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Synthetic Biology Research Centre Newsletter

University of Nottingham
Issue 5 – April 2017

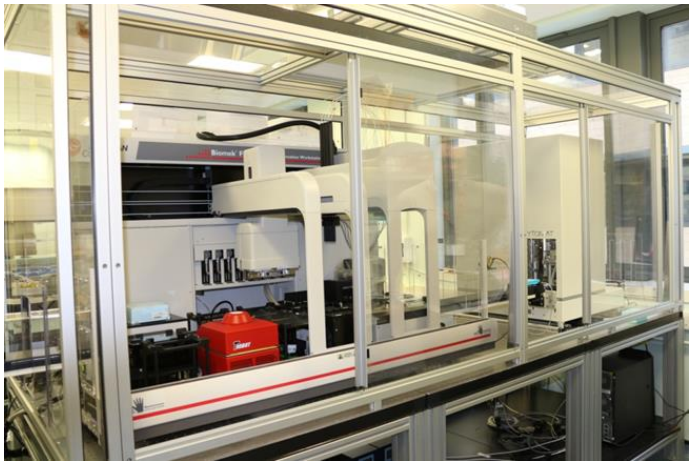
Robots in the Synthetic Biology Research Centre - Nottingham

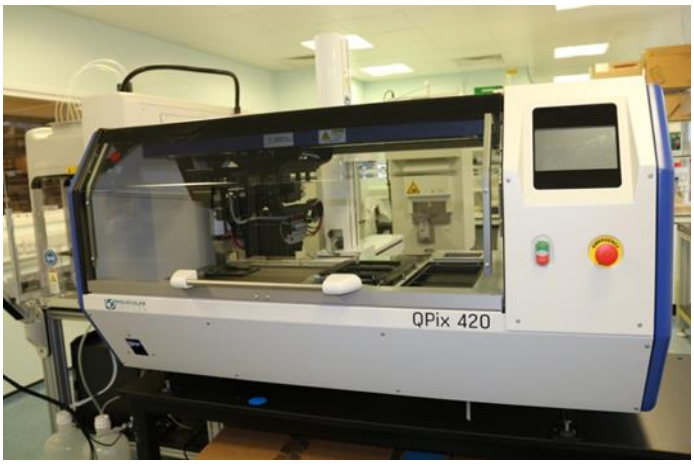
A state of the art robotics suite has been installed at the Synthetic Biology Research Centre (SBRC) Nottingham. The equipment, worth over £1.1m will enable world leading synthetic biology research. Scientists will use the robots to engineer large numbers of bacterial strains to turbo-charge their work towards creating chemicals for industry and transport fuels from waste materials. For example one of the foci of the SBRC is the creation of *Cupriavidus necator* strains capable of producing chemicals such as 3-Hydroxypropionic acid from waste single carbon gases, such as carbon monoxide and carbon dioxide. Furthermore the robots will be used to help advance our understanding of native bacterial CRISPR systems. This technology will play an important role in helping us modify pathways to improve the metabolic flux towards chemical products such as ethanol or 2,3 butanediol.

Thanks to its modular construction our robotics platform is also well suited to help each of our researchers at different stages of their work. For example, a researcher may need to test hundreds of primer pair combinations to select a desired PCR product; or they may need to screen hundreds of bacterial colonies in their search for a desired DNA fragment or gene with required properties. Currently these types of experiments can take weeks or even months to accomplish. Using the robotic platform these types of work will take less than a week. Additionally, thanks to built-in Data Acquisition, Reporting Tools and a barcoding system, the scientists can easily access and extract all the necessary information about protocols or samples at any future time point.

The robotic platforms enable automation of common pipelines in molecular biology including plasmid assembly, transformation of bacteria, colony picking and screening. The SBRC-Nottingham will work with other researchers in the University and the wider area in order to fully utilise the high-throughput capabilities of the equipment. The platforms contain liquid handling robots, thermocyclers, a colony picker and spreader, incubators, shakers and a plate reader, connected by a robotic arm.

