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PROJECT FINAL REPORT

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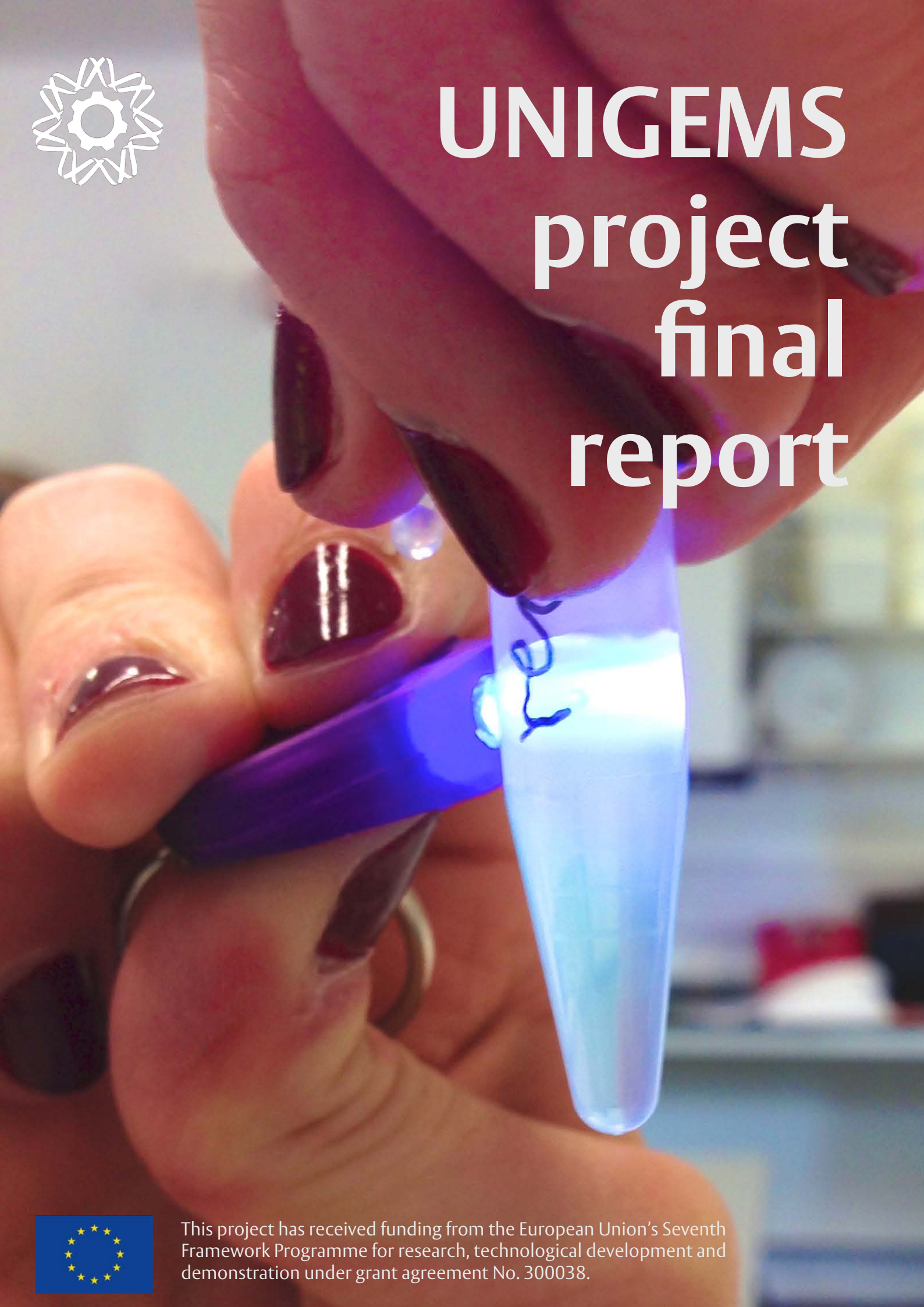

UNIGEMS project final report

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No. 300038.

Executive summary

The term ‘synthetic biology’ is used to describe several overlapping fields of research, but our research and the UNIGEMS project follows most closely the definition: ‘the construction of novel genetic systems and pathways from a set of ready-made and compatible genetic parts (DNA sequences) to design organisms with desirable characteristics’. The UNIGEMS project aimed to develop resources to facilitate teaching of synthetic biology in higher education. It comprised two equally important components: the development of novel or improved parts and protocols that would allow their use in undergraduate training in synthetic biology and the Marie Curie Fellow’s training in teaching and lecturing within academic environment and his professional career management and development activities.

During the project, we selected and tested DNA parts and protocols to be used in practical, student-driven experiments demonstrating various techniques and approaches in synthetic biology. We developed three experimental resources to provide a framework for teaching synthetic biology, starting from basic microbiology laboratory practice and bacterial transformation, a method of DNA assembly to create novel plasmid molecules and the regulation of gene activity using ready-made parts.

In preparing the resources, we assumed that students would have little initial knowledge or experience of these techniques (for example, engineering students or first-year biology students), but also assumed that they would be supported by experienced staff with a biological or microbiological background and would have access to typical molecular biology and microbiology equipment, services and reagents (e.g., PCR machines, incubators, antibiotics).

We tested the genetic components and protocols with undergraduates during three workshops we designed, prepared and ran at the University of Reading.

We also developed a simplified protocol for bacterial transformation and adapted it into an experimental kit that is available from the NCBE. Its development and production allowed the Fellow to experience the challenges and approaches in product development. The NCBE has supplied more than 200 kits since April 2013, delivering practical bacterial transformation to at least 3 600 students in the UK and the rest of Europe. This initial kit, while targeted at secondary schools, is based on the same method and approach we used on courses with undergraduates. We also successfully tried this protocol in numerous workshops with diverse audiences, from 10-year-old children to secondary school teachers and laboratory technicians.

We anticipate that the undergraduate resources will provide a foundation, which interested parties will use to support their own teaching and training in synthetic biology in higher education.

All the DNA sequences, as well as basic plasmid molecules that are manipulated in the resources, are available online (figshare.com) and were deposited in plasmid repositories (addgene.org). All the materials are also available from the project website (practicalsyntheticbiology.net/resources). The project has already had a considerable impact for students and staff at Reading University, inspiring the students to establish a Synthetic Biology Society and to set up the University's first student team to participate the International Genetically Engineering Machines competition.

Project website and other supplementary materials

Project website, sequence and plasmid repositories

The most up-to-date version of the resources, as well as links to extra materials and data are available at http://practicalsyntheticbiology.net/resources.

The sequences of all plasmids and DNA parts described in our resources have been submitted to an online repository figshare.com, where the whole set of resources is deposited under the "Practical synthetic biology" title, which should be used in the figshare.com search facilities. The plasmids themselves have been deposited in addgene.org, an open repository facilitating exchange of plasmids by the research community. To request UNIGEMS plasmids from addgene.org, please search for "Bryk" on their website (the name of the Marie Curie Fellow).

Other supplementary materials

List of materials related to the project, with links, where possible:

1. Report from the practical synthetic biology workshop for undergraduates at the University of Reading in 2013 (the workshop was Deliverable D6): http://figshare.com/articles/Report_from_practical_synthetic_biology_workshop_for_undergraduates/1086123
2. Scan of the Certificate in Research Career Management awarded to the Marie Curie Fellow (attached to this report).
3. The talks given by the Fellow available on youtube.com:
   - Reading Geek Night: https://www.youtube.com/watch?v=cTSozgokHhk
   - Oxford Synthetic Biology Meetup: https://www.youtube.com/watch?v=OUsxIj32tKg
4. A video illustrating the Gibson Assembly procedure performed *in silico* using SnapGene software. http://youtu.be/XI_RS3MuBEI

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A summary description of project context and objectives

Project background

The term 'synthetic biology' is used to describe several overlapping fields of research, but our research and this project follows most closely the definition: "the construction of novel genetic systems and pathways from a set of ready-made and compatible genetic parts (DNA sequences) to design organisms with desirable characteristics". The parts can easily, reliably and predictably be combined into complex systems using compatible interfaces both at the DNA level (common restriction sites, cloning vectors, target genomes *etc.*) and at the gene expression level (common DNA binding sites, proteins that sense and react to other proteins in the pathway, etc.). Once such parts have been characterised, they can be assembled in various configurations and introduced into organisms. This contrasts with previous genetic modification methods where each construct and organism was a bespoke creation.

