E. chromi is a collaboration between designers and scientists in the new field of synthetic biology. In 2009, seven Cambridge University undergraduates spent the summer genetically engineering bacteria to secrete a variety of coloured pigments, visible to the naked eye. They designed standardised sequences of DNA, known as BioBricks, and inserted them into E. coli bacteria. Each BioBrick part contains genes selected from existing organisms spanning the living kingdoms, enabling the bacteria to produce a colour: red, yellow, green, blue, brown or violet. By combining these with other BioBricks, bacteria could be programmed to do useful things, such as indicate whether drinking water is safe by turning red if they sense a toxin. E. chromi won the Grand Prize at the 2009 International Genetically Engineered Machine Competition (iGEM).

Designers Alexandra Daisy Ginsberg and James King worked with the team to explore the potential of this new technology, while it was being developed in the lab. They designed a timeline proposing ways that a foundational technology such as E. chromi could develop over the next century. These scenarios include food additives, patenting issues, personalised medicine, terrorism and new types of weather. Not necessarily desirable, they explore the different agendas that could shape the use of E. chromi and in turn, our everyday lives. This collaboration has meant that E. chromi is a technology that has been designed at both the genetic and the human scale, setting a precedent for future collaborations between designers and scientists.

University of Cambridge iGEM Team 2009
Alexandra Daisy Ginsberg and James King
http://2009.igem.org/Team:Cambridge
www.echromi.com

The E.chromi project has two parts – the molecular design and the human scale thinking.

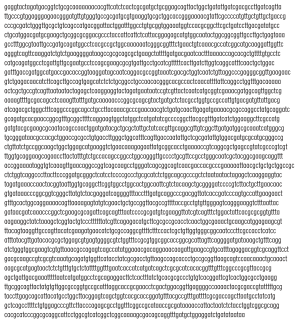
iGEM is the main undergraduate synthetic biology competition, held annually at MIT. In 2009, 120 teams from around the world competed to win the Grand Prize by designing novel BioBrick DNA parts.

Newly introduced to synthetic biology, over a three month period, the Cambridge 2009 iGEM team created two kits of parts that will facilitate the design and construction of biosensors in the future.

Previous iGEM teams have focused on genetically engineering bacterial biosensors by enabling bacteria to respond to novel inputs, especially biologically significant compounds. There is an unmistakable need to also develop devices that can a) manipulate input by changing the behaviour of the response of the input-sensitive promoter, and b) report a response using clear, user-friendly outputs. The most popular output is the expression of a fluorescent protein, detectable using fluorescence microscopy. But, what if we could simply see the output with our own eyes?

The team successfully characterised a set of transcriptional systems for calibrated output - Sensitivity Tuners. They also successfully expressed a spectrum of pigments in E. coli, designing a set of Colour Generators.

