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ENGAGING WITH SYNTHETIC BIOLOGY

TOOLKIT

Introduction

Synthetic biology (SynBio) is an emerging area of science in which scientists 'design' and 'create' micro-organisms that may perform a variety of useful tasks. Production of cheap medicines, clean energy or even food, SynBio seems to have huge potential for applications in many fields. But it also raises numerous challenges and questions.

As an emerging field, public knowledge of the technology is poor. It is thus essential to establish an open dialogue between stakeholders regarding SynBio's potential risks and benefits for society and to explore the possibilities for its collaborative shaping on the basis of public participation.

The toolkit was developed by the partners of the European project Synenergene. It has been created based on the outcomes of a 'knowledge sharing and mutual learning workshop' that was held in Brussels in April, 2014. At this workshop the Synenergene partners and science centers and museums involved in the project came together to share their expertise on SynBio. The outcomes of the fruitful discussions held in Brussels have been fed into this document; the toolkit constitutes a common effort of project partners to compile some guidelines and best practices on SynBio public engagement, informal learning, challenges in scientific research and ELSA (ethical, legal and social aspects).

What will you find in this toolkit?

This toolkit can be used as a 'guidebook' on what is synthetic biology, what are its potential applications and issues, what ethical and societal questions it raises, and how to engage the public in related activities.

As the Synenergene project goes on until 2017, the toolkit will be fed with public engagement experiences, ideas, and results of activities and projects developed around synthetic biology. Seven science centres and musems are involved in the project. In 2015 and 2016, they will organise various events related to SynBio and will operate as neutral places for science and society stakeholders to meet and discuss around SynBio. Learning activities, education kits, forums, laboratory activities, science cafés, theatre, film festivals… different means will be used and tested. The experiences, best practices, and tips will be shared.

What is the aim of the toolkit?

The toolkit aims at giving basic information, tips, and feedbacks about synthetic biology as a socio scientific issue and experiences held in the field of public engagement. At the end of the Synenergene project, the toolkit will synthesize and relate some of the experiences of science centres and museums involved in the organization of public activities on synthetic biology within the project.

Who is this toolkit for?

This toolkit is aimed at science communicators or anyone interested in getting involved in communicating about synthetic biology to the public or starting public engagement activities in SynBio.

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About the Synenergene project

Synenergene is a European funded project that aims to establish an open dialogue between science, industry, society, policy, education and art on the potential risks and benefits of SynBio. The project also explores the possibilities for a 'collaborative shaping' of the field by developing activities in order to raise public awareness of SynBio and involve citizens in the development of future European policies.

Synenergene is a four-year mobilization and mutual learning action plan (MMLAP) supported by the European Commission under the 7th Framework Programme "Science in Society". In these MMLAP projects, key to an open dialogue is a mutual learning process. By understanding each other, sharing ideas and knowledge between stakeholders, participants in science communication activities will learn from and with each other. This will result in a better understanding of SynBio, stimulate reflection, and foster responsible research and innovation within the field.

Synenergene project has received funding from the European Union´s FP7 Framework Programme for Research and Innovation (SiS.2012.1.2-1) under the grant agreement No. 321488.

1. Synthetic biology

Within this chapter, synthetic biology (SynBio) will be outlined, including a description of the techniques employed. Some examples of SynBio results that could be used in public engagement activities will also be highlighted.

1.1. What is SynBio?

The idea of SynBio has been around for the last few decades. Although, in reality, SynBio has only become an **emerging area of research** over the past five years or so.

There is currently **no set definition for SynBio**. During the knowledge sharing and mutual learning workshop held in Brussels 8-9 April 2014, Professor Winfried Römer (Freiburg University) defined synthetic biology as:

- The engineering of biology
- The synthesis of complex, biologically-based (or -inspired) systems which display functions that do not exist in nature
- The design of 'biological systems' in a rational and systematic way

A report produced by the **European Commission in 2010 defines SynBio as**:

1) "Designing and making biological parts and systems that do not exist in the natural world using engineering principles"
2) "Redesigning existing biological systems, again using engineering principles"[1]

When thinking about designing a new 'living system', interesting results could be expected from boosting its efficiency and creating valuable new functions. In reality, biological systems are innately complex, and understanding of them is still growing, meaning **production of new biological systems in SynBio is in its early stages.**[2,3] With the development of biotechnology and genetic engineering, the information and techniques are now available for SynBio to advance.

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[1] '*Synthetic Biology: From Science to Governance*' report, (production from a workshop organised by the European Commission's Directorate-General for Health and Consumers), Belgium, 2010, http://ec.europa.eu/health/dialogue_collaboration/docs/synbio_workshop_report_en.pdf

[2] Serrano L., 2007

[3] Endy D., 2005

1.2. What are the differences between genetic engineering and synthetic biology?

Hasn't this been done already? Does synthetic biology really provide different options from the one offered by genetic engineering technologies? Although overlaps exist between approaches of 'traditional' biotechnology and synthetic biology, new options are emerging. Up to now, biotechnology researchers mostly enhanced existing biological functions or transferred them between organisms, based on the modification or transfer of either one or a few small number of 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.[4]

Synthetic biology is sometimes called extreme genetic engineering, a notion coined and popularised by Synenergene partner ETC Group (Canada). This goes beyond simply gathering insight in or reproducing the behaviour of natural systems – **it builds novel biological systems from scratch or redesigns existing ones**, with expanded, enhanced and controllable properties.

1.3. Developments

The falling cost of DNA sequencing technology has resulted in a wealth of genetic analysis and studies of natural organisms. The data obtained have been deposited in large **databanks that are publicly available online**. These databanks consist of individual gene sequences that can be thought of as 'building blocks'. DNA synthesis technology has also become increasingly affordable. These technological advances imply that **genes can now be synthesised from scratch, and assembled to build entirely new strands of DNA** that do not exist in nature.

This is where the field of SynBio comes in: engineering principles are used to combine these building blocks into complex systems, creating new biological systems that solve tangible problems.

The field is said to have great potential, comparable to the very early days of the computer industry's development. SynBio based biological systems could have applications in numerous industries including the production of biosensors, therapeutics, biofuels, pharmaceuticals and novel biomaterials.

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[4] Virgil Rerimassie, Rathenau Institute and Harald König, KIT, 2014, www.synenergene.eu

1.4. Approaches

Numerous approaches are emerging in SynBio. Two of the main approaches are outlined below.

The bottom-up approach

The bottom-up approach involves **piecing together small biological parts** to create a bigger, more complex system. This includes the creation of a biological system from scratch. Synthetic chromosomes are produced by synthesising and assembling genes.

For these methods to be successful, a deep understanding of biological processes is needed. SynBio is therefore directly linked to studying biological systems that answer questions such as how life could have emerged on Earth, and whether biological processes, and ultimately 'life', could be built in different ways (e.g. using different molecules or chemical processes).

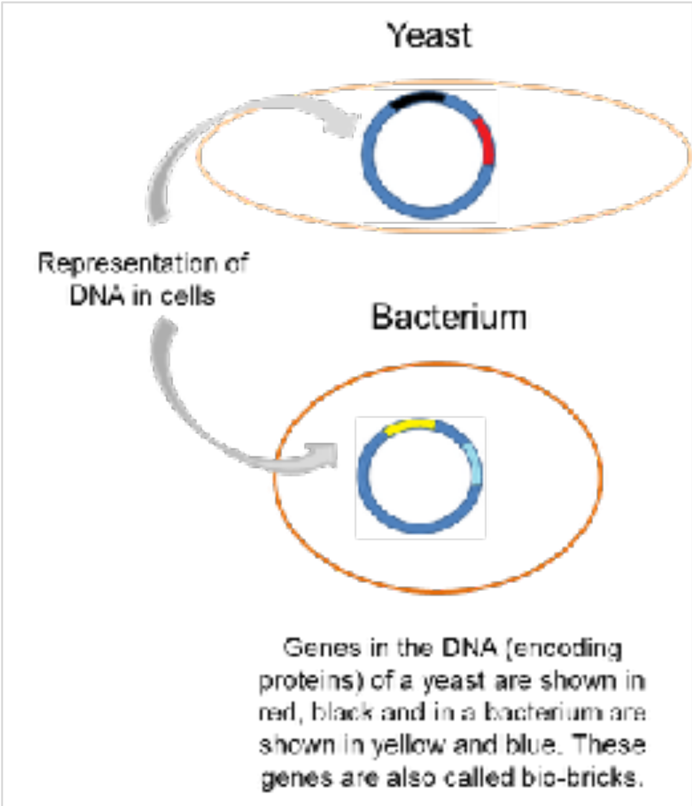
The top-down approach

In the top-down approach, **existing organisms are broken into parts and reduced** to the minimum form capable of survival and easy manipulation. Biological features are then rearranged to **endow these basic organisms with biological functions** they do not possess in their natural state.

Illustration of the top-down approach in SynBio in three steps

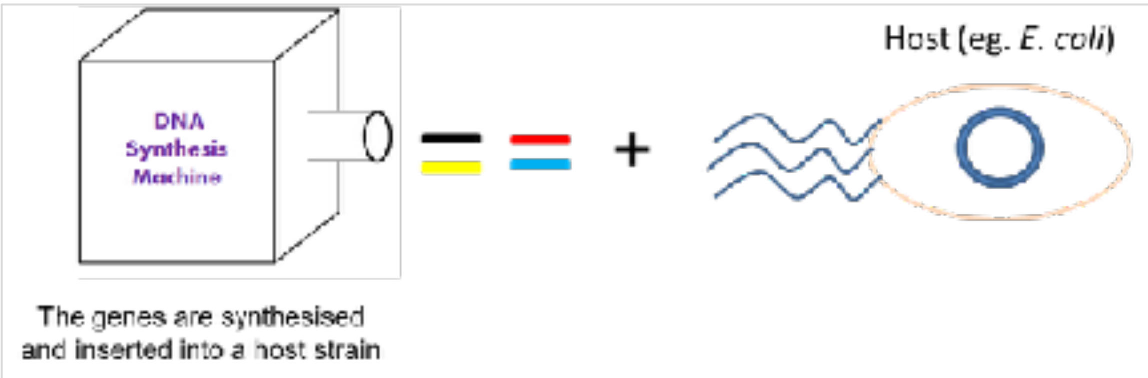
Step 1

The genomes of many microorganisms have been analysed. Many of the proteins that encode gene sequences (also called bio-bricks) are involved in the implementation of selected functions. These bio-bricks and their functions are well known and can be used to construct in SynBio.



