Synthetic biology dialogue – Have your say

A Guide for Teachers

May 2017

www.students.synenergene.eu

About this Resource

Our work aims to unpack some of the personal and societal values that sit alongside synthetic biology, an emerging field of science. With this dialogue, we hope that participants will develop an understanding of their individual and collective agency in shaping the future direction of science and of synthetic biology in particular. This material is intended to give teachers a starting point for their own research and to base their lessons on. It covers a general introduction into 'What is Synthetic Biology' supported with exercises and resources looking at some of its applications. Students are encouraged to research and reflect on the different benefits of the science, its risks and power dynamics. Whilst the dialogue will work as a stand-alone intervention in class, the following resources are intended to help you frame the intervention within the classroom in order to maximise student learning and engagement.

This document should be used in conjunction with the Online Consultation Specification Sheet which covers the basics of how to use the platform.

This resource has been adapted from:

Synthetic biology: a deliberation aid: https://www.forumforthefuture.org/sites/default/files/files/93021%20BBSRC%20Synbio%20Deliberation%20Aid%2016%20July(3).pdf

Overview of contents

1. Introduction

1.1 What is SYNENERGENE?

SYNENERGENE is a four-years mobilization and mutual learning action plan (MMLAP) supported by the European Commission under the 7th Framework Programme. The project aims to contribute to Responsible Research and Innovation (RRI) in synthetic biology by establishing an open dialogue between stakeholders concerning synbio's potential benefits and risks, and by exploring possibilities for its collaborative shaping on the basis of public participation.

1.2 What is synthetic biology?

Synthetic biology represents the latest phase in the development of biotechnology, in which scientists are gaining unprecedented control in programming new biological functions by rewriting the genetic code. This allows them to 'design' and 'create' micro-organisms that may perform a variety of useful tasks. At the same time these organisms are becoming increasingly more estranged from those we may find in nature.

(by Virgil Rerimassie (Rathenau Institute) and Harald König (KIT) [extract])

1.3 What is the aim of this particular online consultation?

This project seeks to:

- give insight into synthetic biology and to what it might mean for the lives of young people as future citizens, producers and consumers.
- support students in developing, expressing and exchanging perspectives on synthetic biology and more broadly the role of science and technology in their lives.
- engage in dialogue with world leading scientists and to share the results and invite them into the conversations with young people.

The consultation will launch on 2nd May 2017 and will be open to a range of participants aged 11-25 in the UK, Germany as well as several other countries. It will be open until 21st May 2017. Using a range of media from video to text, the dialogue will introduce participants to synthetic biology and some of its applications in the context of a future bio-economy.

Engagement with the dialogue will initially last between 20-40mins. Students can return to the consultation at any time and discuss and refine their responses with other participants including the scientists. No prior knowledge is assumed, as students contribute their thoughts and feelings, world leading experts will take part

with theirs alongside answering questions. The initial results of the dialogue will be analysed and shared with schools by the 16th June and complete results published online later in the year. Results will also be fed into policy documents from the organisers of the dialogue, the SYNENERGENE project.

2. Teaching Resources

2.1 Introduction to Synthetic Biology

Biologists study life, specifically organisms and their relationship to their environment.

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Engineers solve problems using science and math. They use an engineering design process, which is a series of steps towards solving a problem.

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Synthetic biologists solve problems by applying engineering principles to biology.

Synthetic biology represents the latest phase in the development of biotechnology, in which scientists are gaining unprecedented control in programming new biological functions by rewriting the genetic code. This allows them to 'design' and 'create' micro-organisms that may perform a variety of useful tasks. At the same time these organisms are becoming increasingly more estranged from those we may find in nature.

Synthetic biologists look at biology from an engineering perspective. In the words of synthetic biology pioneer Drew Endy, up to now in biology it was always 'nature at work'. However, 'if you consider nature as a machinery, then you can see that she is not perfect and she can be revised and improved'.

Given synthetic biology's potential to contribute to addressing grand challenges societies are facing, such as regarding health, sustainability, scarcity of resources and energy security, it is no surprise that this new discipline has been embraced by scientists all over the globe. On the other hand, like any other science and technology synthetic biology is not without risks. In addition, synthetic biology may raise moral questions and concerns, since it allows mankind to put 'life' and 'nature' on the drawing board like never before.