Nigel Minton, Director of the SBRC-Nottingham said: '*This is a fantastic addition to our research capability. The robots will allow us to not only automate many routine procedures but carry out 100s of experiments in parallel –something we can't do currently. This will free up our specialist and highly-skilled research teams to focus on the more academically challenging aspects of their research and enhance our progress towards using bacteria to make chemicals and fuels for us sustainably'*.





Above – Automated shaker – incubator, plate hotel, plate reader and robotic arm.

Top left – Gene assembly, PCR, DNA size selection, cherry picking & quality control.

Top right and left – Colony picking, culture plating, sample collection, inoculation, & analyte purification.

More information is available from:

Professor Nigel Minton, Director BBSRC/EPSRC Synthetic Biology Research Centre, University of Nottingham nigel.minton@nottingham.ac.uk

The SBRC Nottingham is a BBSRC/EPSRC joint funded research centre led by Professor Nigel Minton and employs approximately 120 researchers including academics, research and technical staff and PhD students. The main location for the SBRC is the University's flagship CBS Building on the University Park campus, Nottingham. In the UK, six synthetic biology research centres have been funded by the government in Bristol, Cambridge/Norwich, Manchester, Edinburgh, Warwick and Nottingham. These centres are part of a £200m investment in Synthetic Biology by the UK government.

Beckman Coulter was selected as the supplier of the robotic platform after a competitive tender process. They are working closely with the SBRC during the installation of the equipment. Contact Magdalena Jonczyk (Magdalena.Jonczyk@Nottingham.ac.uk) for more information about the robots and to arrange a tour of the facility. Contact Alan Burbidge (Alan.Burbidge@Nottingham.ac.uk) for more information about the SBRC Nottingham.

Research news

Scientist calls for industrial scale-up of greenhouse gas-eating microbe technology in UK

A leading green energy scientist who uses bacteria to turn greenhouse gases into usable chemicals is calling for more investment from industry and government subsidies to scale-up this newest of technologies. Professor Nigel Minton from The University of Nottingham says there is significant potential for the industrial scaling up of the new process which uses 'gas-eating' bacteria to ferment polluting greenhouse gases from landfill and industry into useful products like biofuels and plastics.

A report, commissioned by Professor Minton's BBSRC-funded network of gas fermentation specialists C1net, says the UK should do more to increase the production of this new technology which could capture a large percentage of industrial waste gas from our factories and landfill.

As the burden on global oil and natural gas resources increases to meet demand for energy, plastics and medicines, the University's Synthetic Biology Research Centre has been engineering microorganisms to convert natural and waste gases into valuable chemical and fuel products. The technology has been rolled out in commercial-scale demonstration plants in China and the US and could make a contribution to reducing greenhouse gas emissions and dependency on fossil resources. However, there is currently little industrial development and use of the technology in the UK.

Professor Minton is calling for the biofuel subsidies currently given to biomass processors to be extended to the gas fermentation industry: "Gas fermentation can produce low carbon fuels from a range of waste feedstocks that do not pose the risk of increasing demand for land, like biomass production does. But the new technology is not competing on a level playing field. "Fuels produced from renewable feedstocks are eligible under the UK's Renewable Transport Fuel Obligation, but low carbon fuels produced from carbon-containing waste gases are currently not eligible to contribute towards the obligation, despite the greenhouse gas emissions reductions they can provide. This is proving a significant barrier to the commercial deployment of the gas fermentation processes. A broader and more encompassing framework is needed to increase the production of low carbon fuels in the UK. This could be achieved by focusing on the ultimate goal of lowering the greenhouse gas emissions of transport fuels, and supporting all low carbon fuels."

The BBSRC C1net report makes several recommendations to the government's Department for Business, Energy & Industrial Strategy and the industry sector:

- Long term policy support for all low carbon fuels and products either through incentivising their use or disincentivising the use of fossil resources. This may be achieved, in part, through amendment of the RTFO, to include low carbon fuels made from non-biological waste feedstocks. Incentivising the use of all low carbon fuels according to the degree to which they reduce carbon emissions would provide an outcome-oriented approach, ensuring technology and feedstock neutrality.
- A framework whereby the production of chemicals and materials are not at a disadvantage to fuels where they lead to similar benefits. In the near term, there could be a role for public procurement in stimulating the market for products with renewable content or recycled carbon content. In the longer term this may be achieved with an appropriately defined carbon tax.
- Policy support aimed at increasing the availability of sustainable biomass resources, and/or further supporting the use of waste resources.
- Improved access to capital for all low carbon technologies, for example through the use of loan guarantees, or by including the technology platform in the priorities of publically-backed lenders.