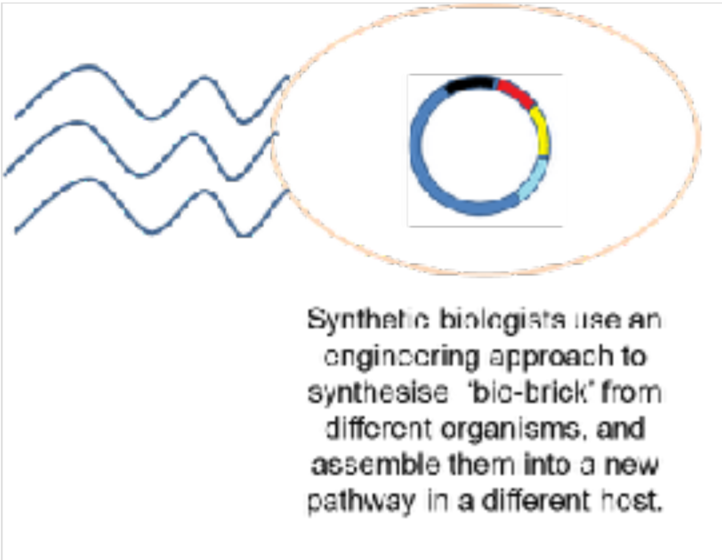
Step 2

Synthetic biologists use an engineering approach to bring together selected bio-bricks. DNA can be chemically synthesised by a machine. The man-made DNA is then inserted into a host organism using recombinant DNA techniques.



Step 3

An organism with new biological functions has been generated using synthesised parts of DNA that have been incorporated into the cell. Computer-based algorithms and modelling are increasingly used to predict the behaviour of the engineered organisms.



1.5. Examples and Future Applications

Metabolic pathways are a series of **biochemical reactions that occur within a cell**. They are important for maintaining highly regulated environments within the cell and for producing molecules and proteins, such as biofuels and drugs. With genomic research flourishing, online databanks holding genetic information on pathways involved in producing interesting compounds are expanding. Detailed investigation into **how these pathways work** will inform SynBio methods for **introducing or combining reactions (or parts of them) in living systems with the aim of creating interesting new products** that can be scaled up for industrial production. Some SynBio examples are detailed below, along with potential future applications that could be used as examples in public engagement activities.

➢ Applications related to health

Although great strides have been taken to cure and treat many diseases, a lot of challenges remain unsolved, including drug-resistant microbes, cancers, and obesity. Synthetic biology has already made promising developments in tackling some of these therapeutics challenges.

Production of pharmaceutical agents

Drug discovery and production is often a difficult and expensive process. Some drugs, like antibiotics, are industrially produced from microorganisms and are cheap and widespread.

Others on the market have not been so easy to synthesise within microorganisms. SynBio has the **potential to produce some of these drugs** by inserting metabolic pathways into host organisms that can be scaled up for mass production (Khalil *et al*, 2010). The semi-synthetic[5] production of the **drug 'Artemisinin'**, **used to treat malaria**, is a good example.

The example of the semi-synthetic production of Artemisinin
Malaria threatens between 300-500 million people worldwide, and kills more than 1 million people per year. Artemisinin is **currently the most effective anti-malaria** drug on the market. Itwas discovered in the *Artemisia annua* plant. As such, this plant has the metabolic pathway to produce the drug.

The original production of artemisinin involves **extraction from the plant**. Using this method, the production cycle from planting to drug production can take up to 1.5 years, making its production **costly and difficult** to manage and supply.

In 2006, artemisinic acid, a substance which can be used to produce artemisinin, was **produced in a yeast strain**. This strain was constructed using an engineered pathway, with several genes from the plant inserted into the genome of a host yeast strain. Artemisinic acid is synthesised and exported from the yeast cells making its extraction and purification inexpensive. The biologically synthesised artemisinic acid is then chemically modified to obtain the drug Artemisinin.

The industrial **production of 'semi-synthetic' Artemisinin** is now underway and will be used to supplement supplies of this drug. This is the first success story that uses a combination of metabolic engineering and SynBio techniques to produce a pharmaceutical precursor on an industrial scale (Paddon and Keasling, 2014). This provides an example of the potential of SynBio processes to produce therapeutic agents.

➢ Production of biofuels

A biofuel is defined as a fuel derived immediately from living matter; for example, natural oils from plants like oil palm, soybean or algae. These can be burned directly in a diesel engine or a furnace, or blended with petroleum, to produce fuels such as biodiesel. The use and production of biofuels have dramatically increased over the past few decades. The production of biofuels from genetically engineered microorganisms has recently received lots of publicity, yet many challenges remain related to scaling up production and quality of the biofuel.

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[5] Semi-synthetic can be defined as the production of a compound that is from a biological source but has undergone further chemical treatment (once extracted from the biological source) to produce the final product (such as a drug).

The example of bio-alcohols

Genetically engineered microorganisms with synthetically produced genes provide an alternative method for biofuel production. Currently the most widely used biofuel is bioethanol, which is mostly produced from sugar cane and corn. Some microorganisms in nature produce branched-chain alcohols that have a higher energy content compared to ethanol and can also be used as biofuels. However, these natural microorganisms **cannot synthesise such compounds in the quantities** required for industrial-scale production. SynBio approaches have been used to engineer *E. coli* that produces branch-chain alcohols such as 1-butanol and isobutanol.[6]

➢ First synthetic chromosome for a yeast

Recently, a **first synthetic chromosome** was generated in baker's yeast (*Saccharomyces cerevisiae* chromosome III). The synthetic chromosome was created by successively **replacing the entire natural DNA sequence** by chemically synthesised DNA fragments that carried numerous and designed changes in DNA sequence.[7]

The performance is a great step towards creating a completely synthetised complex genome capable of producing antibiotics or cleaner biofuels. It would also act as a tool for scientists to learn about how genomes are built and work.

➢ Some further examples

The following table provides an overview on some further existing and potential SynBio applications.[8,9]

Field	Application	Organization	Summary
Health	Insect control	Oxitec (UK)	The company develops engineered insects, which reduces their population, thus preventing spreading of diseases.
Biofuels	Cyanobacteria	Joule (USA)	Cyanobacteria convert carbon dioxide into liquid hydrocarbons – 'functional equivalents of diesel and ethanol'.

[6] Atsumi et al. 2008

[7] Annaluru et al. 2014

[8] Synthetic Biology Project, 2012, Inventory of Synthetic Biology Products – existing and possible (draft), Available at http://www.synbioproject.org/site/assets/files/1326/synbio_applications_wwics.pdf, last accessed on the 26th of April 2015

[9] Rooke, J. *Synthetic Biology as a source of global health innovation.* Systems Synthetic Biology no. 7(3), pp. 67-72, 2013, Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3740098/, last accessed on the 26th of April 2015

Chemicals	BioAcrylic	OPX Biotechnologies (USA)	This application is developed to replace acrylic acid based on petroleum, which is used in production of materials such as paints and adhesive.
Food	Valencene	Isobionics (Netherlands)	Valencene is a citrus flavouring. With a special fermentation process Isobionics plans to produce a synthetic bio-based version of this flavour.
Agriculture	Self-fertilising plants	Pivot Bio Inc. (USA)	The company plans to engineer plants that can metabolise nitrogen from the atmosphere. This application will help to reduce farming costs, especially in developing countries.

2. Enhancing public engagement about synthetic biology with ethical, legal, and social aspects

2.1. ELSA and their relevance for public engagement and communication

The acronym ELSA means **Ethical, Legal and Social Aspects** and refers to specific topics for consideration public engagement. ELSA represents **the 'human face' of research and innovation**, one that can open up discussions and dialogue between the experts' community and the broader public. ELSA issues are broadly **connected to the concept of the risk society**, where scientific research and technological innovation bring together new solutions and new dilemmas.

Ethical aspects deal with the choices and dilemmas that scientific research and technological innovations create for society. For example, benefits for health and the environment coming from novel technologies need to be evaluated and compared to risks for recognised values.

Legal aspects concern changes and adaptations in the regulatory framework following transformations and uncertainties caused by scientific and technological development. For example, changes in regulation that responded to biotechnological developments such as GMOs. The scope and application of the precautionary principle in regulating the effects of technological change are part of this cluster.

Social aspects deal with knowledge co-production phenomena at the science-society intersection. For example, a growing relevance of 'citizen science' is observed, where students, amateurs, and other publics provide both original findings and data to be used by official researchers.

The following chapter highlights some relevant aspects regarding the development of synthetic biology as **necessary background information for public engagement**. But where are ELSA to be found regarding synthetic biology? How do we select the ethical, legal, and social topics that are relevant for the public? This chapter provides science communication practitioners with knowledge about SynBio's ELSA.

2.2. The ELSA of synthetic biology

The importance of addressing ethical, legal, and societal issues of synthetic biology is recognised both in the academic literature and in the documents published by authoritative scientific and policy making institutions. The most relevant aspects are related to justice and fairness and the debate over synthetic biologists 'playing God' (ethical issues), biosafety, biosecurity, and intellectual property rights (legal issues), together with emerging collective phenomena related to the development of synthetic biology, like the iGEM[10] completion and the DIY[11] (Do-It-Yourself) synthetic biology movement (social issues).

➢ Ethical issues: justice, fairness, and playing God

Proponents and supporters of synthetic biology claim that this new field may deliver huge benefits for human health and the environment in the near future; yet, the **fair allocation of the benefits and burdens of synthetic biology across society** is a relevant social issue[12]. For instance, applied synthetic biology research has so far mostly concerned the production of terpenoids, natural products generally derived from plants and used, among others, to produce drugs against malaria, like artemisin. The microbial production of artemisic acid allowed the drop of production costs of arteminisin. However, this undoubtedly positive development is pushing African and Asian farmers who were producing natural artemisin out of the market, raising questions about the impacts that producing this type of drug in developed countries may have, both on eradicating malaria in the long term and supporting sustainable development in the poorest countries.[13]

As with many other advanced technologies, synthetic biology generally has an ambivalent impact on issues like economic development, public health and global justice and raises several important questions about the extent to which these innovations tackle problems or create greater complexity in managing them.[14] It is **in the context of commercialisation** that (distributive) **justice and fairness clearly emerge**. The market value of global synthetic biology in 2020 is estimated to range from ~$20 billion to ~$40 billion, 10 times bigger than in 2013; yet, unequal access to research tools and products **can aggravate existing inequalities** at the global level.[15]

[10] The iGEM competition, www.igem.org

[11] DIY Biology, www.diybio.org

[12] Newson, A.J. *Current Ethical Issues in Synthetic Biology: Where Should We Go from Here*?, UK, 2011.

[13] The Health Council of the Netherlands. *Synthetic Biology: creating opportunities.* The Hague: The Health Council of the Netherlands, 2008: 47. Available at https://www.gezondheidsraad.nl/sites/default/files/200819E_0.pdf , last accessed 19th July 2014 47. ETC Group. Extreme Genetic Engineering: An Introduction to Synthetic Biology. Ottawa: ETC Group, 2007. Available at http://www.etcgroup.org/sites/www.etcgroup.org/files/publication/602/01/synbioreportweb.pdf , last accessed 19th July 2014.

[14] BBSRC, *Synthetic Biology: Social and Ethical Challenges*, UK, 2008.

[15] Bubela, Hagen, Einsiedel, *Synthetic biology confronts publics and policy makers: challenges for communication, regulation and commercialization,* 2012.