Haven't we been doing this already?

Does synthetic biology really provide different options from those genetic engineering technologies that we already knew? Although there are overlaps between approaches of 'traditional' biotechnology and synthetic biology, new options are emerging. In biotechnology, up to now, scientists mostly enhanced existing biological functions or transferred them between organisms, based on the modification or transfer of one or very few genes. Synthetic biology approaches allow the combination of multiple genes, newly constructed 'biological parts' or the use of non-natural molecules to construct new biological pathways, functions and (in the future)

entire organisms, that have no blueprint in nature. The construction of such complex functions is facilitated by the chemical synthesis of whatever DNA sequence as well as by rational design processes that are increasingly guided by computer-based modelling.

(by Virgil Rerimassie, Rathenau Institute, the Netherlands, and Harald König, Karlsruhe Institute of Technology, Germany)

The following two videos provide a brief introduction to the science and history of synthetic biology, helpfully capturing the current costs and current applications of the science. They cover similar material.

video 1: https://youtu.be/UHBdEwNbXI0

video 2: https://youtu.be/mlOFE9-3CN0

Both the videos are there to provide an introduction into Synthetic Biology. Whilst they cover similar materials, the second video, made by Grist, is on the whole more balanced, whereas the first Video made by the Freudenthal Institute, is solely a technical explanation. That is, it is a 'really, really cool' portrayal of synthetic biology (as the Grist video terms it), particular from 5 minutes onwards. For instance growing tree houses is not a realistic application of synthetic biology, terraforming Mars is unlikely, and even the malaria vaccine and biofuels do not consider the numerous externalities, such as expansion of sugarcane/food-fuel crops (responsible for deforestation/poor labour conditions) needed to produce these products or the fact that small farmers around the world already produce malaria vaccine!

You might want to consider introducing 'other voices' on the Science into your class for example this video from SynBio Watch, a Civil Society Organisation that aims to offer critical perspectives on the synthetic biology industry grounded in ethics and social, economic, and ecological justice. This video is a useful resource as it starts to ask questions of some of the externalities. I.e. how will society use this science, and what could some of the potential negative impacts be?

video 3: https://youtu.be/C726wUGLdL4

(also available in Spanish, Portuguese and French versions from: https://www.youtube.com/channel/UCMIEsye5eODSoiBB8MhgCng)

Further reading:

- Brief introduction to synthetic biology for a science museum audience by the Building with Biology project: http://buildingwithbiology.org/about-syn-bio

- Ethical considerations of synthetic biology and biodesign: https://www.scu.edu/ethics/focus-areas/technology-ethics/resources/ethics-of-biodesign/
- Discussion of ethical implications: http://www.swr.de/swr2/wissen/synthetische-biologie/-/id=661224/nid=661224/did=12163514/bym3jz/ (available in German only)

2.2 Engaging with the themes of the dialogue

The dialogue will introduce participants to synthetic biology and some of its applications in the context of a future bio-economy. We will focus on the following five areas of application:

- Palm Oil Substitutes
- Bio Economy
- Future Food
- Health
- DIY Biology

In the following sections, we present a case study for each area that was chosen to stimulate debate about the ethical dilemmas posed by applications of synthetic biology.

2.2.1 Palm Oil Substitutes

Case study: Ecover and the palm oil substitute from Solazyme/TerraVia

With the help of synthetic biology, algae strains or microorganisms can be modified genetically to produce various kinds of oil. The company Solazyme (now renamed as 'TerraVia') has been claiming their algal oil could serve as a substitute for natural palm oil. A company producing eco-friendly household products (Ecover) has decided to use this substance in their products, but has halted its development after campaigns from NGOs criticized the use of genetic engineering methods in eco-products. The NGOs point to the potential social and ecological problems raised by the production based on synthetic biology (global justice, risk of environmental release, weakening of eco-labels).