- Targeted R&I support addressing specific technology challenges and scale-up.

Developers of new processes, both in academia and industry, must credibly assess the economic viability of these processes, ensuring that they understand the conditions in which the processes will be commercially viable. They must also take a proactive approach in communicating the benefits of new products and processes.

The full C1Net report is available here.

Professor Nigel Minton discusses his research into bacterial gas fermentation, which looks to turn greenhouse gases into usable chemicals on BBC World Service radio 'Science in Action'. To hear SBRC Director and C1net lead Nigel Minton being interviewed by Roland Pease on C1Net gas fermentation work and the subsidies issue, please visit the following link

http://www.bbc.co.uk/programmes/p002vsnb

For details on joining C1net please contact: Jacque Minton, C1net Network Manager jacqueline.minton@nottingham.ac.uk

Recent Publications

1. Towards improved butanol production through targeted genetic modification of *Clostridium pasteurianum*

Katrin M. Schwarz[1], Alexander Grosse-Honebrink[1], Kamila Derecka, Carlo Rotta, Ying Zhang, Nigel P. Minton[a]

Article online at: http://dx.doi.org/10.1016/j.ymben.2017.01.009

2. Development of *Clostridium difficile* R20291ΔPaLoc model strains and *in vitro* methodologies reveals CdtR is required for the production of CDT to cytotoxic levels

Bilverstone, T.W., N.L. Kinsmore, N.P. Minton, and S.A. Kuehne

Anaerobe, 2017. 44: p. 51-54. DOI: http://dx.doi.org/10.1016/j.anaerobe.2017.01.009.

3. Microbial solvent formation revisited by comparative genome analysis

Poehlein A, Solano JD, Flitsch SK, Krabben P, Winzer K, Reid SJ, Jones DT, Green E, Minton NP, Daniel R, Dürre P.

Biotechnol Biofuels. 2017 Article online at: https://www.ncbi.nlm.nih.gov/pubmed/28286553

New to the Team

Loretta Waddon

"My name is Loretta Waddon and I am based in The Centre for Biomolecular Sciences. I have recently joined the Synthetic Biology Research Centre (SBRC) as PA to Prof Nigel Minton (Centre Director) and Dr Alan Burbidge (Centre Manager). I hold a Bachelor of Science in Information Technology and since joining the University in November 2004, I have worked in various PA roles for The School of Pharmacy."

Ruth Cornock

"I joined the School of Life Sciences/SBRC in November 2016 as a full time research technician working with Dr Ying Zhang and Prof Nigel Minton. Prior to this I had studied for an undergraduate degree and PhD in Nutrition at the School of Biosciences, graduating with my PhD in 2010. I then spent 5 years working in the School of Biosciences in a number of technical positions, specialising in molecular biology techniques, including qRT-PCR. In my spare time I like to binge watch box-sets, do cross-stitch, cook and go to live music gigs. I also like to get outdoors and love to take photos of wildlife. Working with Clostridia is completely new for me, but is presenting lots of good challenges for me to apply my existing knowledge to!"

David Tooth

"In my 'spare time' I'm a Bioanalyst with 30 years' experience in Biopharmaceutical and Academic environments, where I developed expertise in characterisation and quantitation of components in Proteomics and Metabolomics research, with particular interests in the application of mass-spectrometry. My other roles include being a father to 3 sons and a free-lance Trombone and Tuba player in most musical genres throughout the Midlands."

Professor Phillippe Soucaille

Professor Philippe Soucaille joined the SBRC through a 25% FTE permanent contract with the University of Nottingham. Philippe is spending week-long blocks of time in Nottingham to strengthen metabolic engineering capability within the SBRC. In addition, Philippe has been provided with two PhD studentships to help nurture the next generation of metabolic engineers.