Genetic sequence

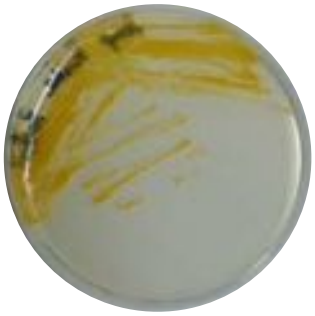


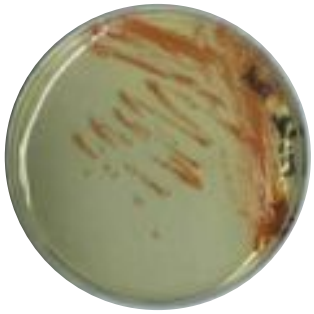
BioBrick DNA

Orange
BBa_K274200

Red
BBa_K274100

Colour expression in E.coli bacteria





Biological Design & Living Colour

Genetic sequence

Green
BBa_K274003

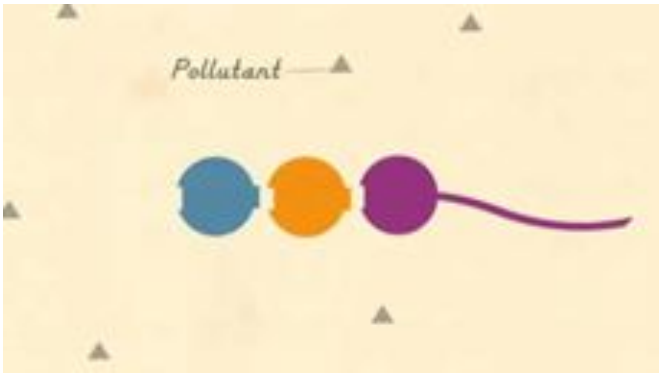
Brown
BBa_K274001

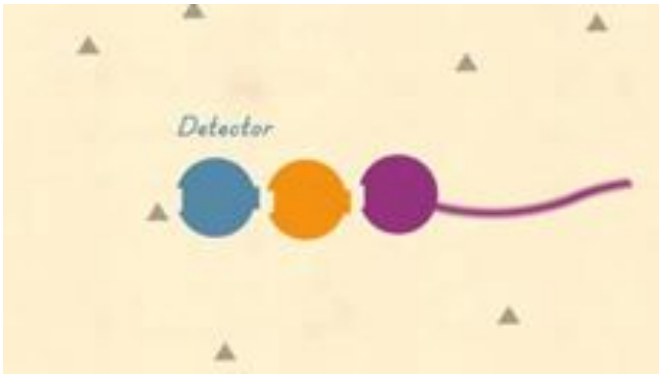
Violet
BBa_K274002

BioBrick DNA

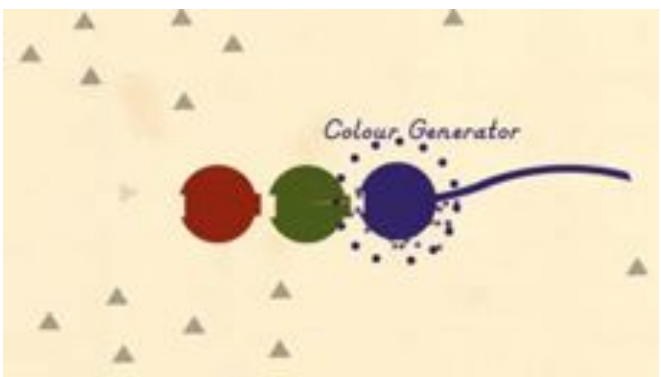
Colour expression in E.coli bacteria

BioBricks are standardised pieces of DNA that can be joined together to design and build new biological systems. In 2009, the seven undergraduates in the Cambridge University iGEM team selected genes from a variety of organisms found in nature. From this DNA, they designed and constructed E. chromi - a kit of BioBricks that can be inserted into E. coli bacteria, modifying them to secrete one of five different colours. E. chromi won the Grand Prize at the 2009 International Genetically Engineered Machine Competition.


Pollutant


Detector


Sensitivity Tuner


Colour Generator

"I'm part of the Cambridge 2009 iGEM team, and our project was called E. chromi. And what we were trying to do is to improve bacterial biosensors. They are bacteria that can tell you the concentration of a pollutant in water, and they can do this because inside them they have a detector. So we developed two different parts, the sensitivity tuner, and this actually tells the detector when to turn on and when to turn off. So you have control over what level of the pollutant you are detecting."

"And how does the bacteria show that it's on or off?"

"We used something called a colour generator, which means our bacteria changed colour when the detector got switched on."

"Wow, so they light up in a different colour?"

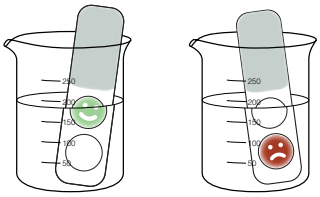
"They actually change colour, visible to the naked eye."

"So lets say, if you put a swab of the bacteria in a polluted river, the bacteria would just change colour?"

"Yup exactly. Though you'd probably want to put a sample of your water on a bacterial plate, maybe not the other way round!"

From an interview with Vivan Mullin, by Ira Flatow NPR Science Friday, see www.echromi.com