Ethical issues can also be seen regarding popular and shared understanding in the field of synthetic biology; for example, by considering the relevant image of **synthetic biologists 'playing God'.** This metaphor is used when considering the vast potential applications of synthetic biology, and suggests that, through the possibility of creating human life from scratch, scientists are in some way paralleled to God,[16] thus blurring the boundaries between the natural and the artificial. In mass media coverage of synthetic biology, the 'playing god' metaphor has been used to communicate some of the most ambivalent expectations regarding the field; at the same time, this image is **considered misleading in referring to the work of synthetic biologists**, because it may communicate an only projected irresponsibility frame, while it belongs to the ethical domain.[17]

➢ Legal issues: biosafety, biosecurity, intellectual property rights and patents

Possible **contamination by accidental or intentional release of synthetic organisms** is among the principal anticipated safety and security risks.[18]

The fundamental modification of microorganisms, let alone the possible creation of 'brand new' ones, may lead to difficulties in **predicting the impacts on environmental and human health** and therefore need to be to regulated, managed and monitored. Increasing uncertainty regarding synthetic organisms and their relation with the environment are mainly related to differences in physiology. Interaction of synthetic organisms and the environment is considered critical due to specific attributes synthetic organisms need to survive in certain environments. Here, synthetic organisms may exchange genetic material while competing with non-modified ones or take up free DNA from the environment.[19]

In the agricultural sector, The Presidential Commission for the Study of Bioethical Issues (PCSBI) also refers to the spread of new or sturdier pests – animal or plant – that may be difficult to control or negatively impact ecosystems.[20]

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[16] NBC News, 'Researchers creating life from scratch', 19th August 2005, last accessed December 3rd 2014, link: http://www.nbcnews.com/id/9005023/ns/technology_and_science-science/t/researchers-creating-life-scratch/#.VH7UPGSG-eM

[17] Rutherford, Adam, *Synthetic biology: 'Playing God' is vital if we are to create a better future for all*, the Guardian, 27th July 2012, last accessed October 7th 2014, http://www.theguardian.com/commentisfree/2012/jul/27/synthetic-biology-playing-god-vital-future

[18] Presidential Commission for the Study of Bioethical Issues (PCSBI). New directions. The Ethics of Synthetic Biology and Emerging Technologies. Washington, DC: The Presidential Commission for the Study of Bioethical Issues, 2010. Available at http://bioethics.gov/sites/default/files/PCSBI-Synthetic-Biology-Report-12.16.10_0.pdf, last accessed 19th July 2014.

[19] Dana, Genya V., Todd Kuiken, David Rejeski, and Allison A. Snow. *Synthetic biology: Four steps to avoid a synthetic-biology disaster.* Nature 483, no. 7387: 29-29, 2012. and Biotechnology and Biological Sciences Research Council. *Synthetic Biology: Social and Ethical Challenges.* By Andrew Balmer and Paul Martin. London: An Independent review commissioned by the Biotechnology and Biological Sciences Research Council (BBSRC), 2008. Available at http://www.bbsrc.ac.uk/documents/0806-synthetic-biology-pdf/ , last accessed 19th July 2014.

[20] PCSBI, New Directions. *The Ethics of Synthetic Biology and Emerging Technologies*, p.62, USA, 2010.

Other Commission concerns include airborne spread of disease agents manipulated using synthetic biology techniques. A specific concern regards the diversity of the individuals conducting synthetic biology research. Due to the threat of airborne disease agents manipulated using synthetic biology techniques, the range of practitioners expands to include scientists from a variety of disciplines, as well as students and amateur scientists, which are gathered under the growing DIY biology movement.

While **heterogeneity of participants to scientific research** is considered a positive factor contributing to scientific development, the need has emerged to warn those involved in all levels of synthetic biology development about potential misuses of the technology.[21] This issue is commonly referred as the dual-use potential of technologies, i.e. the fact that advances in research can be either used both for beneficial purposes and harmful ones. Major breakthroughs in synthetic biology might find, for instance, military application or be used in terrorist actions. The history of advances in life sciences has unfortunately taught us lessons regarding development of so-called biological weapons such as anthrax.[22] In the case of synthetic biology, such risk is only projected and hypothetical, but such a dual-use potential constitutes a dilemma for the researcher as well as for those who support and regulate the research (e.g., governments).[23]

Intellectual property and patenting issues have also been taken up while discussing legal implications of synthetic biology. On the one hand, the push towards the development of discrete and substitutable parts makes synthetic biology best fit the current proprietary patenting regime; on the other hand, the modularity of SynBio research fuels a different strand that promotes the free access to 'standardised biological parts', collected by the iGEM community in an ad hoc and publicly available registry.[24] While discussions on these aspects are ongoing both at the academic and professional level, it is still difficult to define what mix of open source and proprietary intellectual property regimes can best foster the field's development.[25]

➢ Social issues: iGEM competition and DIY biology

[21] NSABB - National Science Advisory Board for Biosecurity. Addressing Biosecurity Concerns Related to Synthetic Biology. Washington, D.C.: National Institutes of Health, 2010. Available athttp://osp.od.nih.gov/sites/default/files/resources/NSABB%20SynBio%20DRAFT%20Report-FINAL%20%282%29_6-7-10.pdf, last accessed 19th July 2014.

22 Kelle, Alexander. Beyond patchwork precaution in the dual-use governance of synthetic biology. Science and engineering ethics 19, no. 3 : 1121-1139, UK, 2013.

23 Miller, Seumas, and Michael J. Selgelid. Ethical and philosophical consideration of the dual-use dilemma in the biological sciences Science and engineering ethics 13, no. 4: 523-580, Australia, 2007.

[24] IGEM (n.d.). *Registry of Standard Biological Parts*. http://parts.igem.org/Help:About_the_Registry

[25] Henkel, Joachim, and Stephen M. Maurer. *The economics of synthetic biology*. Molecular Systems Biology 3, no. 1, 2007.

Social issues are here interpreted as co-production phenomena related to **involvement of non-professional scientist**s into organised and structured practices of knowledge creation.

In relation to synthetic biology, the clearest example is most likely the International Genetically Engineered Machine competition (iGEM), an undergraduate Synthetic Biology competition during which student teams are given a kit of biological parts at the beginning of the summer from the Registry of Standard Biological Parts. Working at their own schools during the summer, they use these parts, as well as parts of their own design, to build biological systems and operate them in living cells. **The iGEM competition** was developed in 2003 and has grown from a small group of participating students to including teams from universities worldwide. It now includes a prize fair – the Giant Jamboree – where students from all over the world discuss and present their projects. The competition is an innovative hands-on educational activity in which undergraduate students suggest novel ways for innovation in synthetic biology. The hope is that some projects may lead professional researchers in new directions.

While it is an education initiative, there's a more radical interpretation of this kind of activity, which is mainly based on the DIY movement in synthetic biology. **Do-It-Yourself biology or DIYbio**, is a global movement spreading the use of biotechnology beyond traditional academic and industrial institutions, to the lay public. Practitioners include a broad mix of amateurs, enthusiasts, students, and trained scientists, some of whom focus their efforts on using the technology to create art, explore genetics or simply tinker.

2.3. ELSA in science communication

Broadly speaking, ELSA issues deal with **possible unforeseen risks deriving from the development of synthetic biology**. This means public engagement initiatives should include relevant discussion on risks associated with applying synthetic biology in ways that could impact citizens and consumers.

Controversy on genetically modified organisms (GMOs) set a negative benchmark for public debates; while there's agreement that synthetic biology is removed from the controversies around GMOs, it's possible the same discussions may be repeated.

Science communicators involved in public engagement initiatives may find the information provided in this chapter relevant for several reasons. in general terms, they can use it as background knowledge to design their activities, but also consider ELSA issues as relevant dimensions for evaluation; one question to consider is whether the public has been sensitised to reflect and consider issues around synthetic biology as an result of public engagement.

Discussion ELSA aspects may take different forms; for example, holding focus groups and informal discussion meetings at science museums and centres to gauge public opinion. Moreover, synthetic biologists might discuss their views on these aspects through interviews and discussion panels. Exhibitions could focus on the ELSA of research and innovation, showing relevant and accessible data and information.

More generally, all techniques and methodologies for public engagement described in this toolkit can focus and include ELSA aspects.

3. Public engagement in emerging technologies

3.1. Introduction

The European Commission has adopted the concept of **Responsible Research and Innovation (RRI) as a principle for its innovation policy.** The aim of RRI is to create a research agenda that not only increases economic competitiveness, but also **reflects the grand challenges society is confronted with**, such as the implications of climate change or an ageing society. Furthermore, widely held public values should be considered, not just technical feasibility and economic aims. Agendas shouldn't be delivered in a top-down or command-orientated way; rather, stakeholders should be involved, so they become mutually responsive to each other. Experts of different disciplines, stakeholders and the broader public should be mobilised and involved in learning and exploring issues together.

This abstract aim must be brought to life. One means is **setting up Mutual Mobilisation and Learning (MML) events** as explained in the introduction. Rather than contributing directly to policy, MML events enable members of the public to come up with an opinion that may or may not be relevant to stakeholders and policy makers. Usually, direct participation is not the main focus.

This section presents some points to consider for those responsible for setting up such events. Of course, every event faces different challenges depending on the format, participants, issue at stake and many contextual factors – organising such an event is a challenge in itself. However, merely conducting an event should not be an end in itself. Events should be used to trigger a broader debate.

3.2. Public encounter with science and technology: different paradigms

Why should the public be confronted with, or have a say in, issues of science and technology? Ever since the mid-1980s, when the idea of public involvement gained momentum, different rationales have been guiding the public's encounters with science and technology. These rationales attempt to explain why participation is good and what it is good for.

Following different rationales, various paradigms for public involvement have been established, such as Public Understanding of Science,[26] Public Engagement with Science,[27] and Public Participation.[28] These paradigms carry different imaginations of the role of the public addressed and suggest different methods. Discussion over participation has mostly been conducted along these paradigms.

Highlighting the importance of the guiding rationales – which often remain hidden or implicit – will help to better understand the differences. Rather than dividing approaches according to the prevalent communication types,[29] **focus is placed on the conceptual aims of the event and the role assigned to participants.** For the success of any event, it is important to be very clear over its intention. This is not to suggest an implicit value hierarchy among different rationales, nor to suggest a (teleological) timeline as if there was a progressive development from 'public understanding' to 'public engagement'. All three paradigms date back to the 1980s.

Public Understanding of Science (PUS) was called into life with the influential Royal Society's report (The Royal Society 1985). Many scientists were concerned that the gap between science and the public was rapidly increasing. To foster public trust in science, and as part of a general enlightenment programme, PUS promotes the idea of the scientifically literate citizen, able to develop an informed opinion on issues of modern science and technology. At the same time, it tries to convey some of the fascination of scientific insights and technological developments to raise the public attention. The original rationale of PUS (as formulated by the Royal Society in 1985) was to provide 'objective' information on science and technology to citizens in order to render them well-informed enough to develop an opinion of their own (which was expected to be fact-based and, hence, positive). Later, the understanding of the objective changed slightly to actively convincing the public of the advantages of science and technology and to foster acceptance (Bauer et al. 2007). The public is conceived of as a rational recipient of impartial information and thus mainly as an object; the flow of communication is unidirectional. Typical procedures are public lectures in universities or educational science events.