Conferences and Workshops

CALENDAR of Key Synthetic Biology Activities and Events

4 – 6 April 2017
SynBioBeta
London
http://synbiobeta.com/conferences/synbiobeta-london-2017/

12 April 2017
Combined NIBB Industrial Biotechnology and Bioenergy Careers Fair, University of Sheffield
http://cbmnetnibb.group.shef.ac.uk/event/industria l-biotechnology-and-bioenergy-careers-fair/

22–23 May 2017
2nd International Advanced Biomanufacturing Conference.
Royal Albert Hotel, Sheffield
http://www.sheffieldbiomanufacturing.org/index.php/news-events/event/2nd-international-advanced-biomanufacturing-conference/

9-11 October 2017
The European Forum for Industrial Biotechnology and the Bioeconomy
The Square, Brussels
www.efibforum.com

5 – 7 November 2017
C1net Conference 3,
East Midlands Conference Centre, Nottingham
For information visit:
www.c1net.co.uk

Workshop in India

In January 2017 the SBRC led a workshop in India to explore possibilities for using waste biomass in the generation of sustainable fuels and chemicals. Ten UK researchers from four universities (Oxford Brookes University, University of Newcastle, University of Nottingham and University of Southampton) met with ten Indian academics from two leading universities (DBT-ICGEB and DBT-ICT) and representatives from three Indian IB companies to characterise the challenges of using India's waste biomass and to formulate proposals to start to derive value from the waste. Of the 550m tonnes of biomass generated each year in India, much can be used as feedstocks to generate new products. For example municipal solid waste through anaerobic digestion can generate biogas, lignocellulosic waste can be used in the production of second generation ethanol, as demonstrated by the operational pilot plant in Kashipur which is turning 10 tonnes ricestraw per day into ethanol at 80% theoretical yield. Other waste streams identified which cause environmental problems, as well as being inefficient use of carbon, include industrial and domestic waste water where the biological oxygen demand is high, waste from the paper and pulp industry and animal dung. All of these are sources of carbon which can be exploited through anaerobic digestion to generate methane (as a fuel source) and CO_2 for subsequent capture through anaerobic or aerobic fermentation into other fuels and commodity chemicals.

The workshop was a really useful opportunity to meet new potential collaborators, strengthen existing links, experience first-hand the advances being made in India towards sustainability and to start the process of putting together proposals to take steps, complementary to those already established, towards a more sustainable carbon economy.

C1net Workshop 3 on Metabolic Modelling, 23rd - 27th January, 2016 at St James' Hotel, Nottingham, UK

'Scientists from all over the world, from Denmark to New Zealand, met in Nottingham to gain insight in the building and use of structural metabolic models under the professional guidance of Prof. David Fell and Dr. Mark Poolman. The computational representation metabolic networks has been achieved through the program ScrumPy, a powerful tool in helping scientists represent and analyse complex metabolomes. With the aid of ScrumPy, scientists can import enzymatic databases of any organism and subsequently simulate changing growth conditions, gene knock-outs and projected yields of academically and industrially relevant metabolites. The course was set up to teach the participants the basics of the programming language Python, which is essential to manipulate data within ScrumPy. Interspersed by interesting talks on the mathematical background of network analysis, biotechnological applications of network analysis, flux balance analysis and how genome-scale models are built, we worked through practicals, which were designed to teach us not only how individual problems can be solved through Scrumpy, but also to show what the program is capable of.

'Many of the participants are not likely to be using ScrumPy in their research projects, but they might have to communicate efficiently with the bioinformaticians who do. The communication between the dry and the wet sides of the lab is greatly facilitated by workshops such as these. The workshop gave me not only insight in how structural models are made, it also gave me the ability to ask the right questions and gave me an idea of what I can expect our in-house bioinformatics experts to help me with and what I can't. For example, I learned that I can anticipate very interesting findings towards interesting knock-out candidates in my system, but I can't expect kinetic enzymatic data to be taken into consideration in a mere structural model, which was one of the things I was previously unaware of.