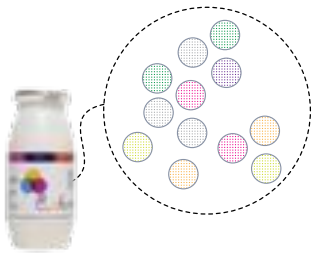
2009



2010

2015

Collaboration



2039

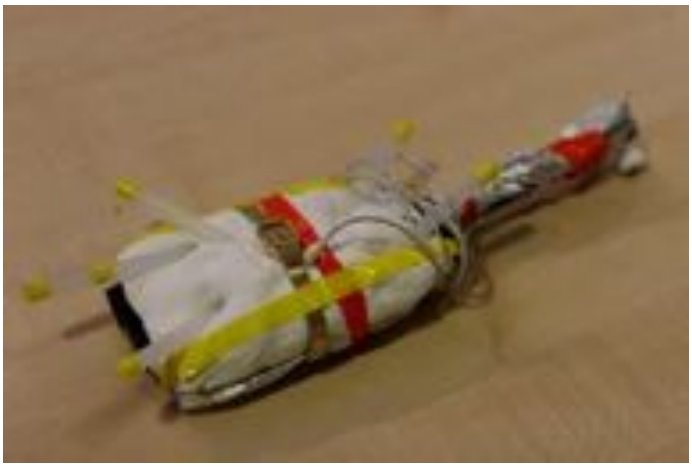
2049

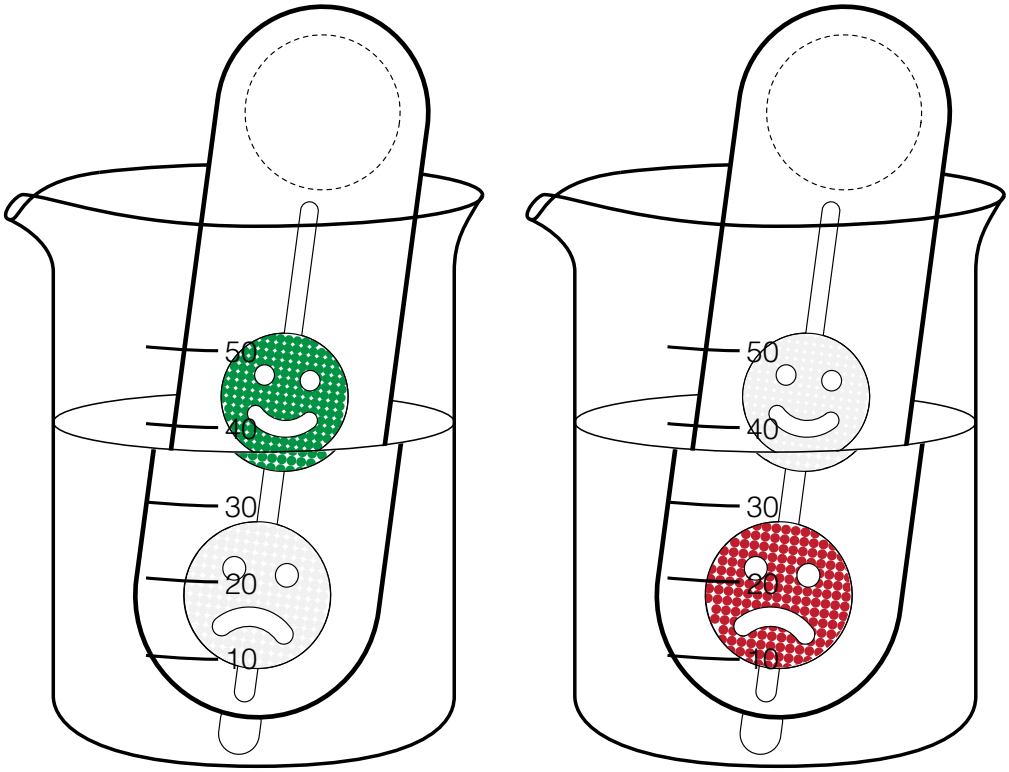
2069

In 2009, the Haseloff Lab at Cambridge invited designers and artists to join in the intensive two week pre-iGEM crash course in synthetic biology that students complete before beginning their iGEM project. Designers Alexandra Daisy Ginsberg and James King learnt with the team, then, as the students developed ideas for their competition project, we thought about how we could contribute to the project, as designers/artists. We worked with the team through a series of workshops over the project period to explore E. chromi's potential, alongside the development of the technology in the lab. Together, we imagined a **timeline** proposing ways that living colour could evolve over the next century. These scenarios, which emerged from the workshops, explore the different agendas that could shape E. chromi's use, and in turn our everyday lives. This work fed back into the overall conceptual direction of the technical lab work.

Workshops


orange
future is not bright unless
it's Orange





2011

Arsenic Detector

Using E. chromi, the first biosensors appear for cheap testing of drinking water in the developing world.