Further reading:

- The New York Times on the Ecover case: https://www.nytimes.com/2014/05/31/business/biofuel-tools-applied-to-household-soaps.html

- The Dutch Rathenau Institute on the Ecover case: https://www.rathenau.nl/en/publication/industrial-biotechnology-under-spotlights
- The critical NGO Biofuelwatch on Solazyme's oil: http://www.biofuelwatch.org.uk/wp-content/uploads/Synbio-and-Palm-Oil-Briefing.pdf
- Informationsdienst Gentechnik: Ecover wegen Synbio-Waschmittel in der Kritik: http://www.keine-gentechnik.de/nachricht/29206/

2.2.2 Bio-economy

At the moment, we live in a petroleum-based economy. The question is how long it can continue. The bio-economy is a highly promising prospect for a more sustainable economy. The underlying premise of the bio-economy is that biomass will constitute the key feedstock and photosynthesis will be the most important production mechanism. Biomass consists of plants, wood, and algae, but also of offal. These ingredients are fed into the process of biorefinery, where enzymes or bacteria help convert them into sugars, fibre, proteins and synthetic gas, the components of products such as biofuels, bioplastics and medicines.

Case study: Second generation biofuels

To avoid conflicts that may originate from the limited availability of biomass ('food vs. fuel?'), synthetic biologists strive to make useable lignocellulose – the non-edible component of plants – for the use in the production of biofuels. Specifically designed microorganisms should help metabolise lignocellulosic biomass in fermentation processes. Another idea is to modify microorganisms (e.g., algae) to directly produce the desired fuels (or their chemical predecessors). But the viability and efficiency of such procedures still have to be proven.

Further reading:

- Newsweek report about algal biofuels: http://www.newsweek.com/2015/03/20/promises-and-perils-synthetic-biology-312849.html
- Critical view by the NGO Biofuelwatch: http://www.biofuelwatch.org.uk/2016/mascoma-report/
- Rathenau Institute, Report: 'Getting to the core of the bio-economy' (pp. 24-25): http://groupedebruges.eu/sites/default/files/publications/downloads/report_bio based_economy.pdf#page=24

2.2.3 Future food

Food production is a traditional application area for genetic engineering. Consequently, synthetic biology has many potential applications in agriculture. For some people it's the reason for big expectations, for others to be cautious.

The applications range from genetically changing plant or animal traits to enhance the productivity or the reliability of agricultural production to attempts to replace agricultural products such as those from livestock by synthetically produced ones, for example 'animal-free dairy products'. Applications also include attempts to restore or at least improve the quality of contaminated soils by deploying specifically engineered microbes (bio-remediation). Proponents of synthetic biology applications in agriculture point to the challenges posed by an increasing world population, on the other hand, critics are concerned about the impact of synthetic biology food on our health and about environmental issues in case of environmental release.

Case study: 'Cow-free' milk

The company 'Perfect Day' is developing what they call 'cow-free' milk. The product is made using milk proteins derived not from cows, but from genetically modified yeast. The results of the fermentation process is said to be similar to milk in terms of taste and texture. The company claims that its production process is 'more humane, eco-friendly, and sustainable than industrial dairy production'. This application is still in R&D and not yet in commercial use.

Further reading:

- Report about lab-grown milk in National Geographic: http://news.nationalgeographic.com/news/2014/10/141022-lab-grown-milk-biotechnology-gmo-food-climate/
- Story about the company in Fortune: http://fortune.com/2016/08/31/animal-free-cows-milk-perfect-day/
- Critical comments by the Organic Consumers Association: https://www.organicconsumers.org/essays/cow-free-milk-false-solution-industry-agriculture
- Overview (and critique) of various applications of synthetic biology in agriculture: http://etcgroup.org/sites/www.etcgroup.org/files/files/outsmart_a4report_v5_0.pdf

2.2.4 Health applications

An increased understanding of human health at the molecular level, combined with increased options for manipulating genomes – this mixture stimulates many hopes for improvements in medicine fuelled by synthetic biology. For example, synthetic biology and genome editing could offer new forms of gene and gene-based therapies against HIV or cancer, and infectious diseases such as malaria or zika could be fought against by genetically manipulating their carriers, such as mosquitoes, using so-called gene drives. Synthetic biology is already used to improve the bio-detection of diseases with the help of new low-cost diagnostic tools and to produce vaccine or medicine components by means of bio-synthesis – yet it has not proven to be able to compete under market conditions and the impacts of gene-based therapies and gene-drives are still unclear.