The workshop concluded with three field reports on successful examples of how ScrumPy was used and a stimulating QA session. I am looking forward to attend further meetings!'

Christian Gude – SBRC PhD Student

Visitors to the SBRC

Hiram Isaí Mendoza

Hiram is a PhD student in Biotechnology with a focus on biofuels at the Universidad Autónoma de Nuevo León (UANL), México. In his spare time he likes to practice crossfit, to taste different types of food and to meet new friends. He will spend six months at the SBRC working on CRISPR-Cas technology to edit bacterial genomes under the supervision of Dr Angel Pech and Professor Nigel Minton.

Magda Patricia Vargas

Project in the SBRC: Enhancing succinate production in "*Geobacillus thermoglucosidasius* facilitated by a pyrE mutant" under the supervision of Dr. Rosa Solis and Professor Nigel Minton.

"*The work that I will be doing in the SBRC means a lot to me personally and professionally. Fortunately, in my country we have the opportunity to go to other places like this to train in areas related to our postgraduate studies in addition to our project, to complement our training as scientists. It is challenging because the project work here is different from what I was doing in Mexico and is outside the comfort zone but is where the most amazing things happen*."

Meet our iGEM Team

The International Genetically Engineered Machine (iGEM) Foundation is an independent, non-profit organization dedicated to education and competition, the advancement of synthetic biology, and the development of an open community and collaboration.

The University of Nottingham has recently recruited a multi – disciplinary student iGEM team headed by SBRC director Prof Nigel Minton. The team members are being advised by PhD students from the SBRC and are currently undergoing training sessions on various aspects of the competition, while thinking about their final research project. As well as undertaking the research itself during the summer months, the team will also be required to carry out a number of outreach activities and create an iGEM WIKI page. In November the team will attend the iGEM "Giant Jamboree" in Boston, USA, where they will deliver a presentation on their research project.

Watch this space for further developments!

iGEM Team 2017

Student Team Members:

Edwin Jake Yeboah

"I'm Edwin but my friends call me Jake and I study Biotechnology. I play guitar and bass, I've played rugby for 4 years and I like to stay active. I find viruses, bacteria, and the immune system very interesting and I am also interested in computer modelling and coding. What interests me about iGEM is the freedom and independence we get as students to work on a project that we picked ourselves. Also, BioBricks are something that I have not had that opportunity to use before and I'm very excited to use them in our product of choice."

Eleanor Boardman

"I am studying for an MSci in Biochemistry and Genetics and I hope to go on to complete a PhD in microbial genetics as I am fascinated by genetic regulation, both as found in nature and how we can harness these systems in synthetic biology. During a BBSRC funded placement at the Synthetic Biology Research Centre, Nottingham I worked on the use of CRISPR Cas9 to increase biofuel production in an industrially relevant Clostridium. I am looking forward to meeting like-minded people from a range of settings, collaborating and sharing ideas during iGEM".

Georgette Sebastiao

"My name is Georgette Sebastiao, I am from Angola and I am currently in my second year of a 5-year chemical engineering course. I see iGEM as a fantastic opportunity to acquire hands-on experience and have a taste at what engineering is all about, that is, applying general and engineering-specific knowledge and concepts into solving real life and real people's problems. The competition will also provide insight into the world of synthetic biology, which I find to be of great interest".

Matthew French

Hi, my name's Matt and I'm a 3rd year Biotechnology student. I'm part of some sport societies on University Park and Sutton Bonington and play when I can. I applied to iGEM because I'm very interested in synthetic biology and, since I'm attempting to pursue a career in it, it's a great opportunity to gain some experience in the lab and work in a multidisciplinary team.

Natalia Kotynska

I am a third year Biotechnology student. My research interests include microbial biotechnology and genetics, in particular various applications of microorganisms to obtain valuable products, and how synthetic biology can be used to engineer organisms, which could be used as novel cell factories. I enjoy the most the practical aspects of my studies. Participation in iGEM competition allows students to have a real impact on the science and society. I believe that medical and environmental aspects of iGEM are especially important to modern society".