2011
ARSENIC DETECTOR
Using E. chromi, the first biosensors
appear for cheap testing of drinking
water in the developing world.
2019
COLOU

Serinus canaria

BBa_K359801

BBa_K359802

BBa_K359803

BBa_K359804

BBa_K359805

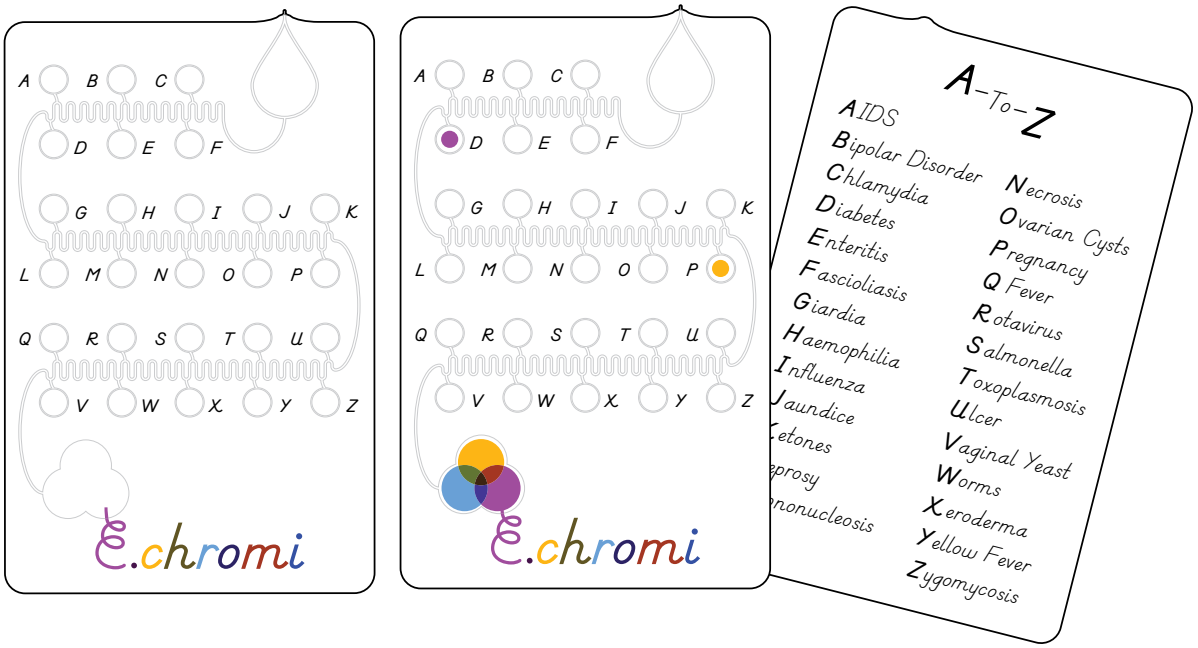
BBa_K359805

2019

Colour Hunters

From canary-yellow M&Ms to melanin-coloured Coke, food colourings are made by bacteria. Professional Colour Hunters scour the biosphere, collecting genes that generate rare pigments to sell to industry.