Case study: Paper-based diagnostics

Synthetic biologists have successfully engineered gene circuits, that is, a couple of genes plus the proteins needed to read those genes that work together like an electronic circuit to perform a task. Synthetic gene circuits have been used to build biosensors to detect a wide range of molecules, such as arsenic in drinking water or viral pathogens in blood. By freeze-drying the gene circuit, researchers have been able to create a paper-based diagnostics system for diseases such as zika (though still under development).

Further reading:

- The Genetic Literacy Project on paper-based diagnostics: https://www.geneticliteracyproject.org/2016/05/26/synthetic-biology-on-a-piece-of-paper-brighter-future-for-disease-diagnostics/
- Short press article about paper-based diagnostics (including introductory video): http://newatlas.com/low-cost-paper-based-zika-test/43229/
- Longer article in The Atlantic on paper-based diagnostics: https://www.theatlantic.com/science/archive/2016/10/to-make-vaccines-anywhere-just-add-water/503525/

2.2.5 DIY Biology

Do-it-yourself biology (DIYbio) is the application of synthetic biology principles or methods in contexts outside of established research institutions (also dubbed ‘garage biology’, ‘biohacking’ or ‘homemade genetic engineering’). Its proponents strive to make the technology accessible to everybody and often also support ideas of open innovation, open access, or the democratization of science (‘citizen science’). While it is not clear what can actually be achieved by ‘hobby’ synthetic biologists, the idea also raises concerns about the safeguarding mechanism (knowledge about dangers

among the protagonists as well as precautionary measures in the 'labs') and whether biohackers will conform to regulation of genetically modified organisms (GMOs).

Case study: 'Glowing Plants' project

In 2013 some hobby scientists from a hacker space in the Silicon Valley embarked on a project to genetically engineer plants to glow in the dark by inserting genes from fireflies into them. The project was a huge crowdfunding success on Kickstarter, but almost immediately gave rise to concerns about regulatory loopholes in crowdfunded science. The project transformed into a company, the company was included in a prestigious incubator programme, but up to now, it did not produce any glowing plants. The company lately shifted its focus on producing 'fragrant moss'. Despite the creativity and money invested in this project, actually engineering plants to show a desired behavior seems not as easy as the DIY movement claims.

Further reading:

- Original Kickstarter campaign: https://www.kickstarter.com/projects/antonyevans/glowing-plants-natural-lighting-with-no-electricit
- ETC group's 'Kickstopper' campaign against the project: http://www.etcgroup.org/kickstopper
- Nature news (2013) on the controversy: http://www.nature.com/news/glowing-plants-spark-debate-1.13131
- Report in Austrian journal 'Die Presse' about the controversy: http://diepresse.com/home/science/1415176/Biologie_Die-Erde-mit-Pflanzen-illuminieren?_vl_backlink=/home/science/index.do (Available in German only)
- Report in Technology Review (2016) on current status of the project: https://www.technologyreview.com/s/601884/why-kickstarters-glowing-plant-left-backers-in-the-dark/
- Short animation about 'bioluminiscent streetlamps' by Rathenau Institute: https://www.youtube.com/watch?v=xGQ6Cp1dC4c&t=3s
- Report on biohacking 'party' at a festival: http://www.popsci.com/sxsw-2015-i-made-recombinant-dna-someones-kitchen-while-drinking-beer
- Report on biohacking as democratizing biotechnology: http://blogs.plos.org/synbio/2016/05/03/synbio-democratizing-biotechnology/

3 Additional Resources

- SYNENERGENE's Synthetic Biology Learning Platform: http://www.fi.uu.nl/synenergene/

  - Classroom activities: Lesson modules and teaching materials
  - Activities for informal settings: Non-school-based materials and events on synthetic biology
  - Auxiliary materials: Guidelines, manuals and tips for dialogue
  - Subject information: Basic and more in-depth information about synthetic biology
  - Socio-ethical aspects: Information on the potential impact of synthetic biology on society

- Building with Biology 2016 Kit: http://www.buildingwithbiology.org/digital-kit-contents

Building with Biology

The kit was designed to help museum and scientist partners engage public audiences in conversations and hands-on activities about the field of synthetic biology and the ways this emerging technology is interconnected with society.

Contents are free to download.

- Forum for the Future: Synthetic biology deliberation aid: https://www.forumforthefuture.org/sites/default/files/files/93021%20BBSRC%20Synbio%20Deliberation%20Aid%2016%20July(3).pdf

A collection of supporting materials and deliberative questions to help individuals and groups interested in engaging with synthetic biology to consider a broad range of risks and opportunities and a variety of perspectives on them.