Vikram Chhapwale

Hello! My name is Vikramaditya Chhapwale, Vik for short. I like computers, programming (really anything tech related) and spending too much time watching Netflix. I am currently studying Computer Science and am a First Year Student. I am interested in iGEM because I am interested in the field of genetics, especially in its applications regarding the development for synthetic lifeforms, which is what I'd like to go into after university".

Christopher Graham

"My name is Christopher Graham and I study Biochemistry and Genetics. Although not taught in my degree, I am highly proficient in bioinformatics and Molecular Dynamics simulations of proteins. I have great experience in bacterial culture and membrane protein purification. The majority of my work so far has been focused on the BAM complex of gram negative bacteria and I am rather obsessed with it. I am interested in iGEM for the potential to produce new products through genetic manipulation, to learn new techniques in my own area, to meet some people interested in the same field as I am and to learn more about synthetic biology methods."

Thomas Parke

A 3rd year Law student, 'I am greatly interested in synthetic biology and its potential for expanding the chemical diversity of current antibiotics to address the antibiotic crisis we are facing. Synthetic biology and its potential use in prevent the development of cancer and diseases. Its use in the development of biofuels and renewable chemicals'.

Responsible Research & Innovation

Lego Serious Play® Workshops on Risk in Synthetic Biology

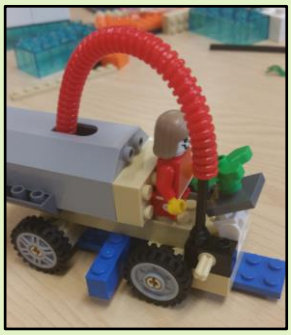
Carmen McLeod, Brigitte Nerlich and Louise Dynes organised a series of workshops in October 2016, on the topic of 'exploring risk in synthetic biology'. A mix of academic staff, postdocs, PhD students, and technical staff contributed to discussions. The workshops were based around Lego Serious Play® (LSP) and led by Dr Stevienna de Saille, a trained LSP facilitator.

LSP was originally developed as a methodology for corporate strategising workshops in which a certified facilitator uses a specialised sets of bricks to guide participants through a step-by-step process of building a metaphoric model through which a story can be told as part of producing group knowledge. The central idea is that using both hands to make something physical in response to a question stimulates a deeper level of creative thinking, while storytelling through the model creates active rather than passive engagement with hard-to-articulate values and beliefs. We were interested in using LSP as a novel and quite experimental workshop tool for creating a collective learning experience for members of the SBRC to explore what risk means for them in their current work.

Lego is a pervasive metaphor in synthetic biology where 'biobricks' suggests segments of DNA which can be snapped together in infinite combinations. Many might be aware that the prize for the iGEM contest is shaped like a giant Lego brick. In our LSP workshops, participants used *literal* Lego bricks to construct models and *metaphors* of risk and responsibility associated with doing work relating to synthetic biology research. Our results show that participants used Lego to visualise and verbalise a variety of representations about science, risk, risk mitigation and responsibility. Some examples were concrete and well-known to bench workers, and some were more hidden and abstract related to institutions, incentives and power. Overall, our analysis demonstrated that the LSP format gave scientists the opportunity to 'play out' sometimes surprising visions of risks and responsibilities through constructing verbal and visual metaphors. These constructions went beyond what scientists would normally talk about in traditional interviews or focus groups and provided novel insights into the reality of their working lives. The results of the workshops are being written up in a paper for a high impact journal, and a special issue of *Life Sciences, Society & Policy*.

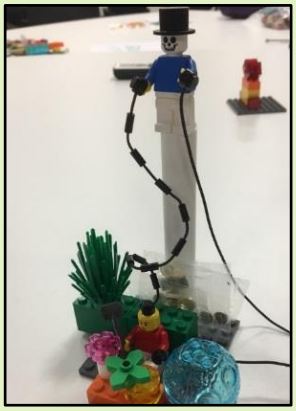
Here is a small sample of some of the constructions made in the workshops:

1. A model demonstrating some of the literal risks to researchers of working with combustible materials. The scientist is represented with a skull face because of potential risk of being killed in a fire or explosion.



2. A model depicting a researcher's concern that their work with bacteria might result in the introduction of harmful mutations to the environment or people. The figure on the right represents the scientist at their bench, and on the left there is a figure with no legs.