Th is approach was best summarised by Drew Endy, one of the founders of the field, who commented in 2005 on what synthetic biology should make possible within the next five years: "Undergraduates and high school students, without prior training in biology or biological engineering, should, over a period of weeks, be able to design synthetic biological systems of their own invention comprised of several dozen pre-existing standard biological parts … and show it to work". To realise this vision, MIT established a Registry of Standard Biological Parts (called BioBricks™), an open repository of genetic components. Since 2005 MIT has also hosted an annual competition for undergraduate and graduate students called the International Genetically Engineered Machine (iGEM). The teams participating in iGEM design and produce - during their summer holidays - synthetic biological systems, using existing BioBricks™ and newly-developed parts that they contribute to the Registry. In many media outlets and publications, as well as in many European universities, synthetic biology is synonymous with iGEM, and synthetic biology activities only take place because of, and during, iGEM-related activities.

Th e limited uptake of the synthetic biology activities in higher education in Europe is probably in part due to poor characterisation and compatibility of the parts and an uncertain legal landscape regulating the use of BioBricks™. There are currently more than 12 000 biological components ('parts') registered in the BioBricks™ repository, of which about 5 000 are available to order. Only a small fraction of those (~1 500) have been shown to work relatively reliably. Most of the parts are therefore of limited value: their sequences are unknown, they are poorly documented and there is no evidence that they function. The BioBricks™ Foundation requires that contributors release the parts to public domain but it does not prohibit commercialisation and patenting of the inventions developed on the basis of

BioBricks™, which makes the system open to abuse and may discourage the contribution of high-quality parts. Critically, it does not address issues concerning existing BioBricks™ that violate patents.

The project rationale

The increasing popularity of iGEM attests to the fact that students find the topic attractive and the results prove that the teams are highly innovative. iGEM exposes participants to the principles and methods of scientific research, and requires that each project must consider ethical issues during the developmental phase, thus encompassing a complete range of topics relevant in real-life research. Synthetic biology, however, is used in research and teaching in very few universities in Europe. iGEM 2010 had 36 teams registered from 13 countries of the European Union, but almost half of the European teams (17 teams, 47%) come from only two countries, the UK and Germany. Most teams' host institutions do not have dedicated synthetic biology training available, and there are currently no formal curricula devoted to synthetic biology in Europe.

One of the key reasons for the low uptake of synthetic biology is the lack of reliable resources for university teaching. Even with the availability of the BioBricks™, given and rapid development of new DNA assembly protocols, the effort required to develop practical resources is prohibitive for many researchers and lecturers. A set of reliable and extensible resources for an undergraduate synthetic biology curriculum would therefore greatly facilitate training and research in this field across Europe.

Project aims

UNIGEMS aims to select and create a compatible and extensible set of curated parts, and develop them into teaching resources to assist in synthetic biology training. UNIGEMS also aimed to prepare and deliver practical courses for university students and other audiences within University of Reading and beyond. UNIGEMS comprised two equally important components:

a) the creation, characterisation and development of novel or improved parts and protocols that would allow their use in undergraduate training in synthetic biology
b) the Fellow's training in teaching and lecturing within academic environment and his professional career management and development activities.

A description of the main S&T results

A major S&T result of the project was the development of a series of protocols and DNA parts that combine into a teaching framework that we believe will greatly facilitate development, teaching and practice of introductory synthetic biology courses at undergraduate level.

Simple bacterial transformation protocol

We developed a simplified procedure for bacterial transformation, i.e. for introduction of plasmid DNA into bacterial cells. Traditional protocols employ commercially available competent cells (i.e. cells that have been chemically treated to enhance their ability to take up DNA from the environment) that have to be stored at -80°C, use very small amounts of DNA and can take up to 90 minutes. Our procedure is based on the Transformation and Storage Solution (TSS) developed by Chung and colleagues (1989). To make bacterial cells competent one suspends them in a specially-prepared buffer on ice. The final protocol we developed allows bacteria to be made competent by suspending cells scraped from a solid agar plate in a small volume of the TSS buffer. Plasmid DNA is added, the cells are incubated for 15 minutes, then inoculated directly onto a selective medium. This procedure, while it sacrifices transformation efficiency (our procedure is approximately two orders of magnitude less efficient than the currently available research–grade protocols), is much simpler, requires fewer reagents and far less time. This makes it possible to perform successful bacterial transformation during a typical practical class.

Another development that made the transformation protocol robust and successful was the use of kanamycin instead of ampicillin as a selective antibiotic on the agar plates. Kanamycin has several health and safety advantages over ampicillin, but cells need longer to express resistance to it compared with ampicillin. Plating the cells onto selective media with a reduced concentration of the kanamycin (approximately half that normally used) overcomes this difficulty.

Bacterial transformation kit for schools

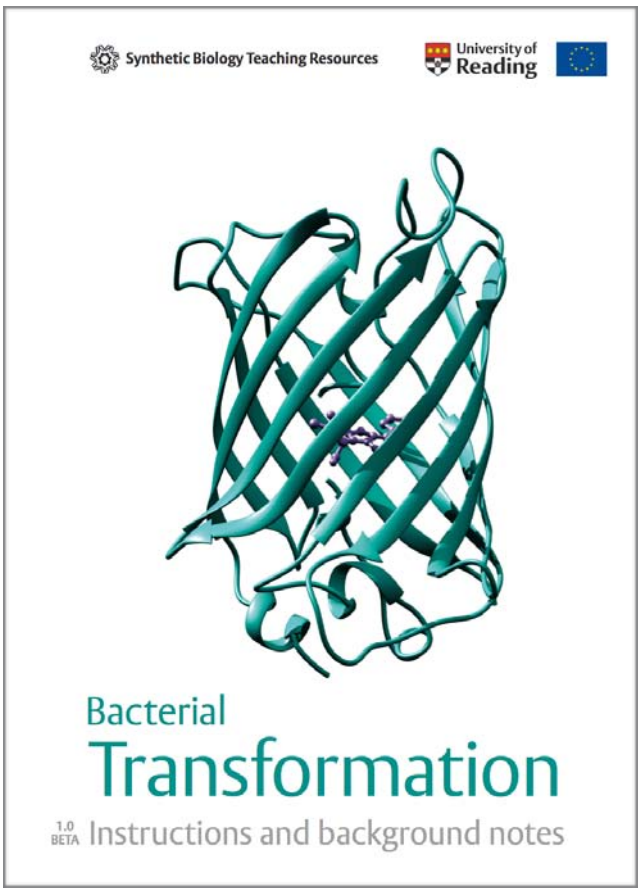
As a test bed for the development procedures of the more complex protocols, we used the TSS-based protocol to produce a bacterial transformation kit for secondary schools. The kit enables 18 transformation reactions to be performed, if necessary, without the use of micropipettes (a costly instrument that not all schools have) and without competent cells that need to be stored at -80 °C. The kit has been available from the NCBE since April 2013 and has sold over 200 sets in the first year on the market, providing training and education on bacterial transformation and basic microbiological practice to a minimum of 3600 students in the UK and the rest of Europe.

Student's manual for the protocol is shown above and also available (along with teachers' guidelines) from NCBE's website: http://www.ncbe.reading.ac.uk/NCBE/MATERIALS/DNA/transformation.html.

Resources for introductory undergraduate synthetic biology

We developed a set of three practical resources to facilitate the introduction of synthetic biology techniques and approaches, in particular the assembly of pre–made, characterised parts into genetic circuits to modify bacterial characteristics. Our resources enable training in basic microbiological techniques such as aseptic methods and growing bacteria, as well as general good laboratory practice (which is essential for work with genetically-modified organisms). In preparing the resources, we assumed little initial knowledge or experience in these techniques by the participants (for example, engineering students or first-year biology students), but also assumed that they would be supported by experienced staff with biological or microbiological background and had access to typical molecular biology and microbiology equipment, services and reagents (i.e. PCR machines, incubators, antibiotics).