Timeline



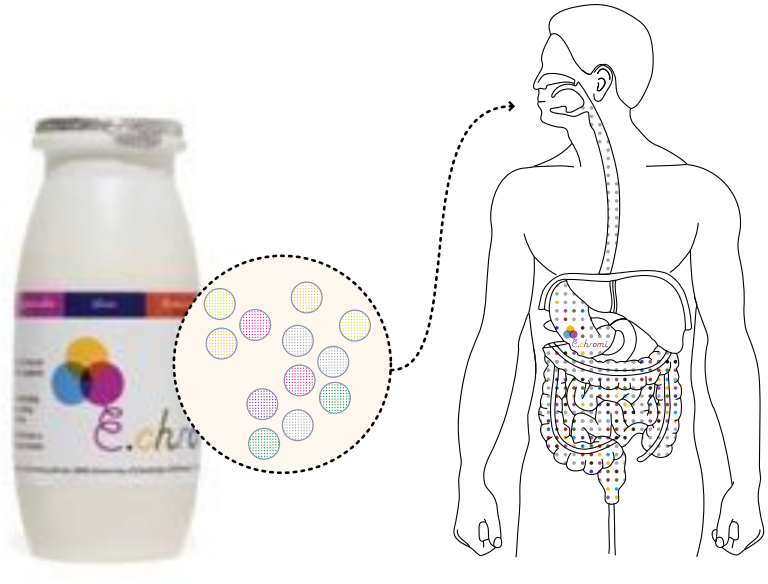
2029

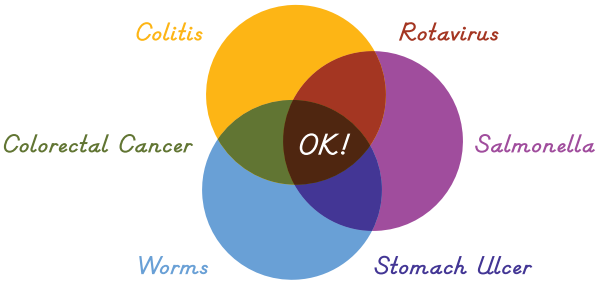
Universal Indicator

Lab-on-a-chip technology impregnated with E. chromi bacteria encourages daily testing for an alphabet of diseases. Checking for AIDS to Zygmycosis, consumers become a little more neurotic.

Timeline


A B C
D E F
G H I J K
L M N O P
Q R S T U
V W X Y Z
E.chromi
A B C
D E F





1. Drink

Synthetic E. chromi bacteria are ingested as a probiotic yoghurt.

2. Colonise

Colonising the gut, the E. chromi keep watch for the chemical markers of disease.

3. Monitor

If a disease is detected, the bacteria secrete an easily-read colour signal, visible in faeces.

E.chromi - cheap, personalised disease monitoring from the inside out.

Timeline

2039

The Scatalog

Cheap, personalised disease monitoring now works from the inside out. Ingested as yoghurt, E. chromi colonise the gut. The bacteria keep watch for chemical markers of diseases and can produce easy-to-read warning signals.

2049

Orange Liberation Front

A Dutch terrorist group protests against the patenting of their national colour, orange. The OLF are threatening to detonate an antibiotic bomb at London Fashion Week, killing all colour in revenge.

Timeline


O.L.F.
FREE THE RAINBOW

2069

Red Sky in the Morning, Google Health Warning

Google releases pollution-mapping bacteria that colour the sky red in zones of excess carbon dioxide. Diplomatic warfare erupts as they drift across international airspace.

Building new life forms at the iGEM Jamboree

By Alexandra Daisy Ginsberg
Published on www.wired.co.uk
09 November 2009

When you're faced with the entire living kingdom as a materials library, what do you design?

With this question in mind, I walked into the 2009 International Genetically Engineered Machines (iGEM) Jamboree, equipped with an aluminium briefcase full of multi-coloured poo. I was with fellow designer James King and the Cambridge University iGEM team: seven rainbow-haired undergraduates who spent their summer engineering a new kind of E.coli that secretes a palette of seven colours, christened E. chromi after a tense online vote.

Three days and 112 presentations of synthetic biological machines later, we found ourselves on stage, electrified, in front of 1,500 people in MIT's largest auditorium as we were presented with the grand prize, a giant milled-aluminium Lego block - the BioBrick - by the founders of synthetic biology.

iGEM, in its sixth year, is growing exponentially. Five teams took part in the first open competition in 2004, and this year 1,700 undergraduates in 112 teams from 26 different countries entered.

"This science is as good or better than at conferences," Tom Knight, one of synthetic biology's founders, told me over supper after the first day, as we swapped science fiction recommendations with the Cambridge professors (Knight's favourite, The Space Merchants, was in my suitcase). "There's an 11-year old entrant this year, but he's sick so can't make it," Knight said. In the end, the 11-year-old sent a video submission of his solo project, the BioBrick-A-Bot, "a Lego robot for automated BioBrick DNA assembly." While I was certainly using Lego at 11, I certainly wasn't using video, let alone persuading university authorities to let me enter genetic engineering competitions. How did we get here, and so fast?

The aim of the competition is to add to the Parts Registry, a squat, mundane-looking freezer quietly humming away upstairs in Knight's lab in the Gehry-designed Stata Centre. This is the only tangible artefact of all the invisible molecular science that happens during the three days of iGEM. The "parts" are interchangeable components of DNA - BioBricks - which the students use to design novel biological systems, inventing new BioBricks as necessary along the way. While the competition is an effective way of filling the freezer's drawers, it is also introducing more students (and universities) to this bright new field, a rebranding of genetic engineering that embraces the engineer's dream of simplicity. At Cambridge University, synthetic biology isn't even on the syllabus yet. And that's how I ended up in Knight's lab, having the door of the ice-filled Registry opened for me by Knight himself.