3. A model showing the risk of economic interests (represented by the figure in the black hat) controlling the work of the scientist who has different motivations for working in synthetic biology.



Outreach Activities

LEGO Microbiology at FIRST® LEGO® League

On Friday 6th January, members of the SBRC helped out at the FIRST® LEGO® League outreach event which took place here at the University of Nottingham.

FIRST® LEGO® League (FLL®) is a global science and technology competition with over 250,000 young people aged from 9 to 18 taking part each year. This is a global science and technology challenge for teams of students, to encourage an interest in real world issues and develop key skills that are crucial for their future careers. The students work together to explore a given topic and to design, build and program an autonomous LEGO robot to solve a series of missions.

Schools from around the East Midlands attended the event and as well as designing and building their project, there was an exhibition area for pupils to have a go at some table top outreach activities.

The SBRC hosted some LEGO related activities including; building a bacterium from LEGO for the younger pupils and the older pupils had a go at designing plasmids using LEGO.

Louise Dynes, SBRC Outreach Officer who organised the SBRC stand said '*LEGO is a great way of teaching microbiology to pupils, particularly building plasmids! I would like to thank everyone who helped out and made this day a success!*'

'Bacteria is Curious'

Engaging Nottingham primary school children with microbiology through dance

We have recently been working on a project with ignite! a not-for-Profit Company based in Nottingham that develops creative approaches to the teaching and learning of science and Dance Equation in order to bring microbiology to life through dance.

Our project was designed to target primary school children within a 'harder to reach' community that faces social and economic disadvantage and where parental engagement in science is typically low. As a result we worked with Henry Whipple Primary School in Nottingham which is located in Bestwood.

A class of Year 5s worked with Louise Dynes (Outreach Officer) from the Synthetic Biology Research Centre supported by three scientists, and Rebecca Hart from Dance Equation. The sessions with the school took place over a couple of months culminating in a performance which was shared with parents and members of the local community at the school on 9th

February 2017 as part of Nottingham Festival of Science and Curiosity. The project had a 'pupil led' emphasis which helped to encourage a sense of ownership amongst the pupils and in turn increased engagement levels – for example the pupils designed their own title for the project 'Bacteria is Curious'. The pupils also had a sense that this activity was different to learning in the classroom as they were in the hall (often in PE Kit) being active and learning through movement. The project began with an introductory session by the scientists before Christmas followed by weekly sessions in the New Year.

Each session began with a 'circle time' activity involving Dave the Phage (a microbe mascot) which was a fun, accessible activity which enabled all pupils to get involved - pupils throw Dave the Phage and then the recipient picks a question out of a bag which aids reflection on the learning from the previous session. The focus was initially on learning about bacteria through a range of physical games. They explored *Escherichia coli* and how they spin using flagella by spinning in a clockwise motion, they swarmed as group to learn about *Pseudomonas* and they represented *Salmonella* through the use of pili to attach themselves by twitching. The group also explored antibiotics and antibiotic resistance, and undertook an activity which involved moving like different bacteria and demonstrating whether they were susceptible by stopping to lie down on the floor or resistant by dancing."

The pupils developed an awareness through a session with the scientists that there are good and bad bacteria, and specifically looked at example such as *Lactobacillus*, *Bifidobacterium* and *Clostridium autoethanogenum*. They carried out a glitter gel experiment which demonstrated that bacteria live everywhere and can spread easily, followed by a movement activity which demonstrated how the spread of bacteria is reduced through hand-washing. The pupils also undertook a swabbing experiment across different areas of the school. Their samples were taken back to the lab to be tested so that results of the tests would be available to discuss at the next session and to see if the pupils' predictions were right.

The project was a very successful collaboration between science and arts-based partners which enabled pupils to explore microbiology creatively and to help build an awareness amongst both children and families that science is relevant and accessible.

Through a questionnaire at the end of the project we asked the children: 'Do you think the project has helped you to enjoy science more?' and the response was 100% 'Yes'.

The final film of our project can be viewed at - https://vimeo.com/205359171.

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