Public Engagement with Science (PES) aims at influencing research and innovation by considering citizens' opinions and societal needs to shape science policies. This rationale is reflected in real-time or constructive technology assessment going back to mostly Dutch initiatives in the 1980s. It departs from the notion that technology development does not follow a predetermined logic but results from the co-evolution of technology and society.

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[26] Bauer et al. 2007

[27] Hagendijk and Irwin 2006

[28] Arnstein 1969

[29] For example, the British National Coordinating Centre for Public Engagement understands public engagement as an umbrella term indicating any way in which research can be shared with the public that involves a two way dialogue.

Going a step further, 'upstream' engagement was introduced to guide technology development from its beginning through stakeholder and lay knowledge, perceptions, and interests. To this end, the public had to be 'engaged' in a co-designing process in a suitable form at an early stage. The public is conceived as a subject, a source of inspiration and an important player. The communication flow from the public to the decision makers is bi-directional but not symmetric, with some initial input from scientists and developers. Today, this idea is being promoted in a new form under the header of Responsible Research and Innovation (RRI). Typical approaches include focus groups, scenario workshops or public dialogue events, where the main aim is to stimulate an open debate over associated visions and problems to find new solutions.

Public Participation with Science (PPS) usually aims at empowering civil society in decision-making processes. In the 1960s, emancipatory calls for public participation have prompted the development of procedures to influence the political agenda through citizen deliberation. The rationale of PPS is to give a voice to the public and provide an alternative view. During the 1980s, methods were designed to collect the assessments of an informed group of lay people as an example of (rather than statistically representing) the 'public voice', and to convey their findings to policy makers. Their findings should contrast stakeholder interests that usually guide debate on contested technologies and often entail an irresolvable juxtaposition of arguments and positions. The most popular format is the citizen conference as developed by the Danish Board of Technology. The public here is conceived of as a source of alternative ('life-world') knowledge to complement or effectively criticise expert knowledge. It is a subject rather than an object of communication efforts, and the communication is bi-directional.

The following table depicts paradigms, relating rationales and typical procedures.

Paradigm	Public Understanding of Science (PUS)	Public Engagement with Science (PES)	Public Participation with Science (PPS)
Rationale	Informing and convincing: to provide information and foster acceptance	Opinion formation: to align technology development to public values	Political impact: to give the public a voice
Role of the public	Passive audience	Actively debating	Designing policy
Example process	Conference, typical exhibition, lecture	Focus group, public dialogue	Citizen conference

Thus, the call for public involvement has resulted in the development of several participatory formats, from science events to focus group deliberations and citizen conferences. The methods relate to specific paradigms – even though they are not completely determined. The paradigms again are rooted in different rationales regarding the role and purpose of participation.

In practice, the rationales do not strictly correspond with particular procedures. For example, consensus conferences have often been used to increase public attention to particular issues, without eliciting policy response. Focus groups, designed to tap into public attitudes, often have strong policy implications as policy makers use them to align their activities to opinion.

Any public event may be used for different purposes: raise public attention, convey a message, listen to alternative voices or provide the public with an opportunity to let off steam. Although some formats are better suited for particular purposes than others, the result of a specific event doesn't just depend on the format. It also relies on the issue, the context, on how and when the event is set up, who participates, on the information conveyed and on how the opinions of the participants are collected and processed, etc.

The most important aspect, however, is whether the organisers are aware of their own intentions, i.e. what the rationale is and which paradigm they subscribe to.

3.3. How to choose a clear rationale for debating synthetic biology

When organising public dialogue events, it is important to have a clear idea about what a dialogue entails and what decisions on their design must be taken. It important to reflect on the criteria for them, and the criteria in turn heavily depend on the aims. The rationale(s) chosen must be clear to identify the relevant paradigm. A dialogue is not a discussion or a debate. In a discussion or a debate there is often a 'winner'. The focus often lies on informing and convincing. In a dialogue, however, there is no winner. The informing aspect still plays an important role but the 'convincing' part disappears. The main aim is to clarify values, ideas, emotions and opinions about a certain topic, so that mutual learning and opinion forming can take place.

Informing rather than convincing

Synthetic biology is a tricky issue few people are familiar with. Surveys[30] have shown that nearly **two-thirds of respondents have never heard of it**. While public awareness is low, people must have an idea about synthetic biology in order to get involved in a participatory activity. Providing balanced information is even more important when lay people deal with an abstract issue with a lot of speculation and little practical relevance.

What do you want people to know? For example: the basic science, possible applications, future opportunities regarding health, the environment, industry, general competitiveness, broader societal implications, potential risk, etc.

[30] Gaskell et al. 2010, Hart 2013

Why do you want people to know this? For example: to disseminate knowledge for its own sake, to increase interest among the public, to enhance acceptance, to raise awareness for possible problems, to enable people to take their own decision, etc.

Who is going to tell it to them? For example: scientific experts, relevant stakeholders, policy makers, a balanced panel of pro and con voices, professional science communicators, etc.

What do you want to avoid? For example: to annoy people with scientific babble, to present wrong facts or exaggerated claims, to give the taste of PR through the predominance of lop-sided arguments pro or con, to confuse people with disturbingly divergent views, to foster resistance to technology, to raise false hopes, etc.

Opinion formation

In the context of RRI, an informing and convincing lay person (in the sense of PUS) is not enough; public opinion formation – i.e. **enabling participants to come up with their own assessment** to be conveyed to policy – is one of the main aims. Organisers must make sure an event renders results, i.e. that people come up with interesting statements and new aspects. It should provide useful hints at what stakeholders and the public consider desirable regarding synthetic biology and what may throw up problems relevant for policy makers. It should not be reduced to a mere copy of the experts' opinions. People should be encouraged to disagree, to introduce new aspects and to connect the abstract issue to everyday-life experiences.

What do you want to arrive at? For example: a collection of interesting statements, a survey of relevant or random opinions, a thorough debate of single aspects of an issue, a consensual statement of a group of people, several opposing statements on the same issue, a collection of authoritative stakeholders' positions, etc.

Why do you want this output? For example: to learn comprehensively, to identify non-expert or stakeholder views, to elicit a broader debate among the public, to establish an end-point to a debate held for its own sake, to raise media interest, to generate something to communicate, to gain material for a social scientific investigation, etc.

What do you want to avoid? For example: to repeat well-known expert positions only, to conduct a sluggish and uninspired debate without new insights, to raise issues non-relevant to the issue at stake, to risk hijacking by interest groups, etc.

Participation in decision making

It has already been mentioned that MML events generally don't directly contribute to policy, but indirectly enable members of the **public to come up with an opinion that may or**

may not be relevant to stakeholders and policy makers. If, however, there is a clear message from participants that aims at actively influencing public policy, organisers should not be afraid of communicating it. In some cases, **explicitly contributing to decision-making** may also be an aim of an event – especially if it includes a direct participation of policy-makers. In this case, the rationale needs to be particularly clear.

What do you want to achieve? For example: to provide a neutral space for giving people a voice on an issue, to communicate a particular message to policy, to bring alternative views to the fore in an issue that is already highly polarised, to support a particular interest, stake or view through engaging the public, etc.

Why do you want to achieve this? For example: to contribute to escaping from a political gridlock, to help frame an issue for further political attention, to support a view on an issue in the sense of a sponsor or on one's own behalf, to prevent or promote the implementation of a technology or project, etc.

What do you want to avoid? For example: to fail in building media attention, to miss the needs of policy makers, to present the 'wrong' message due to unclear statements from participants, to communicate a message vaguely, etc.

Other issues

Apart from choosing the right rationale, and being clear over why it has been chosen, there are several other points to consider:

Documentation: as laypeople or stakeholders will not provide fully formulated assessments or opinions, the organisers must document the process and results of public dialogues. The main aspects or topics the documentation should focus on may vary according to the format of the event. A range of possible issues have been discussed in Chapter 2 on ELSA.

Framing and metaphors: In addition to information, anchor points in more familiar technologies are necessary (see Chapter 4) to stimulate debate. Factual explanations are not enough to bring the issue 'to life'. Organisers of public dialogue events must introduce perspectives and analogies that link the new and unknown to the familiar. Experts or important actors might suggest their own perspective or frame the issue in a way that establishes open dialogue. Note that the information provided by initial experts' statements contribute to this framing process.

Outlook

The following sub-chapters are framed in relation to these points and offer concrete examples. The description of the activities include: some lines about giving information about the subject in the context of a particular activity; how to make people think by themselves and have opinions; and how to involve policy makers and make them aware of what people think, etc.

4. Public engagement activities

4.1. Public dialogue

What are Public dialogue activities?
Public dialogue activities aim at nurturing **exchanges about scientific innovations and new technologies between the public and experts** (scientists, policy makers, or other expert stakeholders), sharing the potential impacts for society and related issues with an audience. During the activity, members of the public learn about the topic and understand its issues, listen to different viewpoints on these issues, exchange, and can elaborate their own opinion.

There are many ways to conduct dialogue activities, with various potential stakeholders involved and different aims. Public dialogue activities can help foster dynamic science governance which considers citizens' opinions. Some institutions facilitate the political engagement of citizens using different tools and approaches. Public debates can certainly contribute to create mutual exchange and shape society.

Experiences - Science Centre AHHAA, Tartu, Estonia
"The most valuable lesson was the fact that people are very interested in the issues we covered. This shows that there is a need for organising similar activities in the future." Helin Haga, Science Centre AHHAA, Estonia.

Before organising a debate, it's important to understand society's expectations, beliefs, and fears. This is essential to identify the best way to involve the public in the debate. A good knowledge of your audience influences the whole framing of your activity. It will also help identify the stakeholders that could be involved and the format of the debate such as a timeframe, desired results, or scale. Some studies have already sought public opinion on synthetic biology[31][32].

What rationales do public dialogue activities serve?
The idea of public dialogues is to enable participants to be empowered and approach different opinions or visions on a subject. The first rationale here is **informing the public** about the topic to give them enough information to understand further issues. The second is **opinion formation,** as the public should **come up with building their own assessment**.

[31] TNS-BMRB, *Synthetic Biology dialogue*, UK, 2009-2010, http://www.bbsrc.ac.uk/web/FILES/Reviews/1006-synthetic-biology-dialogue.pdf

[32] Ipsos MORI, *Public attitudes to science 2014*, UK, https://www.gov.uk/government/publications/public-attitudes-to-science-2014

Mutual learning processes should take place, involving experts and opportunities for the public to interact with them, ask questions, and finally come up with an enlightened opinion. In the context of responsible research and innovation, these opinions and exchanges can be gathered into assessment reports that could constitute a great tool for policy makers who can then consider and include people's wishes, expectations, or fears into the development of policies.

➢ Organising public dialogue

The involvement of experts

Scientists, researchers, as well as policy makers, local authorities, science journalists, and science communicators, are often invited as experts to share their knowledge, questions, and opinions about the topic in many public dialogues. The greater the variety of stakeholders involved, the closer you will get to the spectrum of opinions and perspectives on the subject.

Actively involving stakeholders in the preparation of the dialogue will help form relevant issues and questions, anticipate the scale of the subject to be tackled, and avoid frustration or conflict.[33]

What outcomes can you expect and how to use them?

