. There are no distractions or extraneous information so I can use it routinely in my lessons*' and that the '*Primary Careers Tool has been instrumental in helping us to implement a careers drive through the curriculum*' [**E1**, p20-21].

The Ogden Trust, a charity promoting physics education to disadvantaged school children across England, adopted NUSTEM's Primary Careers Tool. In 2018 and 2019, 402 teachers from 296 schools across England received training from the Ogden Trust which includes use of the Primary Careers Tool. The Ogden Trust's National Teaching and Learning Lead confirms: '*The Primary Careers Tool is an excellent addition to the primary teacher training that we offer at the Ogden Trust… It's taken real expertise to develop a tool that allows large numbers of classroom teachers to broaden the careers language and ambition of their students*' [**E1**, p21].

4.3 Enhanced learning and participation for adult education and community engagement through regional organisations in the North East of England

NUSTEM was one of three finalists shortlisted for the 7th Airbus GEDC Diversity Award in 2020 [**E4**], and the Theory of Change and its approaches have been adopted by other organisations for STEM public engagement and enhancing regional social welfare. The BRIDGE (Building Routes Into Degrees with Greater Equality) project is a research collaboration between Northumbria, and Gateshead and Derby Colleges, to examine the lack of diversity in enrolment on construction degrees and careers. The BRIDGE project adapted the Theory of Change to create greater diversity in construction access programmes and careers. Gateshead College runs a successful apprenticeship programme where employer/educator partnerships give students a salary, a professional qualification, and a guaranteed job opportunity [**E5**, p9]. However, in 2016 **only 8%** of participants were women [**E5**, p52]. Through the NUSTEM workshop model to raise awareness with potential applicants at local schools, International Women's Day events, '*Construction Weeks'* offering interactive workshops for those aged 14-24, and pop-up community engagement events, this was **increased to 23%** in 2018 [**E5**, p18-21, p52]. This success encouraged NUSTEM to expand the project to Derby College, the 14th largest Further Education college in England (with 4500 aged 16-18, 10,000 adult students, and 2,000 apprentices) but in the 55th most-deprived local authority, with 32% of the student population living in deprived wards, and above average BAME student populations [**E5**, p10]. Derby College had **zero women** in construction apprenticeships in 2016, but, after the Theory of Change engagement model was applied with the same events and interactive workshops, the 2018 student cohort for construction apprenticeships **was 39% female** [**E5**, p43].

The engineering-based Theory of Change model has also been adopted by the North of Tyne Combined Authority's (NTCA) STEM and Digital Skills programme to address the STEM skills gap in adult populations [**E6**]. The NTCA covers Newcastle, Northumberland, and North Tyneside local authorities (approximately 880,000 population, home to over 23,000 businesses, and a local economy estimated at GBP17,000,000,000). The NTCA Strategy Manager explains: '*Theory of Change shaped the engagement practice of our outreach work'* and '*was also useful in shaping the commission for an external evaluation of the STEM and Digital Skills programme, thus shaping the means by which we measure success of this initiative… Northumbria University has enabled the combined authority to achieve a significant milestone'* [**E6**].

Broadening out into public education programmes, Museums Northumberland, an independent charity providing the museums service for four museums and two historical sites across Northumberland, have adopted the Theory of Change model in their education and teacher

support work. The CEO of Museums Northumberland confirms the use of '*engineering research conducted at Northumbria University to inspire interest ... [and] to demonstrate the exciting findings of their work in an inclusive and participatory way'* [**E7**]. The CEO also confirms that by '*using the NUSTEM Theory of Change model as an important element of the community value and public education case, Museums Northumberland won a GBP3,140,000 National Lottery Heritage Fund award to create the Union Chain Bridge STEM Learning Programme'* [**E7**]. This aspect of the Union Chain Bridge project has a focus *'to address the many issues currently facing STEM, such as the national skills crisis, and misleading media portrayals of STEM professionals, particularly with respect to female roles in careers*' [**E8**].

4.4 Expanding STEM learning and participation through educational opportunity in Nigeria

Engineering-based workshops and the Theory of Change approach to sustained engagement from teachers and parents have been delivered by Northumbria researchers and the NUSTEM team working directly with 50 schools in Ekiti State, Nigeria, to give hands-on experience of engineering research and STEM careers to these children [**E9**]. The Headteacher of Total Child School explains that '*Scientist of the week material helped me to show real people and introduce science skills*' to '*bring science concepts to life'* and *'has positively impacted on how pupils in my classrooms view science*' [**E10**]. Finally, the Headteacher of the Amazing Grace Schools Group explains '*Prior to our involvement with NUSTEM, the teaching materials our teachers used were often gender-biased, now teachers are more conscious of the type of materials and the importance of using role models in teaching science. This in turn has resulted in girls knowing that they can study science and that science is for them*' [**E11**].

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

Ref.	Source of corroboration	Link to claimed impact
E1	NUSTEM impact report	Evidence for work with children and interactions with key influencers
E2	Emombolu et al. (2020) see [**R6**]	Peer reviewed output corroborates impact of the NUSTEM project engaging primary school children between 2015 baseline and 2017
E3	Interview with Julia Bourne STEM coordinator at New York Primary School (North Shields, England)	Impact on children's awareness and engagement with STEM opportunities
E4	7th Airbus Global Engineering Deans Council Diversity Award finalist	NUSTEM was one of three finalists shortlisted for the 7th Airbus GEDC Diversity Award
E5	BRIDGE Project – Final Report	Impact on diversity of construction programmes and sector from the research approach and Theory of Change
E6	Testimonial - Maria Antonio, North of Tyne Combined Authority	Evidence of impact on adult education and engagement policy
E7	Testimonial - Rowan Brown, CEO of Museums Northumberland	Evidence of impact on public engagement policy
E8	Union Chain Bridge project website	Impact of Museum Northumberland Union Change project on children's engineering education and regional STEM skills
E9	Stemres website – NUSTEM partner organisation in Nigeria	Extent of work with primary schools in Nigeria
E10	Testimonial - Olu Olufunke, Headteacher of Total Child School	Evidence of change in teaching practice and awareness
E11	Testimonial - Afolalu Oluyemi, Headteacher of the Amazing Grace Schools Group (Ekiti State, Nigeria)	Evidence of challenging gender stereotypes in STEM education