I first met plant scientist Jim Haseloff in April when I went to ask him about his work for a design project I was working on at the Royal College of Art. Jim - hugely open and innovative - runs iGEM at Cambridge and invited me and three other designers, to join the pre-iGEM crash course in synthetic biology. He was intrigued to see what might happen. I was picked on within the first few minutes: "So, who can define a gene? Daisy, can you?" Um... Since the team comprised two engineers, a physicist, three biochemists and one geneticist, we were all new to synthetic biology.

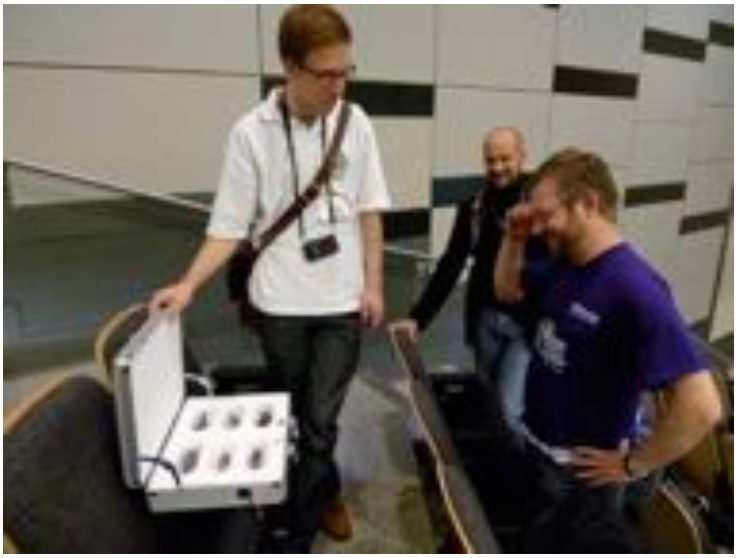
The first slide channelled engineer Theodore von Karman: "Scientists discover the world that exists; Engineers create the world that never was," setting the tone for two intense weeks of lectures and lab practicals to learn the key biology and tools. We ended with a Friday afternoon Dragon's Den of hastily-invented ideas presented to a panel loaded with Synbio Dollars. Back in the lab on Monday, the team's first question was, of course, "What should we design?" Soon, they leapt into designing an entirely new two-part system comprising a sensitivity tuner and seven pigments all derived from the natural kingdoms, an environmental sensor with easy-to-read visual output. Green fluorescent protein eat your heart out.

We visited at intervals during the summer, amazed

Guerilla Intervention at iGEM 2009

We arrived at iGEM as artists/designers, presenting the collaboration, the Scatalog and its contents to everyone we could. From the FBI and the UN, to those developing the technology itself, we asked, “is this a more logical interface for biological computing?”

Interview at iGEM:
http://vimeo.com/7466044




GEM
e.chromi

at how comfortable the team had become in the wetlab, guided by the faculty and iGEM veteran, PhD candidate James Brown. And that's what's so extraordinary about the whole process. In ten weeks, the students have made a serious contribution to cutting-edge science, with the faculty embracing and enabling the imaginations of the next generation of scientists. These students, unaware of the implications when they applied to join, are helping to build the field. Minutes after presenting at the Jamboree, scientists from leading labs were requesting the colour parts the undergrads had designed, Jim proudly told us.

Over the first two days of the Jamboree, mixed teams of engineers, physicists, mathematicians and computer science undergrads (with the occasional biologist) stand up in front of huge audiences and panels of judges to present their inventions, designed and built over the summer, some fully working, many not, but still mind-blowing in concept. In the breaks, they nibble Halloween-themed iced cookies and mingle with world-famous scientists, the FBI (this year's sponsors), a nice chap from the UN handing out badges but probably keeping an eye out for the next generation of synthetic biologists, chief executives of biotech companies, the 50 judges from around the world, social scientists and DIYbio groupies.

As I sit through sessions as diverse as terraforming Mars (Tokyo Tech, engineering iron-oxidising bacteria, adding melanin to tan them and darken the planet, initiating the melting of Martian ice caps while inserting protective antifreeze proteins) or Berkeley's robot-powered generation of more than 800 new parts for their alternative registry, I'm in awe. Valencia designed a bio-screen of electrically light-activated bacteria (the world's first biological 'LCD' screen), Harvard managed inter-species communication between bacteria and yeast using light and Slovenia proved Drew Endy right: synthetic biology is nanotechnology that works.