Running dialogue activities can lead to a variety of outcomes. To avoid dispersion, it is important to make clear what outcomes are expected from the activity and how the outcomes should be used and disseminated.

- ➢ Do you want to inform? To stimulate discussions and thoughts? To come up with lists of ideas and points of views? To help form opinions about a political decision?

- ➢ Are you recording the debate? Do you plan to write an activity report? Do you plan to feed another activity with these outcomes? Will you share the outcomes? On your website? With policy makers? With other participants? At a local or international level?

The role of the facilitator

The role of the facilitator in dialogue activities is crucial for the smooth running of the event. The facilitator needs to be aware of issues, expectations, questions, or risks regarding the topic. An excellent knowledge of the subject will allow him or her to better anticipate the audience's reactions. It is important for the facilitator to be aware of the desired outcomes and to anticipate the structure of the debate. The facilitator should guide the

[33] Science Wise, *Synthetic Biology, A public dialogue to explore the public's views, concerns, and aspirations*, 2010

debate, ease interactions between stakeholders, guarantee neutrality, and ensure respect, trust and safety.

Dealing with controversies

The construction of a dialogue is based on **involving diverse point of views, cultures, and experiences** rather than imposing one of them on the public. When the subject is controversial, conflicts and disagreements can be expected. However, even if some opinions are identified as a basis for these disagreements, they shouldn't be ignored.

Anticipating potential risks and results is key to organising the dialogue in a way that avoids violent conflicts and frustrations. For this purpose and to gain an excellent knowledge of the topic, it is important to ask stakeholders to help in preparing activities.

Audiences tends to be very curious about controversial issues. They often ask serious questions, expressing curiosity or concern. But these behaviors might be culturally defined and may differ depending on the country.

Experiences - Science Centre AHHAA, Tartu, Estonia "Our goal has been to increase public awareness of the (potential) ethical and economic issues related to synthetic biology, bust the myths related to the topic and help to do away with the concerns people may have." Science Centre Ahhaa, Tartu, Estonia

The example of the Play Decide game

The EU-funded project "Decide – Deliberative Citizens' Debates" started in 2004 and was coordinated by Ecsite. The project represents an experimental approach to better understand the role of science centers in the democratisation of science and the tensions and challenges in this field.[34]

Project partners created the discussion game Play Decide[35] to: raise awareness among the public and science center professionals for participatory and deliberative consultations; collect data from debates and discussion on contemporary and controversial science issues; and create an affordable and easy instrument to conduct debates and discussions in science centers. First, participants gain knowledge about a topic. They become able to test various pros and cons about it and finally form an opinion about choices they would make in real life.

A new Decide kit will be created to discuss future scenario and ethical issues about SynBio by the Science Centre AHHAA, in Tartu, Estonia, in cooperation with SynBio researchers of the University of Tartu and the Estonian Academy of Life Sciences.

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[34] Bandelli, *Engagement tools for scientific governance, by playing*, *Jcom* 09(02) (2010) C01, 2010

[35] PlayDecide is inspired by Democs and was produced by the European project "Decide". More information on www.playdecide.eu

4.2. School modules and teachers' training

When it comes to developing school modules and teacher training modules on synthetic biology, a lot can be learned from experiences in the (related) field of genomics teaching and teacher training. One important point is that genomics, humanities and social science researchers and professional science communicators have a lot to offer each other in terms of knowledge and expertise. At the same time, it appears that these groups of professionals are not well-informed about each other's knowledge and expertise, and what is going on in terms of genomics education in schools. In addition, the uptake of innovative additional educational materials and activities developed by groups outside the formal educational field is often overestimated.

This section of the toolkit attempts to **learn from past experiences and research**. Armed with this knowledge, general tips and hints are given about the design of school modules and teacher training aimed at public engagement and participation in the development of synthetic biology.

Choosing a clear rationale

School modules

Concerning school modules for synthetic biology, our choice is to place them within two paradigms: **Public Understanding of Science** (PUS) and **Public Engagement with Science** (PES).

As synthetic biology is an emerging field of science, still full of unknowns and promises for the future, it is a topic that the general public, let alone high school students know very little about. Initially then, there's a need to inform and explain. This general aim fits well within the Public Understanding of Science paradigm.

What do you want the students to know?

- The basic science
- Possible applications
- Future opportunities regarding health, the environment, industry
- Broader societal implications
- Potential risk
- Etc.

In order to provide students with proper information/answers to the above issues, some urgent questions need to be addressed: What's really new in SynBio? Is it 'just' a form of extreme genetic engineering or is it something fundamentally new instead? And what's new in terms of ethical, legal, and social aspects? What realistic and appealing (future) applications of SynBio are available as examples? At the moment, relatively little information is available about these aspects, but what there is will be taken up in this toolkit at the relevant sections. Meanwhile these questions will continue to be studied in the years to come.

As Synenergene is a four-year mobilisation and mutual learning action plan (MMLAP) learning from and with each other is crucial in the project. While fostering audience engagement and participation with synthetic biology, school modules cannot stop at just informing. **School children are the citizens of the future** and important decisions about synthetic biology will be (partly) in their hands. Therefore, **they should be taught how to reflect on issues** so they can form their opinion about (future) developments in SynBio. This aim fits well within the Public Engagement with Science paradigm.

What do you want to arrive at?

- Reflection on ethical issues
- Opinion forming on 'science-in-the-making'
- Engagement in socio-scientific inquiry and debate
- Develop awareness of own arguments and values and those of others
- An ability to think the consequences of a potential decision through
- Participation in discussions on SynBio-related socio-scientific issues (SSIs) by reflecting on multiple points of view, being receptive to other opinions, and demonstrating willingness to grow in terms of knowledge and understanding

To foster opinion forming the following aspects need further research: What metaphors and analogies have proved to be (un)helpful in public communication of SynBio? How are current debates on SynBio framed and what should be learnt from that in terms of do's and don'ts related to education and communication?

Teacher training

When it comes to teacher training for synthetic biology, it is important to realise that what counts for the students, counts for the teachers as well. They are also part of the general public, and therefore the same goals count for students as well as for teachers.

In addition, it is important to realise that when it comes to **discussing controversial science** (such as SynBio is) **teachers often feel overburdened and/or less confident** about facilitating classroom discussions. As science teachers, they may also feel that 'teaching about values' is not part of their job. Teacher training modules should specifically address or deal with the aforementioned issues.

Designing school modules

Figure 1: Visual representation of the designing process. The six topics in the outer ring represent the topics that need analysis to generate criteria for the design. The arrows between the elements signal that all elements influence each other. By thinking 'to and fro' between elements, one can make decisions that will inform a well-balanced and internally consistent design.

Based on years of experience and research designing school modules, it has become clear that designing is not a linear process, following a step-by-step guideline. It's rather a circular, iterative process (see figure 1 for a visual representation of the designing process). To set up a well thought through design for synthetic biology, **six important study topics** are singled out and will give information or 'criteria' for the design. All six topics therefore influence the design, but they do not *only* influence the design, they can also influence the other topics. So, criteria coming, for instance, from 'conceptual analysis' can only be implemented well in the design if these criteria also fit well with the criteria coming from other topics. So, you work in 'rounds'. You think 'to and fro', searching for the best 'match' of criteria coming from the different topics each time. Only in this way can an internally consistent and well-balanced design be achieved.

When examples of learning and teaching activities and guidelines are provided for each topic in figure 1, teachers can choose where to start, depending on their needs, flaws, specific learning goals or emphasis they pursue in their educational practice.

Topic: Target group analysis, e.g. pupils or school groups in this case

It is important to determine the **starting situation of your target group**. In theory, this can be any target audience, but in the case of teaching materials pupils or school groups are considered. Important information you'd like to gather from the target audience is: what knowledge is present, how do they feel about SynBio (concerns?), what experiences do they have with the topic. These aspects should be studied in line with the aims you have set for this particular activity (so connect the information to the topic 'desired performance'). This will steer your research. If you mainly want to focus on knowledge gain, then study this aspect (knowledge present, misconceptions, etc.). If your focus is on moral reasoning about SynBio, then it's important to foreground emotions, feelings, concerns, and values.

Topic: Conceptual analysis
Synthetic biology is a **new form of biology** in which it is possible to design new biological systems that didn't exist before out of loose elements. It's a research field in which developments out of the fields of nanotechnology, biotechnology, information and cognitive sciences merge. It evokes **important societal and ethical questions** about the significance of SynBio for our health or environment.

As SynBio is an emerging technology it is difficult to exactly determine what it is and how it's different from other, already existing research fields. Defining SynBio through interviews with experts will be an ongoing process and will be of constant influence on the content available and used in conceptual analysis[36] of SynBio.

Topic: Contextual analysis
In terms of context, one should think of issues such as: What important **stakeholders** are involved? what **interests** are at stake? What **interesting cases or practices** are useful for the design? What **frames** are/can be used?

Some participants of the iGEM contests will be able to provide the Synenergene project with interesting, realistic and appealing (future) applications of SynBio, which will be appropriate for public engagement and participation activities.

In addition, application and techno-moral scenarios will be produced, which may be used in/of use for school modules. Scenario learning as a means to techno-scientific citizenship education encourages proactive decision making towards a desirable future for society.

Framing issues is an ongoing process at personal and societal level that should be made explicit to enable mutual understanding and bridge controversies. For educators and communicators facilitating public engagement and participation, it is crucial to clarify their own frames and to be aware of how these might influence participants. Frames which are currently often used in the dialogue surrounding SynBio are: 'risk', 'progress', 'moral boundary' and 'gadget' frames.

Topic: Desired performance
On the one hand, the **expected performances** by students will include cognitive goals: the student should be able to demonstrate general knowledge about what SynBio is and how it

[36] For help on conceptual analysis and making concept maps: Institute for Human and Machine Cognition, *The Theory Underlying Concept Maps and How to Construct and Use Them*, USA, 2006, 2008, http://cmap.ihmc.us/publications/researchpapers/theorycmaps/theoryunderlyingconceptmaps.htm

distinguishes itself from 'old' science such as biotechnology, and genetic engineering. Such goals can be monitored using knowledge tests (exams).

When it comes to equipping students with the skills necessary to participate in public dialogue about SynBio, it's much harder to set SMART (Specific, Measurable, Attainable, Realistic, Time-bound) goals. However, promoting democracy in terms of dialogue and deliberation of SynBio in the classroom is crucial to prepare citizens for public engagement and participation in the development of science and technology. As SynBio does not seem an instantly accessible topic, teachers need scaffolding and training for addressing the values component of related socio-scientific issues.

It's important to assess students' moral reasoning criteria, such as: quality of the argumentation; engaging in multiple perspectives; ability to reflect on one's own opinion and values and that of others; and being able to think through the consequences of a potential decision.

Topic: Library of effective approaches
Academic articles and literature on best practices from the science communication field give a wealth of information on how best to use certain (communicative/educative) approaches in your design.

Main sources of theoretical inspiration include:
Constructivism – emphasises the active role of the learner in building understanding and making sense of information. Knowing and learning are situated in social practice.

Situated learning approach – connects to social-cultural theory by assuming humans develop through participation in social cultural practices, e.g. authentic or democratic classroom practices ('doing' democracy).