Kit 1



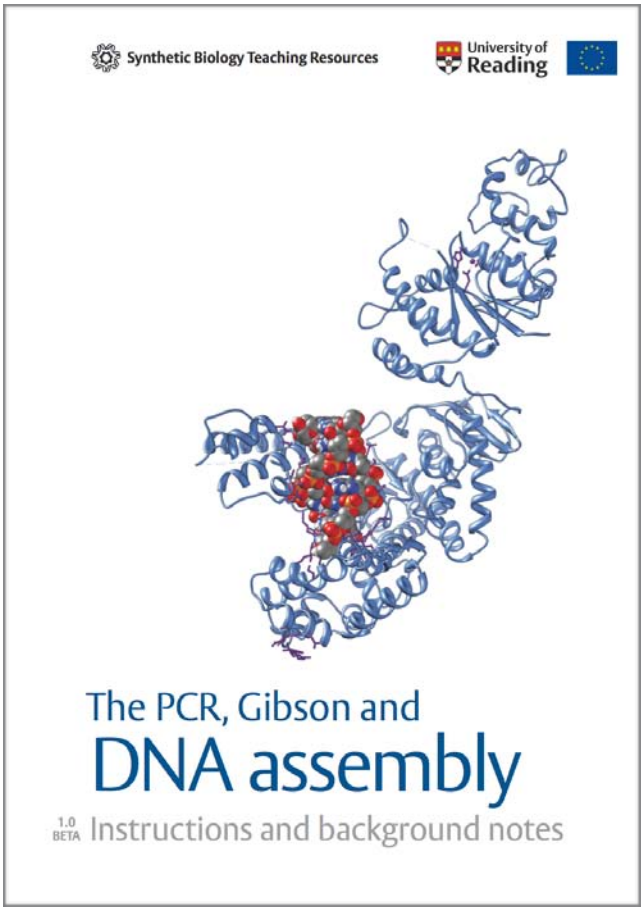
The first practical "kit" is very much based on the simple transformation protocol kit NCBE has been selling for the last year and aims at introducing basic microbiological techniques and practical experience of one of the foundational techniques in synthetic biology, namely bacterial transformation. Students transform *E. coli* with a plasmid DNA that confers resistance to antibiotic kanamycin, as well as a gene encoding green fluorescent protein from the jellyfish *Aquorea victoria.*

Kit 2

The second practical kit introduces another foundational technique in synthetic biology - DNA assembly, as well as basic molecular biology techniques like polymerase chain reaction (PCR). Students use PCR to generate several DNA parts made on the template of plasmid DNA, and then assemble these parts in novel configurations to produce new plasmid molecules, which are then used to transform bacteria. The newly–assembled parts may also be sequenced to confirm correct assembly of the molecules. The plasmids the participants are able to create may encode green fluorescent protein (that emits visible light upon UV/blue light induction), red fluorescent protein that is also visible in daylight without the need to excite it, a banana odour generator that makes bacteria smell like bananas upon adding isoamyl alcohol, and a beta-galactosidase gene that encodes an enzyme that digests lactose. It is worth emphasising that students themselves decide which of the plasmids they want to make and proceed to select appropriate PCR primers and calculate appropriate amounts of DNA parts for the assembly of their molecules of choice. A group of students may create up to four different plasmids encoding different functions or proteins. These plasmids become the basis of modifications and measurements in Kit 3.

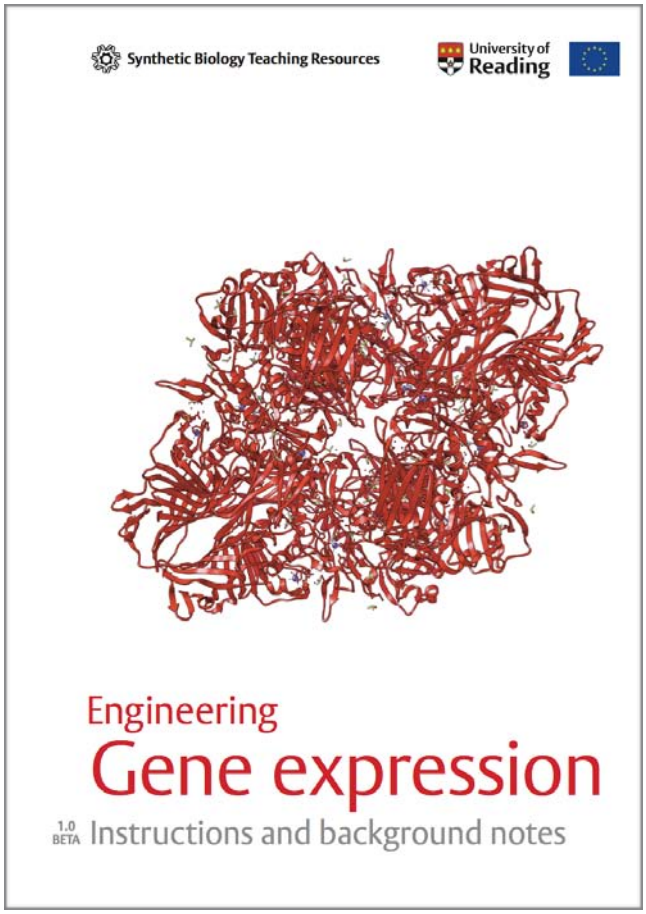
DNA assembly methods are currently a very dynamic research field, and new or modified methods appear regularly. We have decided to use Gibson Assembly, as it is a relatively straightforward method that only requires a single step, 60-minute-long reaction to combine several DNA parts in a desired order. While commercially-available reagents for Gibson Assembly are expensive, in-house preparation of the master mixture reduces the costs considerably. Importantly, Gibson Assembly allows

essentially any plasmid molecule to be turned into a vector or a part for the assembly, by virtue of design and selection of PCR primers, a simple procedure that every molecular biology laboratory does regularly. We do note, however, that given an extremely rapid developments in the field of DNA sequencing and synthesis, it is quite likely that in several years all current assembly methods will become obsolete, as all and any DNA part or whole plasmid will be ordered online and synthesised commercially at low cost.



Kit 3

Finally, the third practical kit expands on the DNA assembly concept: it provides a set of new, ready-made parts that allow the expression of genes on plasmids assembled using Kit 2 to be modified, using procedures learnt in Kit 2: PCR and Gibson Assembly. The concept of this kit is most similar to a definition of synthetic biology: 'the construction of novel genetic systems and pathways from a set of pre-optimised, pre-characterised and compatible DNA sequences to design organisms with desirable characteristics'. The parts provided in the kit allow genes of interest to be 'switched on' constitutively, or after adding a certain chemical. It also permits the modulation of the activity of the genes. The four genes on a plasmid in Kit 2 have been chosen so that each challenges students to quantify their activity using a different approach. While both GFP



and RFP activity could be measured by fluorimeter or cytometer, RFP is also visible in daylight, enabling visual estimation of the RFP production by a given construct. The banana smell must be measured with a series of standard "banana flavours" of different strengths or by gas chromatography, and beta-galactosidase by a colorimetric enzymatic reaction.

The complete set of these resources will equip the participants with foundational skills, techniques and approaches with which they can build and/or modify other genetic circuits, and assess their performance. The resources are all based on intellectual-property-rights-free parts. All plasmids and parts can be used freely, and their sequences (and plasmids themselves) have been deposited in repositories (figshare.com and addgene.com) so that everyone could learn about them and use them. At the time of writing, NCBE is also considering selling the parts and plasmids to higher education institutions at low cost.

The complete set of these resources delivers proven protocols and pre-selected parts that allow a practical introduction to basic techniques and approaches used in synthetic biology, and also introduce good microbiological laboratory practice, a necessity for safe and responsible conduct in any synthetic biology project. The resources guide students in choosing their constructs and then modifying and measuring them. We believe this creates engagement and ownership that sets these practicals apart from conventional "follow the recipe for the predetermined outcome" tasks during practical work.

Potential fourth kit

We also attempted to develop another kit of resources, to allow more advanced circuits to be created: genetic circuits that mimicked computer logic (AND, OR and NOR logic gates). We collected the required parts (they are described in Deliverable D2), however, the transformation reaction of the multi-part assembly necessary for the development of these more complex circuits have proven to have very low efficiency. We are refining the transformation methods (for example, method described in Kit 2 uses virtually the same protocol as TSS-based transformation, yet our initial tests indicate an order of magnitude improved efficiency) and if we succeed, we will consider publishing the advanced, fourth kit of resources "Engineering bacterial logic".

A description of career development activities and results

Another substantial part of the project was related to career development of the grant holder. Principally, the Marie Curie Fellow planned to obtain training and experience in teaching undergraduates in an academic settings. This required the preparation, delivery and assessment of teaching activities and participation in research career management training.