There are niggles, too, which makes it all the more juicy, as we get glimpses of the hidden agendas in a new field of science. The spirit of the competition is open source, so the overflowing auditorium gasps when the Slovenia team, last year's grand-prize winners, reveal that they have filed three patents. The commercial aspect can't be ignored: entering iGEM is an expensive undertaking, and sponsorship drives the process. Support ranges from promotional T-shirts at the Jamboree to big biotech firms providing free gene synthesis and loans of high-end equipment. And then there's the difficulty of separating the work of the labs from the work of the students, which several judges tell me is one of their most difficult tasks.

Questions aside, iGEM is changing science. Students, whether or not they continue in synbio, are learning completely new ways of working. These multi-disciplinary, fast-paced projects that move from design to realisation over a summer are often their first taste of self-directed research. Design is an integral part of synthetic biology, which is why it was so exciting to see design and art making their first iGEM appearance. Teams built their own DIY equipment - the MIT team couldn't afford two $6,000 LED boxes, so "we made them ourselves".

ArtScience Bangalore, winners of best presentation and my iGEM highlight, are a truly ground-breaking team of art students led by artist/designer Yashas Shetty. The team learnt biology with the help of India's National Centre For Biological Science, producing E. coli that smell of rain. They took synthetic biology to new groups, running workshops to teach designers to build working DIY microscopes using webcams and ran creative workshops at a school for the urban poor. This idea of "human practices" - that is, exploring the ethical and social implications of the technology - was a new focus this year, with Imperial College London and Paris sharing a prize for their substantial surveys.

As for the suitcase full of poo, that was our contribution to the Cambridge project. We infiltrated the competition as designers, helping the team to think outside the petri dish. Through a series of workshops, we considered human-scale applications for their molecular circuits and the long-term implications of their work. The poo - also known as the Scatalog - is one of our proposals inspired by the team's E. chromi: cheap personalised disease monitoring. After our guerrilla activity, we suspect that many teams will have designers in tow next year.

E.chromi was a popular win, truly in the spirit of iGEM. As Jim Haseloff reiterated as we recovered afterwards, eating burritos, "We just want to teach the students about synthetic biology." It is a beautiful, simple and elegantly designed system, thought up by the students and producing visible results, while adding useful new parts to the registry.

So how do the Cambridge team feel now, as they return to normal undergraduate life having presented scientific discoveries to the world? Shuna tells me, "I'd never thought of making biological systems before, of using genes in pathways for my own benefit, and the very 'engineer' way of looking at the devices and models. The experience was the most frustrating, exhausting, draining and amazing thing I've ever done."

I ask Mike if he would continue with synthetic biology, he thought about it and says, with absolute sincerity, "I hadn't considered it, but now, I have a responsibility to continue". I can't help but agree with them both. These students have been given a gift, the potential to design world-changing innovations. It has been amazing to be part of it.

Awards

Grand Prize
International Genetically Engineered Machine Competition MIT, USA 2009

Environment Prize
International Genetically Engineered Machine Competition MIT, USA 2009

Nomination
Brit Insurance Designs of the Year Interactive Category, London 2011

Award Nominee
Index: Design To Improve Life Awards
Denmark 2011

Selected Exhibitions

Talk To Me
MoMA NYC, USA
July 24–November 7 2011

Index: Design To Improve Life Awards
Mobile Exhibition, Denmark & Europe
August 2011– August 2013

What If?
Beijing International Design Triennal
Beijing, China September 28–October 17 2011

Life 2.0
Science Exchange, Royal Institute Australia
Adelaide, Australia April 25–July 8 2011

Brit Insurance Designs of the Year
Design Museum London, UK
February 16–August 2011

Becoming TransNatural
Trouw Amsterdam Netherlands
March 4–April 1 2011

Wellcome Trust Internal 'street-fair'
Wellcome Trust HQ London, UK
December 15 2010

Prédiction
St Etienne Biennale Internationale Design France
November 20–December 5 2010

Nano Supermarket by Next Nature
Dutch Design Week, Eindhoven, Netherlands
October 2010

Guerilla Science
Secret Garden Party, Cambridgeshire, UK
July 22–25 2010

Wellcome Trust Windows
Wellcome Trust HQ London, UK
February 1–July 20 2010

iGEM Jamboree 2009
MIT Cambridge, USA
November 2010

Selected Press

What if you could gauge your health with colour coded poo? John Pavlus
www.fastcodesign.com USA
April 7 2011