Problem-based learning – where students are confronted with realistic problems that don't necessarily have 'right' answers, sequence of phases, for example in ethical inquiry, will give teachers and students a footing. With guided participation in real tasks, comes participatory appropriation; students appropriate the knowledge, skills and values involved in doing the task. This so-called *cognitive apprenticeship approach* entails the following steps: orientation; modelling; scaffolding; and articulation, reflection and exploration towards the next step.

For a 'good' learning experience it's good to adhere to David M. Merrill's learning principles:

1. Learning is promoted when learners are engaged in solving real-world problems
2. Learning is promoted when existing knowledge is activated as a foundation for new knowledge

3. Learning is promoted when new knowledge is demonstrated to the learner
4. Learning is promoted when new knowledge is applied by the learner
5. Learning is promoted when new knowledge is integrated into the learner's world

Intuitions and emotions should be addressed seriously in public dialogues and classroom discourses to meet each participant's need to feel known and understood, and to keep them open-minded. In addition, if articulated, interrogated, reflected on and justified (= emotional deliberation), they provide a valuable source of moral knowledge to consider in opinion-forming and decision-making.

The small but steady stream of **publications on the teaching of controversial** issues is helpful in articulating teacher competencies and the (quality of) process and content of classroom discourses.

To help science teachers overcome their insecurity about moderating moral reasoning[37] in classrooms and aid them in 'teaching values', it is suggested to **invest in setting up 'teacher communities' for learning to teach socio-scientific issues** such as SynBio. Teaching SynBio involves the professional identity of teachers. The teachers should develop a kind of 'self-understanding' when it comes to SynBio. Without self-understanding, it's impossible for a teacher to 'coach' students to understand and get involved in moral reasoning about SynBio.

- Expertise required for teaching SynBio: subject matter expertise; pedagogical content expertise; moral expertise; interpersonal expertise
- Subject matter expertise: What is SynBio, possible applications, future opportunities, broader societal issues, potential risks
- Pedagogical content expertise: Use of narratives, use of a problem-based approach, use of teacher and learning activities for (reflection on) moral reasoning
- Moral expertise: applying different roles in the classroom discussions (honest broker, devil's advocate, etc.), applying different approaches for moral education
- Interpersonal expertise: creating a safe atmosphere; creating good relations with students

Topic: Dilemma analysis

As SynBio is a typical socio-scientific issue, it's important to make the values involved explicit, to identify the emotions involved, set out the pros and cons of the emerging technology, and what choices the citizens of the future may have to make. The fact that SynBio is an emerging technology means that information on all the aforementioned issues will grow in years to come. It's therefore important to keep on conducting dilemma analysis as the research field grows and progresses.

[37] Levinson, R. & Turner, S., *Valuable lessons. Engaging with the social context of science in schools. Recommendations and summary of research findings.* London: The Trustee of the Welcome Trust (www.wellcome.uk), UK, 2001

4.3. Science Café

What are science cafés?

Science cafés are events that host **informal conversations between experts and members of the public about a current research topic** – primarily that of researchers. A key difference to a public lecture is the location; science cafés are **held at generic venues** where the public does not expect to encounter science but might otherwise be familiar with, especially during their leisure time. As such, these venues constitute a neutral meeting point between science and public.[38] Examples of places where science cafés are held include cafés themselves but also bars, pubs, restaurants and bookshops. Science cafés have also been held in schools, to give pupils a flavour of what research looks like.[39]

The format of a science café is **flexible and can be adapted to different countries and cultures**. Some involve a single speaker, whilst others involve several and can include researchers from different disciplines around a single topic. Despite the name, science cafés do not only have to focus on science – research in the social sciences and the arts and humanities are also topics for discussion. However, a vital element is the inclusion of **discussion, dialogue and two-way interaction**, either through conversations at tables, a more standard question and answer session or other forms of expression. In this way, members of the public can discuss research in a relaxed environment, with no assumptions about their prior knowledge. Informal settings are also an appropriate setting for learning about and discussing emerging and potentially controversial technologies like synthetic biology.[40]

What rationales do science cafés serve?

In general, the main purpose of science cafés is to **inform and engage members of the public about an aspect of research**. Whilst certain topics, such as those connected to public concerns, are likely to generate interest, the key aspect is for participants to have a conversation with a researcher about the work they are currently doing.[41] In addition, the discursive element of science cafés enables the participants to convey their own opinions and values to the researchers. Previous science cafés have enabled researchers to gauge the extent of public awareness of synthetic biology as well as **exploring public views on potential benefits, risks and concerns.**[42] As such, organisers should consider them as a forum for debate, where science and technology can be held to account, rather than a shop window for science.[41] However, the **informal nature** of science cafés **does not lend itself to**

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[38] Bultitude, K. and Sardo, A.M., Leisure and Pleasure: Science events in unusual locations, International Journal of Science Education, 34:18, 2775-2795, 2012

[39] Grand, A., Café Scientifique, Science Progress, 97(3), 275-278, 2014

[40] Navid, E.L. and Einsiedel, E.F., *Synthetic biology in the science café: what have we learned about public engagement?,* Jcom 11(04) A02, 2012

[41] Grand, A., *Café Scientifique, Science Progress, 97(3),* 275-278, 2014

[42] Navid, E.L. and Einsiedel, E.F., *Synthetic biology in the science café: what have we learned about public engagement?,* Jcom 11(04) A02, 2012

direct participation in decision making so organisers should consider them to correspond more to the rationales of informing and convincing, and opinion formation.

Guidance on conducting a science café on synthetic biology

Most science cafés follow the talk-break-discussion model.[41] The **researcher introduces the topic** for about 20-25 minutes, followed by a break for participants to refresh their glasses or get something to eat. A **discussion of an hour or so** then takes place between the researcher(s) and participants. Discussions between participants and other participants are also encouraged to provide many-to-many interactions rather than many-to-one.

When organising a science café event around synthetic biology, it is worth considering the following aspects:

- Many questions around synthetic biology concern the **ethical and societal implications** of synthetic biology, as well philosophical question about the creation of life. As such, involving researchers from the social sciences and humanities alongside scientists can be valuable in exploring the various dimensions
- The **choice of venue** can have a significant impact on the demographic of participants. For example, venues without good public transport links may limit diversity (principally less wealthy or older citizens who are more reliant on public transport). Venues such as pubs and bars may also prohibit those who do not consume alcohol, for religious or cultural reasons
- The use of **presentation software is often actively discouraged.[41]** Sometimes, this is because the venue is not designed for projection facilities and the use of them distorts the conversation space. Other times, it is because of the philosophical implications of technology getting between the speaker and participants
- **How the events are described and publicised** also affects who attends a science café. Highly educated individuals can be over-represented at science cafés[43] so the choice of event title and even use of the words synthetic biology should be considered
- Many science cafés **do not charge admission**, which often provides a more relaxed atmosphere since there are no concerns about managing tickets. If the plan is to charge admission to the science café (potentially to cover venue hire), it is worth considering the effect it might have on the diversity of participants. Generally said, charging admission should be avoided.

[43] Grand, A., *Café Scientifique, Science Progress,* 97(3), 275-278, 2014

Experiences
In 2011, the University of Bristol organised a science café with local science centre Explore At Bristol, as part of some experiential training for early career researchers. The café started with a leading scientist from the University, Professor Dek Woolfson, and an ethicist, Dr Ainsley Newson, giving their perspectives on the future for SynBio. We then had a break, during which the early career researchers chatted with members of the public on their tables, which were arranged in a cabaret format. Dek and Ainsley then took questions which had arisen from the table discussions and despite the size of the audience (over 70) managed to have a lively, informal discussion that focused mainly on key ethical questions.
Feedbacks showed people had enjoyed the event and felt better informed. Ainsley had some follow up contact from a couple of interested attendees.

4.4. Science theatre

What is science theatre?
At the most basic level, science theatre involves **the incorporation of scientific concepts and research in theatrical performances**. Science and scientists have been the subject of many plays, whether as the central focus such as in Michael Frayn's *Copenhagen* (whose story revolves around atomic physics and the scientists Werner Heisenberg and Niels Bohr), or as an additional facet of a wider story such as in Charlotte Jones' *Humble Boy* (where a father and son are both scientists but the play is about family relationships). However, there has been a recent trend towards collaborative science theatre, where scientists are actively involved in the development of the performance.[44] This collaboration can take many forms – from the researcher acting as an expert advisor or consultant on the scientific aspects to being an active contributor and even performer.

In its broadest sense, science theatre can include all forms of **performance activities based on a narrative**. This can include science comedy or stand-up shows, which use humour to get across scientific concepts that audiences may ignore if presented in a traditional way.[45] If these are performed by researchers it can also help break down negative stereotypes of scientists. Other science theatre models include informal locations such as street theatre, pop-up theatre, science busking and unstructured performance encounters. Science theatre also spans the range of theatrical models – from traditional performances where the audience are observers, to those where the audience are active participants or help shape

[44] Dowell, E. and Weitkamp, E., *An exploration of the collaborative processes of making theatre inspired by science, Public Understanding of Science,* 21 (7), pp. 891-901, 2011

[45] Pinto, B., Marçal, D and Vaz, S.G., *Communicating through humour: A project of stand-up comedy about science, Public Understanding of Science,* 2013

the direction of the performance. An example of the latter is *Deadinburgh*[46] – an immersive theatrical experience where the participants had to make choices in an epidemic scenario. Other ways of involving the audience include theatrical debates where the performers encourage discussion with the audience in between performed scenes.[47]

An advantage of science theatre is that it enables interaction with **audiences with an interest in arts and performance** but may not necessarily have prior knowledge of, or engagement with, science (although arts and science are not mutually exclusive).

What rationales does science theatre serve?

Traditional theatrical models position the audience as passive observers of the performance; as such, performances that use this model tend to focus solely on informing members of the public. However, the more **interactive and participative** the performance, the more opportunity there can be for stimulating **debate and dialogue**. It can also be used to explore people's responses to specific possibilities enabled by science such as emotional and social robots.[48] These responses can then be used by researchers when thinking about the direction of research. As such, organisers of science theatre activities should consider them to correspond to the rationales of informing and convincing, and opinion formation, depending on the nature of the performance.

Guidance on conducting science theatre on synthetic biology

Theatre and drama provide a medium through which **scientific information and ideas can be contextualised.**[49] They are also used to propose 'what if' questions, to explore controversial topics from multiple different perspectives, and to provide a personal dimension to scientific issues and an emotional connection to what otherwise may seem abstract. Because of its (potentially fictionalised) narrative, theatre is also an excellent way to introduce future scenarios based on scientific or technological development. An example of this involved a theatrical debate with semi-improvised scenes which showed what the future of nanotechnology in society could look like [4]. By showing these scenarios without a judgment or a solution, space was created for people's own ideas and opinions.

Whilst science theatre is becoming increasingly popular, many of the performances are developed for and by particular individuals and groups and are thus not easily adopted by others. In addition, there are few examples of performances around synthetic biology. As such, there may be need to create new performance-based activities that are tailored to the specific research area and the rationale for engagement.