Training and experience in teaching undergraduates

The Marie Curie Fellow participated in a series of workshops prepared by the University of Reading teaching and learning support staff, principally through classes for the Postgraduate Certificate of Academic Practice, which is required for all new lecturers at the University. However, the grant holder could not complete this training in full, as the complete programme takes two years, beyond the time of his contract. Nevertheless, below is the list of courses he completed during his teaching and learning training:

Teaching theory and practice courses (TLDS and PGCAP)
MAKING A PROFESSIONAL START WITH YOUR TEACHING
HOW STUDENTS LEARN
GIVING FEEDBACK TO STUDENTS
SMALL GROUP TEACHING
EVALUATING YOUR TEACHING
ENQUIRY BASED LEARNING: RESEARCH - TEACHING SYNERGIES
LEARNING OUTCOMES AND COURSE DESIGN
MAKING TECHNOLOGY ENHANCED LEARNING WORK FOR STAFF & STUDENTS IN HE
USING MOBILE DEVICES TO ENHANCE LEARNING
TEAM-BASED LEARNING: A STRATEGY FOR STUDENT ENGAGEMENT

In addition to these theory classes, the Marie Curie Fellow gained experience in preparing and leading practical classes for a diverse group of audiences and topics thanks to existing networks and collaborations of the NCBE. Below is the list of Marie Curie Fellow's teaching activities:

- A practical bioinformatic class to a group of A-level students in the Holt school, Wokingham, utilising teaching materials he co-created in the collaboration with NCBE in a Wellcome Trust-funded 'DNA to Darwin' project: Mammoth phylogeny and evolution of colour vision in humans, other apes and monkeys.
- A practical bioinformatic class to a group of European teachers during the EBI-ELLS Learning Lab workshop in the Sanger Institute (Hinxton, near Cambridge), utilising teaching materials he co-created in the collaboration with NCBE in the 'DNA to Darwin' project: Mammoth phylogeny and evolution of colour vision in humans, other apes and monkeys, as well as a newly created activity utilising Lego people to explain phylogenetic relationships.
- A microbiology training workshop for postgraduate trainee teachers at the University of Reading and at Crofton School, Stubbington, Hampshire (funded by the Society for General Microbiology)
- A bacterial transformation workshop for a group of teachers on a local teachers' conference in the Holt School, Wokingham, Berkshire.
- With Dr John Schollar, a three-day practical workshop on synthetic biology targeted at A-level students which further proved the robustness of the then-developed parts and protocols.
- At Reading University, a school-wide seminar on synthetic biology, mainly to an audience of microbiologists and food scientists, as well as a lecture on state of the art in synthetic biology in the School of Systems Engineering.
- Lectures to second year undergraduates on bioinformatics and synthetic biology.
- A short talk on synthetic biology during the microbiology lecture series for combined first year students of biological and biomedical sciences.

Practical synthetic biology workshop for undergraduates at the University of Reading

The activities listed above, along with the parts and protocols he developed, allowed the Fellow to design, develop and run two full-time, week-long workshops on practical synthetic biology for University of Reading undergraduates in 2013, and another one in 2014. During these workshops, many of the protocols and parts that are now included in the practical resources were tried and tested on a cohort of 50 students form diverse backgrounds, from biomedical sciences through cybernetics to business management. On the course, grant holder and invited experts in microbiology, GM food and computer modelling, provided students - for the first time in Reading - with a comprehensive set of lectures and

practical sessions on synthetic biology. The 2013 course and its results have been throughly described and analysed in the report produced by the grant holder, which is attached to this report. Moreover, the course had an important impact on the establishment of Reading University's fledgeling synthetic biology community, which is detailed in the Impact and Dissemination sections. Courses in 2013 and 2014 were independently funded with grants applied for and obtained by the Fellow from the Society of Genetal Microbiology and Teaching and Learning Development Fund at the University of Reading.

Research career management training and additional complementary skills

The Fellow participated in a year-long training course, the Certificate in Research Career Management, run by the staff support office at the university, to develop his skills and reflect on his research career. This course leads to an officially-recognised certificate, which confirms the skills and abilities of the participant in managing his research career. Table below shows the classes from this course. Along with these courses, the Fellow had to continually reflect on his skills, abilities and training and provide a detailed description of of his approach and solutions he found (or didn't find) during his day-to-day work.

Certificate in research career management courses
CERTIFICATE IN RESEARCH CAREER MANAGEMENT: AN INTRODUCTION
LARGE GROUP PRESENTATION SKILLS
SUPERVISING RESEARCH STUDENTS FOR POSTDOC RESEARCH STAFF
TIME MANAGEMENT
AN INTRODUCTION TO PROJECT MANAGEMENT
MANAGEMENT SKILLS FOR RESEARCH STAFF
COMMUNICATION SKILLS FOR RESEARCH STAFF
ENTREPRENEURSHIP FOR RESEARCH STAFF

The Table below lists remaining courses the Fellow attended, including obligatory training necessary before he could begin working in the lab, doing GM work or supervise undergraduates.

Obligatory training courses taken	
Genetic Modification Legislation and Practice (H&SS) Laboratory Safety Part 1 (H&SS) Data Protection Act 1998 Freedom of Information 2000 INDUCTION FOR NEW RESEARCH STAFF	

The impact

We have developed a set of three resources that enable students to perform basic microbiological and synthetic biology techniques, from bacterial transformation to DNA assembly and measuring the performance of the assembled DNA. The complete set of the resources enables introductory synthetic biology courses, or shorter preparation courses for iGEM teams, to be run without time consuming preparation of parts and development of appropriate protocols. All protocols and parts we developed are published freely on the project's website and plasmids are deposited in an open repository addgene.org.

We anticipate these resources will become a foundation, or a framework, on which synthetic biology teaching can be developed and tailored to individual scientists' need. Extensive dissemination and networking efforts by the Fellow during the project should ensure widespread adoption of the resources and protocols, leading to their further development, refinement and alternative use (for example, in courses preparing iGEM teams for their summer work). Indeed, we are considering collaboration in iGEM team training with the newly-formed Synthetic Biology Society at the University of Oxford.

We also developed a bacterial transformation kit that greatly simplified the procedures required to introduce plasmid DNA into *E. coli* cells. This kit has been available for sale from NCBE and since April 2013 more than 200 kits have been sold, enabling 3600 bacterial transformation reactions to be performed in UK and European schools. The NCBE and the Fellow ran numerous workshops and courses promoting this kit, and, by association, our work on other synthetic biology resources.

Establishment of the synthetic biology community in Reading

One of the most important consequences of the Fellow's activities at the University of Reading was to involve and inspire students, participants in the practical synthetic biology workshop, to formally establish a synthetic biology community in Reading. Before the Fellow's project began at the University, there were no established synthetic biology activities, resources or community efforts. Following the workshop, students participated in the first Young Synthetic Biologists meeting in London for all current and aspiring iGEM teams. In January 2014, they established a Students' Synthetic Biology Society, with interdisciplinary support from staff from the Schools of Systems Engineering, Biological Sciences and the NCBE, and in April 2014 organised the team and applied to the International Genetically Engineered Machines competition. The Fellow is currently mentoring the 13-student interdisciplinary team that begins its summer project on developing cyanobacteria to produce electricity.

Additional funding received

During preparations for the practical synthetic biology workshop in 2013, the Fellow applied for and obtained additional funding from the Society for General Microbiology for the consumables, sequencing and synthesis services necessary for the course, under the SGM's Education Development Fund Practical Teaching Aids (TA13-2). In addition, the Fellow obtained University funding from the Teaching and Learning Development Fund to run a second practical synthetic biology workshop for undergraduates in 2014, preparing a course tailored to the requirements of the University of Reading iGEM team.

In 2014, the Fellow was a co-applicant on NCBE grant application to the Wellcome Trust and received funding to develop synthetic biology resources for schools. While the scope of the Wellcome and UNIGEMS proposal is similar, a very different regulatory environment in schools compared to universities will require redesign of both parts and protocols to accommodate these requirements.

Additional student supervision

Following the practical synthetic biology workshop in 2013, one of student participating in the course volunteered to do additional research in synthetic biology in the summer under the Fellow's supervision. The student worked for three months on different aspects of DNA assembly and developed a plasmid with green fluorescent protein under medium-strength promoter that was subsequently used during open days at the exhibition by the Department of Microbiology.

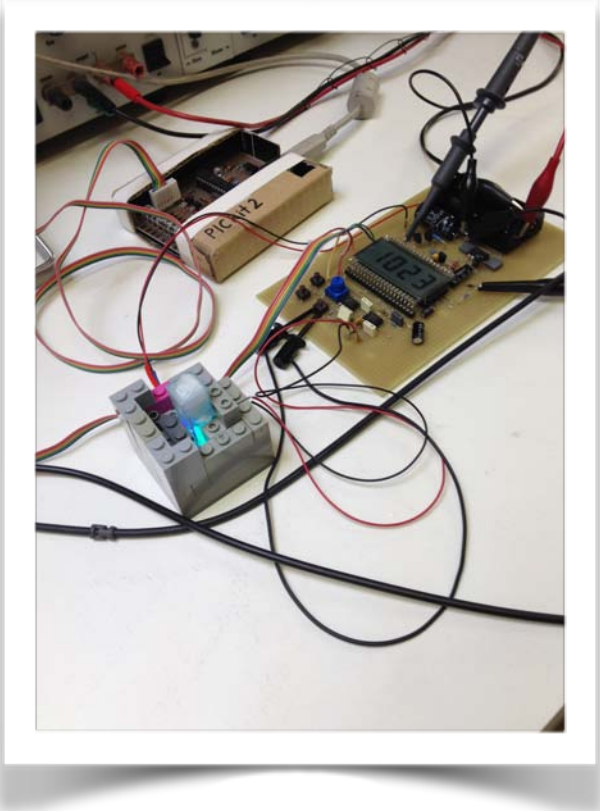
Th is experience is very relevant and beneficial for the Fellow in terms of his future career as an educator or researcher in an academic environment.