3.1 Example Exercises

Example one:

Pick one of the innovations described above. Using the resources provided, and others if you like to research more about the innovations. Discuss the following questions with your team and present this back to the class. You may like to use the prompts below.

- Does this application contribute to solving any of the major challenges of our time? (i.e. poverty, inequality, malnutrition, access to safe water etc.);
- Are there other ways to solve these problems? (i.e. changing consumer behaviour, enhancing existing technologies)
- Who will benefit from the innovation? And how will they benefit? (i.e. how will industry benefit? Which populations will benefit and how? Will it make the world a fairer place?)
- How does the application impact on people's livelihoods? (i.e. Could it cause long term unemployment? Will it empower or disempower communities?)
- How does this application impact on our natural environment? (i.e. can it be contained in development and use? What would the consequences be if released beyond what is intended? Does the product enhance or challenge biodiversity in anyway?)
- How readily can the application be withdrawn or effects reversed? (i.e. how can the application be withdrawn? What might it take to recall or reverse?)

- What ownership model is in place? (i.e. who owns the Intellectual property? How are contributors recognized? What regulations are in place to cover major risks now and in the future? Who owns these?

Parts of this resource have been adapted from: Synthetic biology: a deliberation aid: https://www.forumforthefuture.org/sites/default/files/files/93021%20BBSRC%20Synbio%20Deliberation%20Aid%2016%20July(3).pdf

Example two:

Create your own synthetic biology innovation

Imagine you are the working within the research and innovation department within SynBio an organisation at the forefront of synthetic innovations working across all sectors including Health, the Environment, Industry and Culture.

Working in pairs/small groups come up with your own innovation inspired by the synthetic biology examples. You may like to follow the steps below:

Step one: Develop a mind-map of different ideas and possibilities. The key thing here is to not edit your ideas, everything gets captured/written down no matter how wild or seemingly impossible. Start with big questions like:

- What problem would you like to solve? (i.e. Famine, Climate Change). Or what new product would you like to make? (i.e. new materials for fashion)
- What ideas could help solve these problems?

Step two: Once you have a list of ideas. Agree as a group which ideas you want to take forward are there any that stand out? Could you combine a number of your ideas together to make one innovation? Once you have agreed give your innovation a name and a short description of what it does.

Step three: Use the prompts overleaf to create a five minute presentation on your innovation to the rest of the class. Remember the aim here is not to 'sell' the innovation but to look at the pros' and cons' of the innovation. What purpose does it have? What problem is it trying to solve? What are the positive consequences? Are there any negative consequences?

3.2 Films from the BIO·FICTION Science Art Film Festival

The BIO·FICTION Science Art Film Festival took place in Vienna from 23-25 October, 2014 (http://bio-fiction.com/2014/). It featured an international short film competition with 52 shortlisted films covering synthetic biology from an artistic and/or philosophical perspective. The films are not necessarily related to current

applications of synthetic biology, but rather explore the space of possibilities that is opened up by synthetic biology. The films have stimulated public debate at the film festival and at more than 30 screenings of the 'BIO·FICTION on tour' around the world. The following selection of films can be used in the context of classroom activities on synthetic biology (previewing is recommended, discussion afterwards is mandatory):

Bioluminiscent Streetlamps
(by Steven van Eekelen; 02:22; https://www.youtube.com/watch?v=xGQ6Cp1dC4c)

Reinventing the Dodo
(by Steven van Eekelen; 03:08: https://www.youtube.com/watch?v=lw-2886-Ft8)

Copy & Clone
(by Louis Rigaud; award winner 2014; 03:15; https://vimeo.com/110381374)

Quanticare
(by Amy Congdon, Jenny Lee, Ann-Kristin Abel; 02:23; https://vimeo.com/57805216)

The Arsehole Gene
(by Eric Romero; 06:48; https://vimeo.com/68730448)

New Mumbai
(by Tobias Revell; award winner 2014; 09:17; https://vimeo.com/110383932)

Hybris
(by Arjan Brentjes; award winner 2014; 06:22; https://vimeo.com/110386857)

- Synbio Ads London
(by Benedikt Groß; 01:36; https://vimeo.com/40592029)