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[46] *The Enlightenment Café: Deadinburgh:* http://www.lastheatre.com/portfolio/deadinburgh/

[47] *Nanopinion Theatrical Discussion Game: http://www.nanopinion.eu/sites/default/files/d3.3_discussion_game.pdf*

[48] *Heart Robot:* http://www1.uwe.ac.uk/research/sciencecommunicationunit/projecthighlights/heartrobot.aspx

[49] Dawson, E., Hill, A., Barlow, J. and Weitkamp, E. *Genetic testing in a drama and discussion workshop: exploring knowledge construction*, Research in Drama Education: The Journal of Applied Theatre and Performance, 14:3, 361-390, 2009

When organising a science theatre performance around synthetic biology, it is worth considering the following aspects:

- **Expertise in the performance medium** is required, as is knowledge of the scientific topic. Whilst these can occasionally be represented by a single person, it is more common for science theatre projects to be a collaborative effort, involving researchers and theatre practitioners

- It is worth **clarifying the role of the researcher at the outset** – whether they are providing expert advice or actively contributing or performing. For the latter, training in the performance medium is beneficial since the researchers may be good communicators but have little experience or knowledge of theatre[50]

- The **importance of accurately representing science** is cited as a reason for collaboration between theatre practitioners and scientist.[51] However, the precise and unambiguous use of scientific language does not always make good theatre, and complete accuracy can adversely affect the drama. As such, there needs to be a shared understanding about this tension between scientific rigour and dramatisation between the partners

- As with other sci-art activities, it is possible to create a piece of art (in this case a performance) that meets artistic criteria but fails to engage people about the actual research. There needs to be clarity between the collaborators over **the message that is to be conveyed or the questions** that are being explored

4.5. Laboratory activities

What are laboratory activities?

Laboratory activities require the audience to **actively engage in science**. People **experience** synthetic biology processes and materials by themselves and tend to better remember and understand methods and issues.

What rationale do laboratory activities serve?

Outside the research community, most people are not familiar with Synthetic Biology. As with any engineering process, conducting synthetic biology allows people to **understand Synbio** directly by experimenting. Laboratory activities can be used as an introduction to what SynBio is, and how to do it. Laboratory activities mainly serve the rationale of informing, and are part of **public understanding of science**. These activities can easily nourish a public dialogue based on what has been completed. If you cook with SynBio-made ingredients with an audience, you can start a discussion during the baking phase, asking people what they think about what they did, if they would eat it once it's baked, why, and so on…

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[50] Pinto, B., Marçal, D and Vaz, S.G., *Communicating through humour: A project of stand-up comedy about science*, Public Understanding of Science, 2013

[51] Dowell, E. and Weitkamp, E., *An exploration of the collaborative processes of making theatre inspired by science*, Public Understanding of Science, 21 (7), pp. 891-901, 2011

Organising laboratory activities

Simple experiments in the field of synthetic biology can be adopted for laboratory activities. Many initiatives already exist and **lots of SynBio activities are available on the Internet**. Some groups, like DIYbio even promote the possibility to doing serious SynBio experiments at home or in community laboratory spaces.

Where to find material?

The basic tools for synthetic biology can be divided in these two categories:

- Living organisms
- DNA manipulation tools

“There are no restrictions on obtaining the necessary supplies: you can buy the necessary chemicals, hardware, and strains from lab suppliers and teaching companies, and you can choose from a wide range of DNA synthesis companies to obtain primers for PCR and oligos for cloning”.[52]

National organisations and companies exist and provide kits for the purposes of SynBio activities. The Synenergene website offers many resources that could allow you to find the contact details of local institutions willing to help and inform you about local regulations and distributions.

Internationally, MIT (MA, USA) established and operates from 2003 the Registry of Standard Biological Parts,[53] a community collection of biological components that contains over 13,400 parts. The website provides information and help about SynBio and the use of biological parts. If you're a researcher in an academic lab, a member of a current iGEM team or iGEM lab, you can request a DNA part via the foundation’s website.

What are expected results?

Synthetic biologists apply engineering principles and extend genetic engineering techniques to construct new genetic systems. Participants design, experiment, test, and improve engineered biological systems.

Laboratory activities could have many objectives. Among other skills, participants could learn to:

- Explain how synthetic biology as an engineering discipline differs from genetic engineering
- Explain scientific concepts used during the experiment
- Realise simple scientific experiments in the field of SynBio

[52] Eric Sawyer, *Bio 2.0, Scitable by Nature Education*, USA, 2011

[53] Registry of Standard Biological Parts, USA, from 2003.http://parts.igem.org/Main_Page http://parts.igem.org

- Name and properly use laboratory equipment
- Define and properly use synthetic biology terms

Experiences – Museo delle Scienze of Trento, 'E.colight'

In 2013, MUSE – Museo delle Scienze of Trento – developed a new educational activity in SynBio. The topic was set up in collaboration with the University of Trento. The resulting project was the matter of a bachelor thesis in Biomolecular Sciences and Technology.

The didactic experience named *E.colight* is addressed to high school students in order to introduce scholars in the engineering of living systems and to the potential of SynBio applications. To date, over 100 students have trained in this experiment. Analysis of a satisfaction survey highlighted strengths and weaknesses of the activity. Students were more enthusiastic about using high-tech equipment and performing a series of hands-on steps, but they were impatient to see the results. Educators submitted both a pre-formative and an end-point evaluation to the students to help to estimate understanding and interest they have in the engineering of biology. Results were satisfying and encouraged the museum to go forward with the project and promote it as a mainstream educational activity.

Going further

Hands-on learning, especially in the context of controversial topics, should not simply involve manipulating materials. The opportunity should be taken to **engage participants** in a much deeper investigation of concepts, ideas, and ethical issues raised by the discipline.

Experiences – Copernicus Science Centre, Warsaw, Poland

"In Copernicus Science Centre we organised, the several-months-long GENesis Project, similar to Synenergene. The project concerned controversial issues dividing society, such as cloning, genetically modified organisms and tissue cultures, as well as their influence on our life, legal regulations, ethical norms and culture. Biological Laboratory was directly involved in the preparation of workshops with cell cultures. Participants learned how to work with sterile techniques and principles of working with cell lines. Additionally, we organised a workshop called Xplore Health, where students learned simple techniques of genetic engineering used in the production of new generations of drugs. Furthermore, we prepared a GMO activity – a GMO station, where people could conduct experiments that identify GMO soybeans in food. We used simple and very quick GMO ELISA test. By taking up difficult problems, we encouraged questions, exchange of views and sharing personal opinions and anxieties. It was a unique series of events dedicated to advances in biotechnology which featured a number of events attendees."

What are examples of experiments that you can carry out?
Various experiments can be found on the internet and can be a basis for the development of a laboratory activity. Of course, scientists and the communities of DIY Biology[54] are precious resources in helping organise laboratory activities.

4.6. Public participation in SynBio: working hypothesis and some lessons learned

Technical intervention on living organisms, particularly their reprogramming by SynBio, has a lot of potential scientific, ecological, ethical, economic and political consequences. However, people cannot contribute to the debate on these stakes if the SynBio projects are confined to the academic and industrial worlds. When media deal with these issues, it is most often to present the last feats in the field – such as the production of the first yeast artificial chromosome announced in March 2014 – and the promises of the industrial applications of the new biotechnology. Risks are not omitted. But only some NGOs and researchers intervene regularly in the public space to analyse and contextualise the projects and the diverse issues raised by the generation of synthetic or artificial organisms. Analysis and contextualisation are needed by citizens to grasp the complex reality of these scientific and technical developments and evaluate their relevance. Moreover, the own representations of citizens should be considered, even if they concern a domain where their absence or lack of knowledge is apparently a handicap. This integration is the condition of a living democracy in a strategic area. With this policy requirement, we argue public participation in synthetic biology brings opportunities to adjust to modern social challenges more innovatively.

Four challenges to involve virgin publics[55] facing complex projects supported by distant actors

Involving publics on SynBio implies to meet different challenges:

- Making SynBio innovation projects understandable
- Exploring stakes of SynBio without bias
- Describing the ‘scene of the actors’
- Making SynBio and ‘technomarket’ challenges a public affair

We would add that an evident challenge is not analysed in this toolkit: the necessity to give the public participation sufficient echoes in society, *via* media and internet communication relays.

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[54] Some DIY Bio communities are listed online the website http://diybio.org/

[55] The term ‘virgin publics’ refers to subsets of the population that have no or very small knowledge of the issues to be deliberated on.

Making SynBio innovation projects comprehensible: what are they doing, how and for which purposes?
The lay public has no clear mental representations of the objects produced in the labs and or their nature. The life cell and particularly artificial life cell, or chromosomes and components of the cell are still mainly 'figures of the unknown'. In this context, information by way of scientific popularisation can only be efficient in educated sections of the public. Consequently, we have to **invent new ways to get citizens interested**.

Public perception and representation will be considered, and will evolve, through **discussion and information with aware people** (researchers, students, industrial managers) over time. It is important to use different supports and sources of discussion and information to make the technical, economic, health, environmental and social dimensions of the projects visible. One suggestion is **making people move from a passive observer position to an active one**. This 'gives life' to the field via the SynBio representations that young scientists (e.g. iGEM teams) and artists can 'put forward on the stage' and confront. Concretely, developing cultural production is the anchorage and the resource of fruitful debates. People who would attend this process would progressively and naturally engage and talk about their own views, receive information, discuss and so on. The symbolic significance of the artistic works may raise concerns, interests, and mobilise political issues in a context where citizens will feel legitimate.

Exploring stakes of SynBio without bias
Any perception of bias at the beginning of a dialogue process would be counter-productive because participants may think they are being manipulated or involved in projects devoted to improving acceptability of SynBio. Yet the organisers of SynBio projects are not in positions where they can consider the diversity of stakes.

- ➢ The answer to that challenge is to **involve pluralistic points of views,** coming from inside and outside research and industry communities, and to give everyone sufficient time to express themselves with clear rules of functioning.

Describing the stakeholder scene

A **third challenge is to describe the actors** (scientists, institutions, NGOs, companies) entering the SynBio scene or a particular field of SynBio. This challenge refers to the necessity of having a clear view of the roles and responsibilities of the different stakeholders. Not in juridical terms, but to better know the interests, motivations, histories, aims, relationships, unknowns, uncertainties, sources of financing, etc., of the actors. As we have no means for thorough investigations, we should count on the stakeholders themselves to 'tell their stories'. The main obstacle to this challenge is therefore the reluctance to transparency of some of them, and their aptitude to adapt to different audiences.

- ➢ This approach can be facilitated by **connecting it with regional territories** where actors may feel that transparency has a good payoff. Some experiences as those organised within the Nanoforum induced the creation of local communities: in the area of Saclay for instance, a collective of citizen watch was set up. Such processes can become the crucible of autonomous action, where citizens forge capacities for investigations and questioning about goals and uncertainties of the SynBio projects

Making SynBio a public affair: the political sense of public participation

Involving the public is not only a matter of principle. It has a **political sense** and this can be a big motivation for lay people to be involved in the debate.