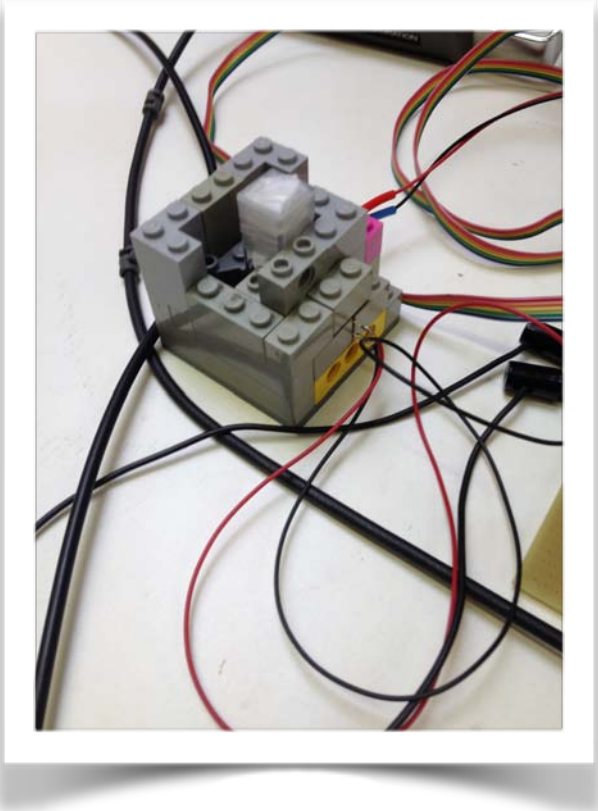
Development of affordable laboratory equipment

One of the complementary activities we undertook was developing simple, reliable and affordable equipment to be used in place of costly and sophisticated hardware to measure constructed circuits' performance. While these attempts are not yet complete, we believe they might be of interest and importance to users of the UNIGEMS resources:

Simple fluorimeter

In collaboration with Roy Palmer, senior electronics technician at the university, we are developing a simple fluorimeter to enable quantification of GFP and RFP emissions. The fluorimeter will be portable, 9V battery-powered, take standard 4-clear-wall cuvettes and use an inexpensive LEDs as light source. The emission spectra will first be narrowed down with a small band-pass filter and then emission strength will be measured following amplification by photomultiplier tube. The body of the device is built with LEGO bricks. The photos below show the current prototype.





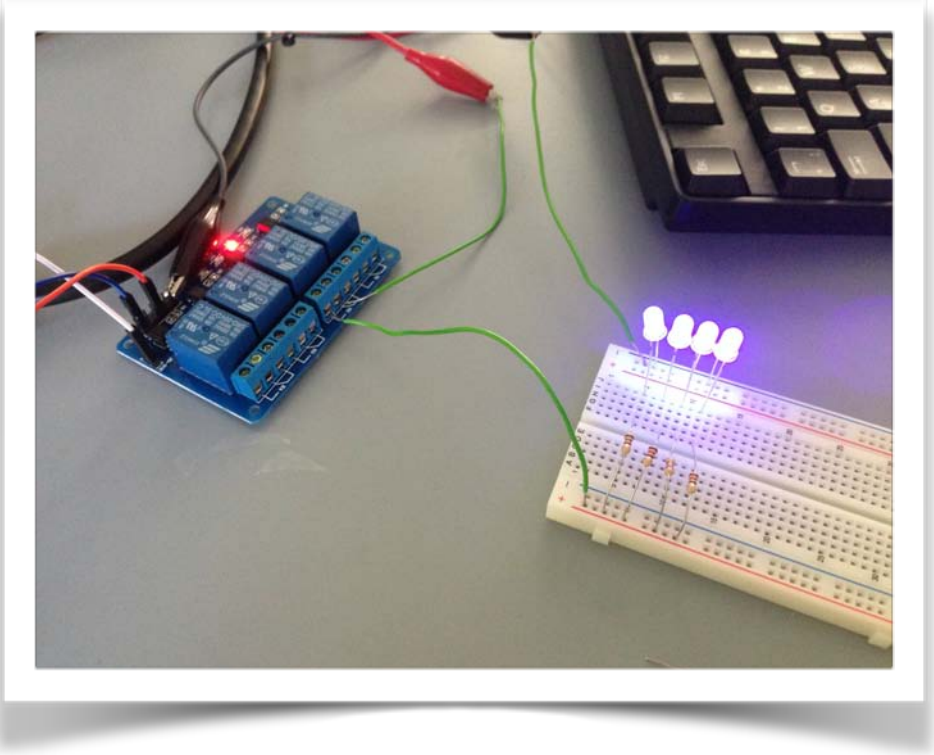
Simple emulsifier

We are also adapting a simple emulsifier, developed previously for an as yet unpublished NCBE resource for schools, to be used to quantify the strength of the banana flavour produced by bacteria (see synthetic biology teaching resources kits no. 2 and 3).

We use a small, 3V, high power brushless motor that turn a small metal bolt (in action it resembles an electric toothbrush) to emulsify small volumes of mixture directly in an Eppendorf tube. We plan to use it to prepare a dilution series of a emulsion made from food-grade banana flavour and compare it with the one produced by the bacteria. The photo shows the motor placed in the tube in the liquid to be emulsified.

Time-lapse photography of fluorescent bacteria

In collaboration with Ioannis Zoulias from the School of Systems Engineering, during the practical synthetic biology course in 2014 we developed an early prototype of a Raspberry Pi-powered circuit that enables time-lapse photography of bacteria growing on agar plates. While we don't expect this device to be as refined as the fluorimeter or emulsifier, we anticipate its use to track growth of GFP expressing bacteria. The early working circuit of UV LEDs controlled by an optical relay programmed with a very simple Python script on Raspberry Pi is shown below. The video of its function is also available on the project's website.



Main dissemination activities during the project

Photographs in this section come from workshops in synthetic biology organised by the NCBE and the Fellow for undergraduates and A-level students at the University of Reading and have been used with permission.

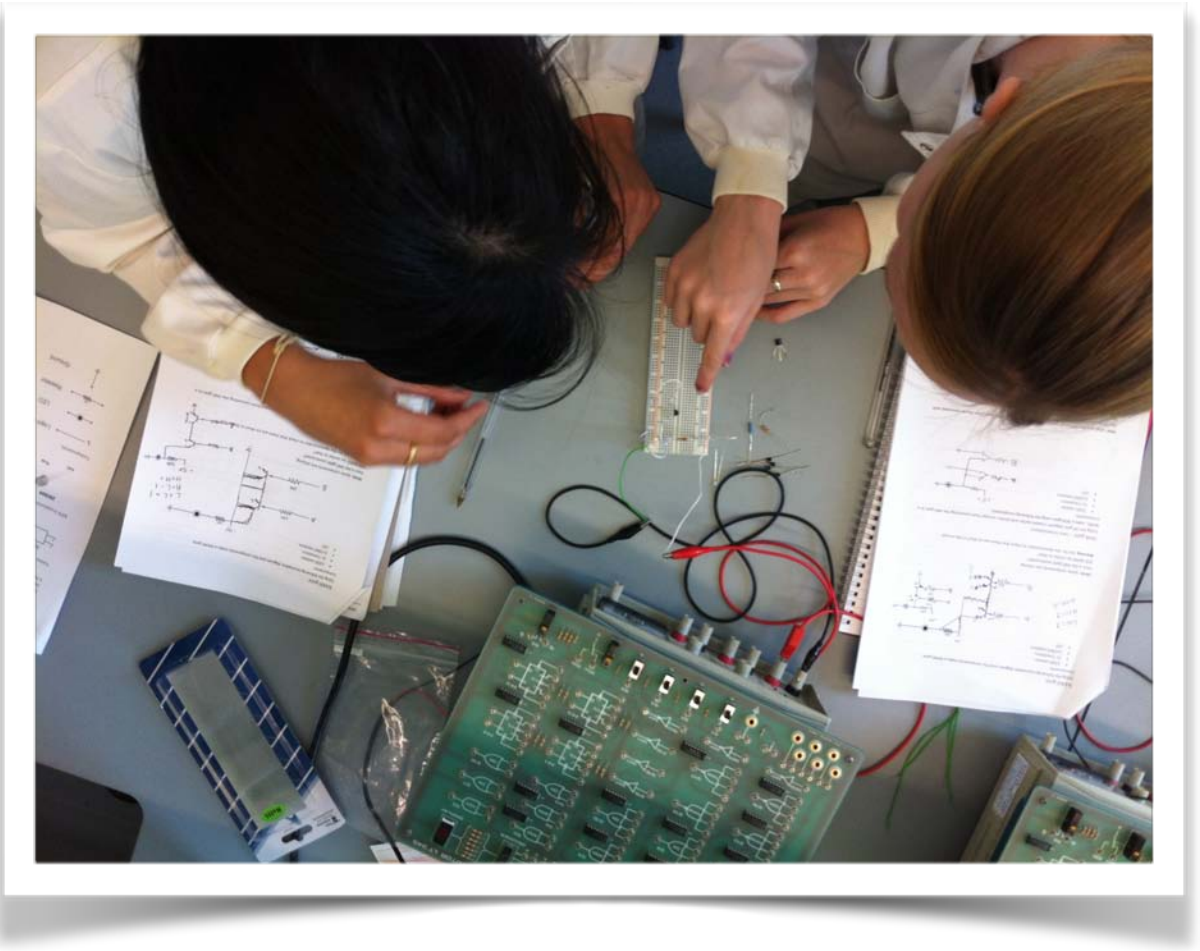
Introductory synthetic biology for A-level students, Reading 2014