Design in Synthetic Biology
Kyoko Nakajima
Axis Design Magazine, Japan
May 2011

Spiel mit Genen und Genesis
Kai Kupferschmidt
Die Zeit/Der Spiegel Germany
March 1 2011

A Broader View of Practice
James Pallister
Architects Journal UK
March 24 2011

E Chromi: embedding design in scientific research
London Design Festival Blog
February 14 2011

How to humanize technology--from the scatological to the sublime Laura Neuhaus
Scientific American USA
January 28, 2011

Fresh as a Daisy
Feature on Biomedical Art by Paola Antonelli,
Nature Medicine
16, 942, October 2010

Talk To Me, MoMA blog,
By Kate Carmody May 17, 2010

Science and Design
Mun-Keat Looi
Wellcome Trust Blog UK
April 06 2010

Technicolor doo-doo
Ariel Bleicher
The Scientist USA
December 11 2009

Building New Life Forms at the iGEM Jamboree
Alexandra Daisy Ginsberg
Wired.co.uk UK
November 9 2009

Students Build Living Microbial Machines
Science Friday National Public Radio, USA
November 6 2009

Our collaboration meant that E. chromi was a technology that was designed from the start at both the genetic and the human scale, and with a long-term outlook. We found that design and science could have meaningful exchange in the lab, which could prove useful when developing technologies in the future.

E.chromi is acting as a precedent for new and emerging collaborations between art, design and synthetic biology, and new ways for designers and artists to work with science.

Future

With many thanks to Jim Haseloff and the faculty, the Haseloff Lab, University of Cambridge, iGEM and the iGEM 2009 team.

The iGEM Team
Mike Davies • Engineer
Shuna Gould • Biochemist
Siming Ma • Biochemist
Vivian Mullin • Biochemist
Megan Stanley • Physicist
Alan Walbridge • Engineer
Crispian Wilson • Geneticist

Science Advisors
Dr Jim Ajioka
Dr Jim Haseloff
Dr Gos Micklem
Dr Duncan Rowe
James Brown
Dr Tom Ellis

Design Advisors
Alexandra Daisy Ginsberg
James King

Social Scientist
Caitlin Cockerton: London School of Economics

Additional Credits
Animation: Cath Elliott, Little Giant Pictures
Illustration: Alice Hoult
Animation Music: Matthew Irvine Brown
Photography: Douglas Adesko, Brian Appleyard/ iGEM HQ, James Brown, Caitlin Cockerton, Jim Haseloff, Daisy Ginsberg, James King, Ösa Johannesson

E.chromi

www.echromi.com

Artist/Designer Biographies

Alexandra Daisy Ginsberg is an artist, designer and writer, using the medium of design to examine the social, ethical and cultural implications of emerging technology and science.

Through intensive research into synthetic biology, Daisy is exploring the role of design in a Biotech Revolution. Now Design Fellow on Synthetic Aesthetics, an NSF/EPSRC-funded project at Stanford and Edinburgh Universities, she is curating an international programme researching the shared and shifting territory between synthetic biology, art and design.

Daisy studied Architecture at Cambridge University, design at Harvard University, and has an MA in Design Interactions from the Royal College of Art. Recent works include The Synthetic Kingdom, a proposal for a new branch of the Tree of Life and E.chromi, a collaboration with design James King and Cambridge University's winning team at the 2009 International Genetically Engineered Machine competition (iGEM). Daisy exhibits her work, lectures and publishes internationally.
www.daisyginsberg.com

James King is a speculative designer working in the field of biological science to investigate the implications of future biotechnologies.
James collaborates with scientists and works between the lab and studio to design potential applications for their research. Together they imagine what might be possible if technologies developed in the lab become adopted by people in their everyday lives. This results in objects, films and images that are exhibited in order to elicit debate on the desirable and undesirable qualities of future biotechnologies.

James' work has been shown widely. Most notably in MoMA's Design and The Elastic Mind exhibition in 2008 and at the Wellcome Trust in 2010 and reproduced in many publications such as Wired, SEED and The Guardian. Subsequently his project, Dressing the Meat of Tomorrow, was acquired into MoMA's permanent collection. James has also presented his work at several scientific meetings and conferences throughout 2009 and 2010.
www.james-king.net