The NCBE and the Fellow were again asked to run the synthetic biology workshop for A-level students, and due to high demand the organisers had to introduce a competitive application process. While not directly related to the UNIGEMS project (this workshop took place after the completion of UNIGEMS), it let us test the developed materials on a different age and experience group, and informed us about challenges and opportunities of introducing synthetic biology practical materials in secondary schools. We have already begun working on such resources thanks to additional funding that has recently been received from the Wellcome Trust.

University of Reading International Genetically Engineered Machines competition team, 2014

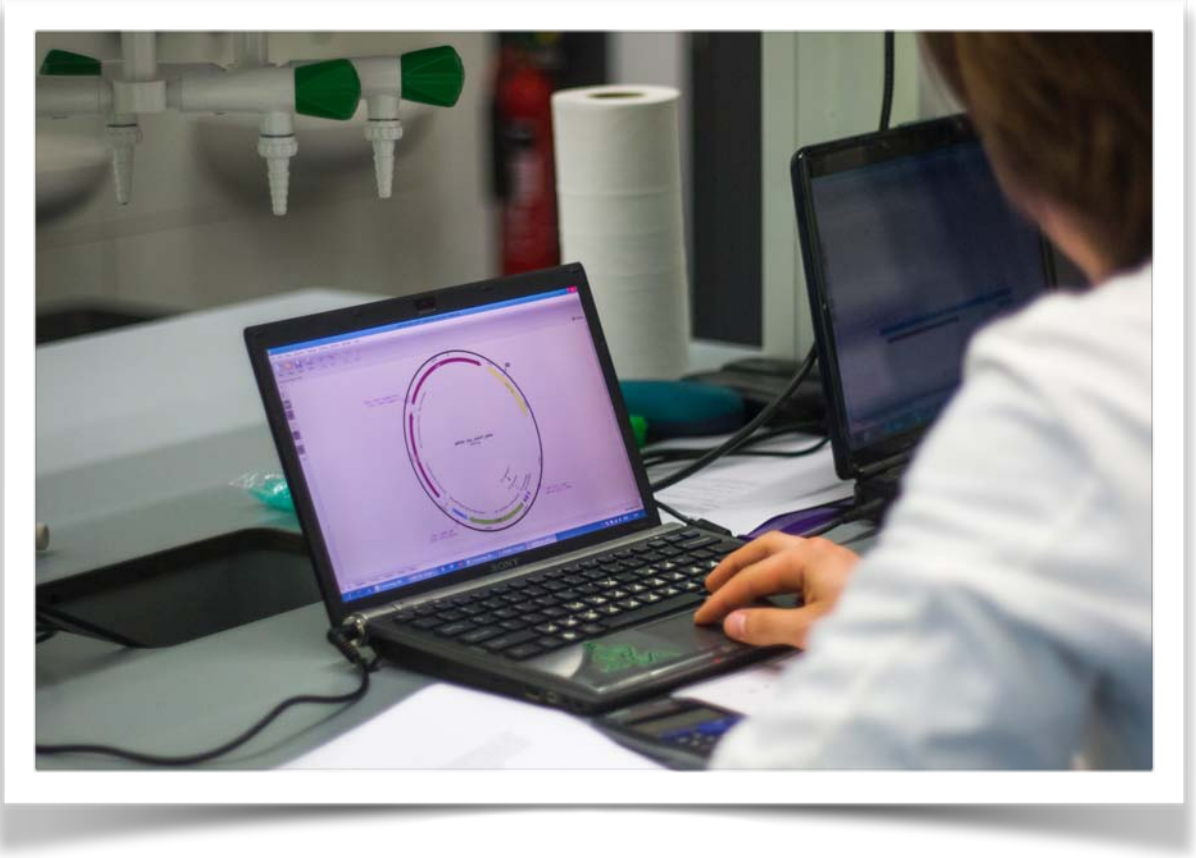
Following the 2013 practical synthetic biology course and the establishment of a University of Reading Synthetic Biology Society by the course alumni, the students organised themselves to take part in the iGEM competition in 2014, and the Fellow is now co-mentoring a 13-student team comprised of first and

second year students from the Schools of Systems Engineering and Biological Sciences. Students will take part in a UK meeting and a US-based meeting later in 2014, and will present results of the research project they are developing: solar-powered cyanobacteria-based fuel cell.



Practical synthetic biology workshop for University of Reading iGEM team, 2014

The second undergraduate workshop at Reading was run by the Fellow and NCBE just after the completion of the UNIGEMS project. It was funded by the University of Reading and, because of the students' involvement in the iGEM competition, it was tailored specifically to their needs. Engineering and biological sciences students were taught basic electronic circuit construction, programming, molecular biology and microbiology methods, including Gibson Assembly and BioBrick™ assembly (a standard assembly technique used in the competition) and built a microbial fuel cell. However, due to demand from other students and members of staff for a more regular workshop on synthetic biology, we are planning on running it either as a part of term-long module for Year 2 students, or as summer research placements beginning in 2015.



Oxford SynBio Meetup, Oxford 2014

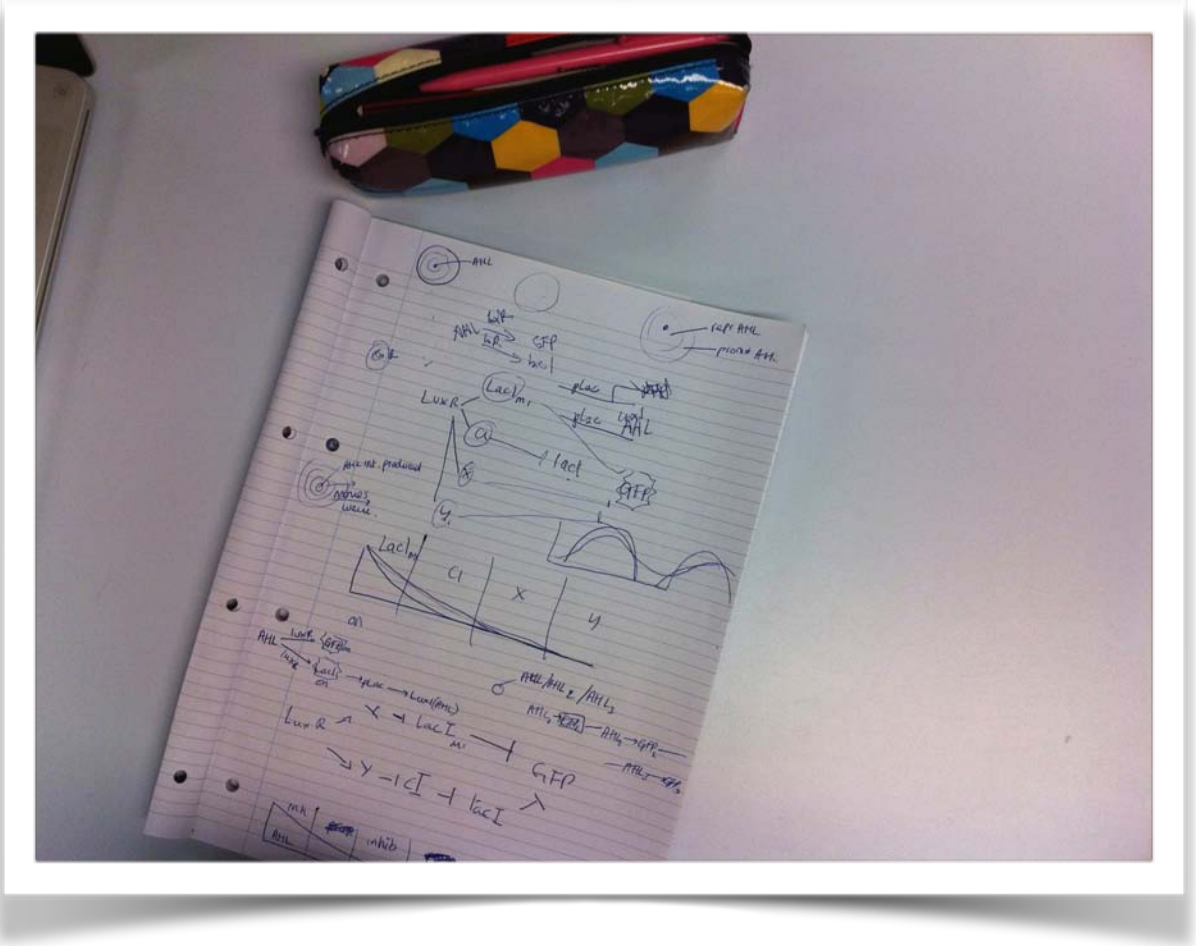
The Fellow was invited as one of the speakers invited to the Oxford Synthetic Biology Society Meetup (http://synox.co.uk), which hosted the majority of UK teams for the 2014 International Genetically Engineered Machines competition for an networking event. The keynote speaker was one of the founders and president of the iGEM foundation, Dr Randy Rattberg. The Fellow talked about his experiences in establishing a synthetic biology community at a university and encouraging students to set up synthetic biology communities at their institutions. All the talks and the Q&A session afterwards were live streamed on the internet and are available on YouTube.com https://www.youtube.com/watch?v=OUsxIj32tKg

BioBricks Foundation Synthetic Biology 6.0, London 2013

The Fellow participated in the foremost International Synthetic Biology conference (http://sb6.biobricks.org) which was held in London in 2013, where he presented a poster outlining the resources he was developing, and met scientists and educators working in a wide range of synthetic biology-related fields. Among other developments, he learned about a novel method of DNA assembly being developed by researchers at Amyris, and was also contacted by a group of students from the Oxford University, interested in establishing collaboration and using the resources. The poster is available for download online http://figshare.com/articles/Poster_for_the_SB6_conference/1086120 and on the project's website.

Introductory synthetic biology for A-level students, Reading 2013

Some of the parts and simplified protocols developed and tested during the undergraduate course described below were also used in during the workshop for A-level students hosted by the University of Reading during three days in July 2013. The NCBE and the Fellow prepared and ran the course. Its success ensured that a second course could be run in 2014, for which we had to introduce a selection procedure due to number of participants exceeding our capacity.



Practical synthetic biology workshop for undergraduates, Reading 2013

Two one-week workshops for University of Reading undergraduates, during which we tested the protocols and approaches used in the practical resources. Sixty students applied to attend the workshop, of which we hosted 37 students and two members of staff from the School of Systems Engineering. The report from that workshop is attached to this report. The success of this event was crucial to the establishment of wider synthetic biology community at the University, and gaining the support, both financial and practical, of several university departments and key academic members of staff. The report from this workshop is available from figshare: http://figshare.com/articles/Report_from_practical_synthetic_biology_workshop_for_undergraduates/1086123 and from the project's website.

Royal Society for Chemistry Meeting, London 2012

The Fellow participated in the RSC meeting "Chemistry for Tomorrow's World 2012: Synthetic Biology: Challenges and Opportunities for the UK" (http://www.rsc.org/scienceandtechnology/roadmap/events/synthetic-biology-event.asp), a panel discussion discussion and debate to explore the science and ethics of synthetic biology. The Fellow has written about his impressions from this meeting on the project's website: http://practicalsyntheticbiology.net/2012/12/03/meeting-report-synthetic-biology-challenges-and-opportunities-for-the-uk/.

Royal Institution meeting on synthetic biology, London 2012

The Fellow was invited as one of three participants on the synthetic biology discussion during Royal Institution lecture series hosted by Alok Jha from The Guardian. The participants were asked to present their idea for a synthetic biology intention, creation or an idea to the public, with subsequent discussion between the presenters and the public on the state of the art in synthetic biology.

Reading GeekNight, Reading 2012

The Fellow gave a talk and answered questions about synthetic biology in general and teaching resources he was developing to a lay audience affiliated with Reading Geek Night community. The Fellow's talk was recorded and is available on YouTube.com https://www.youtube.com/watch?v=cTSozgokHhk.

BioDesign Forum, Cambridge 2012

The Fellow was one of the invited speakers to the first Cambridge BioDesign Forum (http://cambridgebiodesign.org/forum/), set up to bring people from various backgrounds whose research is or may be related to synthetic biology. The Fellow spoke about the teaching resources he was developing and participated in technical discussion about possible approaches to an more efficient design of bacterial transformation. This meeting also resulted in the establishment of a network of potential users or collaborators on said resources in the iGEM Foundation (http://igem.org/Main_Page) via Dr Tom Knight, and in the BioBuilder Foundation via Dr Natalie Kuldell (http://biobuilder.org).

Dial-A-Molecule, Stevenage 2012

The Fellow was one of the speakers at the Dial-A-Molecule meeting in Stevenage (http://www.dial-a-molecule.org/wp/blog/2013/03/using-synthetic-biology-to-dial-a-molecule-ii-defining-the-path-to-success/), where he talked about the need for simple practical resources to facilitate teaching synthetic biology and his plans to develop them. At this meeting he met Prof. Andrew Turberfield from the University of Oxford and discussed potential use of UNIGEMS' resources for physics students at Oxford. This meeting led to the Fellow's involvement in University of Oxford's first Synthetic Biology Meetup in June 2014, and Oxford's Synthetic Biology Society is likely to use UNIGEMS' resources in training their own iGEM team in 2015.

Other dissemination activities

ELLS Learning Lab Biology 2.0, workshop for teachers, Hinxton 2012

A bioinformatic workshop for teachers (https://www.ebi.ac.uk/training/course/ells-learninglab-2012-biology-20-making-sense-biological-data), based in part on materials co-developed by NCBE and the Fellow in a previous collaboration during the Darwin bicentennial. The Fellow taught a group of teachers from all over Europe the principles and practices of molecular evolution and phylogenetics, using case studies in the evolution of Mammoths, colour vision in humans, apes and monkeys, and a simulation of phylogenetic relationships between various Lego people!

Bioinformatic workshop for A-level students, the Holt school, Wokingham 2012

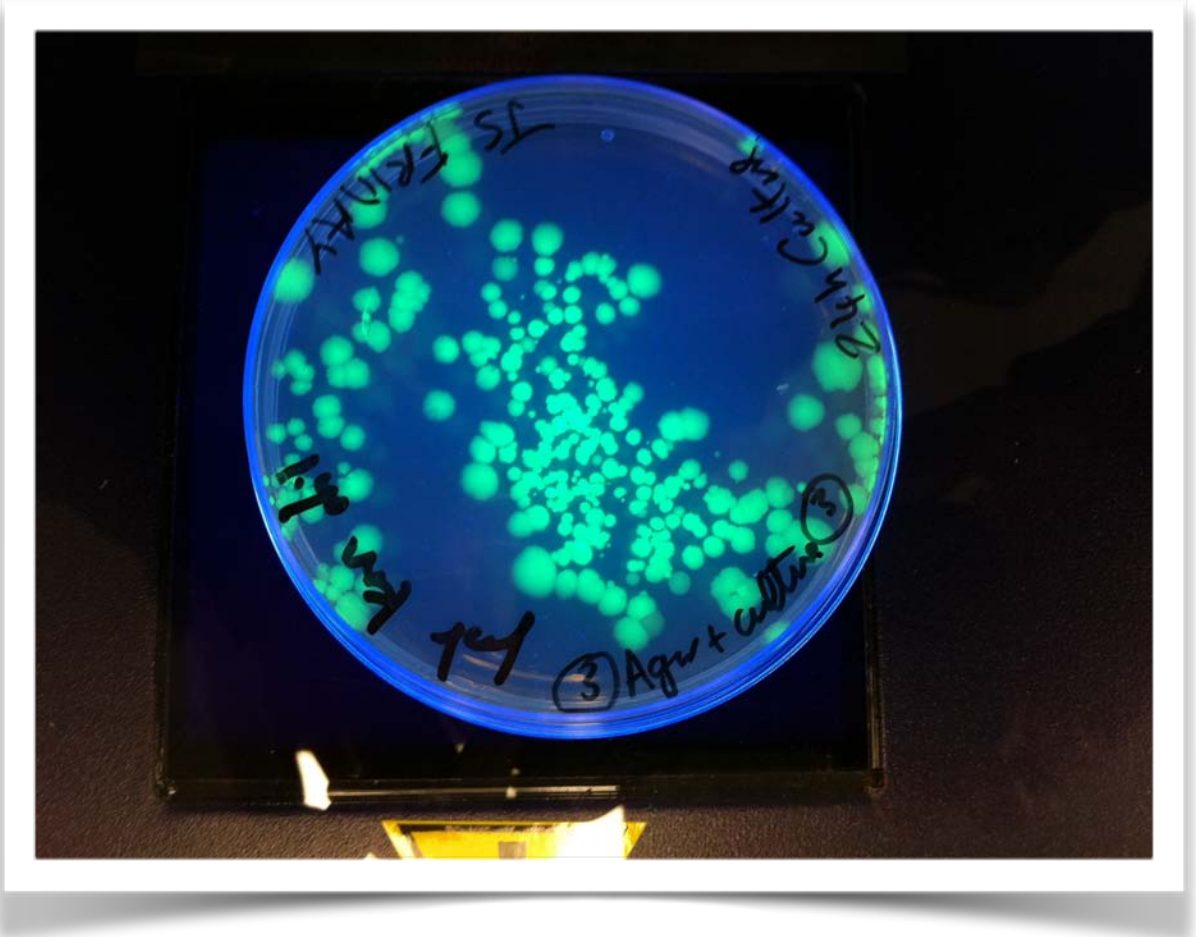
The Fellow taught a group of 20 A-level students in the Holt School in Wokingham on molecular evolution and phylogenetics, using materials he previously co-developed with NCBE in the DNA to Darwin project.

University of Cambridge iGEM training course, 2012

The Fellow took part in a part in the course run for students participating in the University of Cambrige iGEM team (http://data.plantsci.cam.ac.uk/Haseloff/education/BioAssembly/workshop.html). This experience and discussions with students and organisers - Dr Jim Haseloff, Dr Jim Ajioka and Dr Paul Grant, enabled us to better plan and design for the resources we wanted to develop.

Bacterial transformation for 10-year-olds

The Fellow also participated in NCBE's workshop for a group of 60 ten-year olds who were invited to the University of Reading to try their hands in microbiology. The children had a chance of trying the simplified bacterial transformation protocol, and for us it was a test of robustness and efficiency of the developed resources. The protocol tried by the children was the same we implemented in the commercially available bacterial transformation kit.



Comment regarding Section A and B: this project has not resulted in publications, patent or exploitable foreground

Section A (public)

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[1] (if available)	Is/Will open access[2] provided to this publication?

[1] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[2] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[3]	Main leader	Title	Date/Period	Place	Type of audience[4]	Size of audience	Countries addressed
1	Workshop	Dr John Schollar, Dr Jarosław Bryk	Introductory synthetic biology for A-level students, Reading 2014	14-16 July 2014	University of Reading	Students	30	UK
2	Workshop	Dr Jarosław Bryk	Practical synthetic biology workshop for the University of Reading iGEM team	10-20 June 2014	University of Reading	Undergraduates	13	UK
3.	Meeting	Dr Jarosław Bryk (invited speaker)	Oxford Synbio Meetup	19 June 2014	University of Oxford	Undergraduates	~100	UK, Ireland, US
4	Conference	Dr Jarosław Bryk (poster presentation)	BioBricks Foundation Synthetic Biology 6.0	9-11 July 2013	Imperial College London	Researchers, industry, policy makers, others	hundreds	International
5	Workshop	Dr Jarosław Bryk	Practical synthetic biology workshop for the University of Reading iGEM team	10-21 June 2014	University of Reading	Undergraduates	37	UK

[3] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[4] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

6	Meeting	Dr Jarosław Bryk (participant)	Royal Society for Chemistry: Chemistry for Tomorrow's World 2012: Synthetic Biology: Challenges and Opportunities for the UK	14 November 2012	Royal Society for Chemistry	Researchers, students, industry, policy makers, others	~100	UK
7	Meeting	Dr Jarosław Bryk (invited speaker)	Royal Institution, synthetic biology challenge	4 October 2012	Royal Institution	Event open to the public	~50	UK
8	Meeting	Dr Jarosław Bryk (invited speaker)	Reading GeekNight	9 October 2012	Reading	Event open to the public	~50	UK
9	Conference	Dr Jarosław Bryk (invited speaker)	BioDesign Forum	25-27 September 2012	University of Cambridge	Researchers, students, industry, policy makers, others	~200	International
10	Meeting	Dr Jarosław Bryk (invited speaker)	Dial-A-Molecule	19 June 2012	GSK Stevenage	Researchers, industry, others	~100	UK
11	Workshop	Dr Jarosław Bryk (invited to run a course)	ELLS Learning Lab Biology 2.0	25-27 November 2012	Sanger Centre, Hinxton, Cambridge	Teachers	~30	International

12	Workshop	Dr Jarosław Bryk (ran the workshop)	Bioinformatic workshop	18 June 2012	The Holt School, Wokingham	Students	10	UK
13	Workshop	Dr Jarosław Bryk (participant)	University of Cambridge iGEM training course	28-29 June and 4-5 July 2012	University of Cambridge	Students and researchers	15	UK
14	Workshop	Dr John Schollar, Dr Jarosław Bryk	Bacterial transformation workshop for 10 year olds	24 June 2013	University of Reading	Primary school students and teachers	60	UK
15	Lecures	Dr Jarosław Bryk	Lectures on synthetic biology, bioinformatics to undergraduates and members of staff	Throughout the year, 2012-2013	University of Reading	Undergraduates	~300	UK
16	Workshop	Dr John Schollar	Workshop for PGCAP students and school science technicians on basic microbiological practice and bioinformatics	2012-2013	University of Reading, Crofton School	Teachers and teacher trainees	~50	UK

Section B (Confidential[5] or public: confidential information to be marked clearly)
Part B1

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[6]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)

[5] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[6] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Type of Exploitable Foreground[7]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[8]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[8] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

4.1 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	300038
Title of Project:	Synthetic Biology Resources for Universities: Research, development and implementation of resources for teaching synthetic biology
Name and Title of Coordinator:	Dr Dean Madden

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	

• Did the project involve children?	NO
• Did the project involve patients?	NO
• Did the project involve persons not able to give consent?	NO
• Did the project involve adult healthy volunteers?	NO
• Did the project involve Human genetic material?	NO
• Did the project involve Human biological samples?	NO
• Did the project involve Human data collection?	NO
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	NO
• Did the project involve Human Foetal Tissue / Cells?	NO
• Did the project involve Human Embryonic Stem Cells (hESCs)?	NO
• Did the project on human Embryonic Stem Cells involve cells in culture?	NO
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	NO
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	NO
• Did the project involve tracking the location or observation of people?	NO
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	NO
• Were those animals transgenic small laboratory animals?	NO
• Were those animals transgenic farm animals?	NO
• Were those animals cloned farm animals?	NO
• Were those animals non-human primates?	NO
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	NO
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	NO
DUAL USE	
• Research having direct military use	NO
• Research having the potential for terrorist abuse	NO

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leaders	NA	NA
Experienced researchers (i.e. PhD holders)	0	3
PhD Students	0	0
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**0**
Of which, indicate the number of men:	0

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

○	Yes
○	No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
❑	Design and implement an equal opportunity policy	○	○	○	○	○
❑	Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑	Organise conferences and workshops on gender	○	○	○	○	○
❑	Actions to improve work-life balance	○	○	○	○	○
○	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

○ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

Y Yes- please specify workshops, lectures, presentations etc. (see report for details)

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

Y Yes- please specify Deliverables D5

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

- ○ Main discipline[9]:
- ○ Associated discipline[9]:
- ○ Associated discipline[9]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	NO	No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ○ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ○ Yes, in communicating /disseminating / using the results of the project

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○	No

12. Did you engage with government / public bodies or policy makers (including international organisations)

NO No

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

[9] Insert number from list below (Frascati Manual).

N No

13b If Yes, in which fields?

Agriculture		Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment		Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs		Food Safety		Research and Innovation	
		Foreign and Security Policy		Space	
Education, Training, Youth		Fraud		Taxation	
Employment and Social Affairs		Humanitarian aid		Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?		**0**
To how many of these is open access[10] provided?		
How many of these are published in open access journals?		
How many of these are published in open repositories?		
To how many of these is open access not provided?		
Please check all applicable reasons for not providing open access:		
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[11]: ……		
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**0**
16. Indicate how many of the following Intellectual	Trademark	**0**

[10] Open Access is defined as free of charge access for anyone via Internet.
[11] For instance: classification for security project.

Property Rights were applied for (give number in each box).	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑	Increase in employment, or	❑	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
X	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:* *NA*
Difficult to estimate / not possible to quantify	❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

❑	Press Release	❑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
X	Brochures /posters / flyers	X	Website for the general public / internet
❑	DVD /Film /Multimedia	X	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	X	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES
3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES
4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES
5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]