What does this mean? SynBio can have beneficial or harmful consequences depending of the synthetic objects created, their properties, and theirs actions within society and the environment. The development of new microorganism strains by SynBio can be compromised if the perceived risks are higher than the benefits, as was the case for GMOs in Europe. Public participation can be viewed as one of the means of an **efficient governance of the SynBio development**, i.e. governance able to preserve 'the common good' for society (living environments, health, social relationships). This concern leads us towards designing technical developments as engines of social progress.

There, the **challenge is to convince stakeholders** – even politicians – that early gathering and discussion of opinions represent **a 'win-win' strategy**. This mindset can be supported by many experiences of reflexive and constructive innovation,[56] which introduces interaction within projects. This approach has nothing to do with late-stage public debates. We think that people are no more confident in the influence of general debates. They better consider local and early contributions.

Description of SynBio dialogue processes organised in France

Any governance project of synthetic biology requires access to **information by citizens, active support for understanding their social, environmental and political dimensions**, **as well organisation of everyone's participation in order to adjust choices** regarding the commons. As far as SynBio projects relate to the living world – i.e. the fact they affect life forms directly or indirectly connected to our energy resources (even in confinement mode) – their design and control are a public matter (res publica).

[56] Arie Rip, Thomas J. Misa, Johan Schot (éd.), *Managing Technology in Society: The Approach of Constructive Technology Assessment*, Pinter Publishers, 1996.

For that reason, SynBio has been the subject of many political reports. In France, synthetic biology is monitored by the 'Observatoire de la Biologie de Synthèse' (Observatory of synthetic biology) set up by the Ministry of National Education, Higher Education and Research (MENESR). It aims at "the establishment of an upstream dialogue with all stakeholders and all audiences as it was also recommended by the report on the challenges of synthetic biology, written by Genevieve Fioraso for Parliamentary Office for the evaluation of the Scientific and technical choices (OPECST) in February 2012". In 2013, the MENESR established a public forum under the umbrella of the Observatory of Synthetic Biology.

In France, the association VivAgora[57] conducted different dialogues and interactions processes on SynBio between 2009 and 2013. Dynamics led by VivAgora involves a 'spiral process' including the following highlights:

- Six publics debates on the general theme 'Engineering the Living 2.0' (2009)
- Scenarios workshop based on narratives (2011)
- 'Assises du vivant" / "How much is life 2.0?' UNESCO, 30 November 2012

Furthermore, in the context of 'Toulouse White Biotech' demonstrator (TWB), a societal platform is also an interesting experience of reflexivity.

VivAgora 2009: debates cycle 'Engineering the living 2.0'

Between March and December 2009, a cycle of six debates around four axes was organised for 50-60 people already acquainted with SynBio: scientific stakes (which biology in the future?); social, cultural and geopolitical issues; industrial, economical and health perspectives; SynBio: is it really possible? This identification process mobilised 150 people more or less concerned by this emerging technology (futurists, academic experts, industry leaders and associations). A pluralist steering committee (initiated by VivAgora) helped to involve a broad spectrum of specialists

This plan of action, which can be compared to a stakeholder's dialogue, has a big flaw regarding public participation: it is not designed to involve lay citizens or a broad range of people. The main goal was to provide a platform to gather stories of experimentation, representations, state of mind with a small community. The six sessions were filmed and recorded. The videos were indexed according to the method of semantic web experienced by IRI (Institut de recherché et d'innovation). They resulted in the production of information materials and reflection: sheets benchmarks, reports, etc.[58]

[57] VivAgora is an NGO involved in organising debates on societal issues raised by scientific and technological innovations. By promoting the expression and inclusion of all stakeholders, and exploring the diversity of their views and goals, it seeks to build trust and promote a new culture of innovation. In a world where risks and uncertainties are increasing, VivAgora want to make sure those scientific and technological developments benefits the community at large.

[58] All these texts are available at: https://web.archive.org/web/20130621080157/http://www.vivagora.fr/index.php?option=com_content&view=article&id=435:cycle-2009-ingenierie-du-vivant-20-la-biologie-synthetique-en-question&catid=21&Itemid=111

The main results were:

- A **lot of key questions were identified**, first regarding the dialogue, but also in society. Such a dialogue is a tool to unscrew the 'lid of the SynBio cooking-pot'. Questions included: what are the differences between SynBio and GMOs? Is it science or is it engineering? What are the motivations of their promoters? What is a synthetic life? What are the alternative uses of the living world?
- Such a process shows the **diversity of the opinions and representations** and initiates an inventory of the actors/stakeholders involved in SynBio. Synbio appears as a very diverse field, not a unique one with common aims. The confrontation of the opinions is also instructive: it shows that even complex issues should and can be debated as they convey socio-economic issues.
- The procedure can be improved by methods resulting in interesting information usable for general public dialogues and building a **common knowledge base**. For instance, the 2009 process used a mind-mapping utility that involved drawing a 'city' of key concepts.

➢ As a conclusion to this experience, relatively **specialised stakeholder dialogues** seem to be **complementary to general dialogue** processes involving lay people as a mean to make some issues visible and to nourish debates, either by preceding them or along a parallel agenda.

VivAgora 2012: The 'Assises du vivant'

This event was organised with the UNESCO during two days in November 2012. The audience comprised 300 persons partly unaware of the SynBio field. The main theme was the bio economy ('life 2.0') where biotechnology and SynBio were explicitly presented as foundations of its developments. The event consisted of conferences and focused group workshops – one of them dealing specifically with SynBio.

Ahead of the event, a dynamic association mobilised 30 different organisations (mainly NGOs). Their contributions were the production of a newspaper called *Last news from life* where every organisation was invited to explain its vision of life: biomimicry, natural capital, bioart, biodiversity, agroforestry, etc. Moreover, a satellite event called 'Student Generation: to a bionic superman?' was held on 29 November 2012, in partnership with the Science Centre Pierre-Gilles de Gennes, Paris. The aim was to avoid the division in academic disciplines in order to permit students an ethical dialogue on modifying life. Seven student teams from

Sup'Biotech, ESIEE Management, ENSCI Design, Evry University Master of Biotechnology Law and three iGEM's teams contributed.

The satellite event resulted in the following outcomes:

- Fresco on the futuristic technical potential: integrated human memory card in the human body
- Animated film on biotechnology of the future
- A role play about a trial of a man-machine

And four presentations on different themes:

- To be or not to be a frame?
- The bionic as recovery tool equality between men
- Invisibility: a superpower
- The bionic: can it respond to current health issues?

A 'molecular soup' was made by the artist Olivier Goulet. This made people see movements of 'animacules'. Reactions to this absorption were recorded.

The event was attended by about 60 people, creating a friendly space for reflection (bioethics, legal) and development of student interactions. Participants expressed the desire to have a bioethical and legal forum in 2013.

Regarding direct public participation, the main critics' concern the **passive posture of the citizens** during the conferences and the punctual aspects of their active involvement during workshops. A punctual two or three hour workshop cannot be very fruitful for organising constructive confrontation of the opinions; it is a good approach for informing and highlighting some issues.

A 'big event' like the 'Assises du vivant' has some indirect payoffs that complement dialogue processes involving lay citizens:

- It is a **good way to mobilise associations, NGOs** and their own public.
- The issues appear as '*res publica*', a common affair.
- Despite the difficulty in presenting diverse opinions, it is open-minded and pluralistic, and **conveys diverse concepts and experiences** that people are not used to hearing during bioeconomy presentations – such as biomimicry, agroecology, and bioart.
- The UNESCO partner gave an **international tonality** to the event, reminding everyone that biology and biotechnology have geopolitical stakes.
- A call to '**produce a common world**' was launched at the end of meeting:[59]
  "VivAgora and their partners gathered at UNESCO call for dialogue and accountability to bio-economic projects. They demand the establishment of a 'repository to protect potential living' (ecosystems, biodiversity, soil, water...) to give his life to innovation and social value."

This event and the heavy involvement of partners show that **we need a progressive spiral inclusive process for sharing common landmarks**. Mutual recognition is a condition for cooperative production. We consider that different publics can be included step by step, by interlocking initiatives and respecting the dynamics and patterns of each stakeholder groups.

VivAgora 2012: narratives scenarios workshops

In 2012, VivAgora could rely on identifying key players in synthetic biology and controversial topics to structure the ingredients of future scenarios. The VivAgora team offered to lead creative sessions to respond to three fictional stories produced by a writer. The objectives were to help lay people to project themselves into a future imagined from real possibilities and to engage with the situations emotionally.

The first workshop consisted in a group of nine lay participants with no prior knowledge about SynBio, and lasted five hours. A day-long conference and debate was organised three weeks later with 70 participants including the nine contributors.

During the day one, three fictional narratives written specially by a science-fiction writer, Claude Ecken, and read before the meeting, were analysed and discussed. The narratives described the same future world where ideas and applications of SynBio are 'real': pollutants sensors organisms, artificial cell tissues (e.g. interchangeable bio-skin), bio-

[59] http://www.reporterre.net/spip.php?article3601

buildings, daily genomics and xenobiology, bacterial paintings, genes traffic hunting, nanomachines, targeted bioterrorism threats, etc. This future world had three different evolutions frames with varying degrees of pessimism or optimism, i.e. with some social negative or positive perspectives or outcomes.

The aims of the dialogue were:
1) To **give a cultural imprinting on SynBio** by starting with the own perceptions and questioning of citizens
2) To **get people absorbed in this future world**, placed in an imaginative situation where they could identify with the characters, understand the uses of synthetic objects and where they could question the future: artificial *vs* natural, cultural standardisation (*e.g.* same synthetic meat everywhere?), threats on biodiversity, economical access to science progress, prevention *vs* technological protection (*e.g.* against pathogens), evaluation of the different values of innovation (social, economic…), etc.
3) From that, they could **go back to our world and the current SynBio** with the help of information given by scientists, sociologists and philosophers during the second day's conference sessions and debates

There were some negative aspects in this project: there's was significant **difficulty mobilising people** chosen on a random basis. A lot of time was devoted to phone calls with little result; a **few echoes in the press and on the internet** before, during and after the meetings. These drawbacks could be avoided with more time dedicated to the preparation and investments in the communication of such events.

However, from our point of view, as far as public participation is concerned, the lessons learned from that experience have positive aspects:

- The **cross-awareness of the issues** from different points of view, not only from science or technical ones, was real
- A **lot of concepts were raised and discussed** by the 'lay' participants, notably around the senses of synthetic or artificial objects/organisms vs natural ones
- The information from philosophical, SynBio and sociological sources doesn't come before the assembly of participants in a complementary manner. We therefore **avoid 'formatting' the participants**: informative answers to the questions they generated collectively, it doesn't prescribe what they should think about SynBio

Results

This narrative scenario process has **produced three stories** ('The barrel of biogenic', 'The nymph E. coli', 'At the DNA East') **of possible futures** that have generated many reactions of enthusiasms or dislikes. During the workshop, the participants had many discussions on:

- Artificial versus natural

- Artificial standardization? The case of feeding
- Biodiversity under threat?
- Haves and the rest of humanity
- Protection, medicalisation and risks
- Biosensors and bio-indicators: prevent pollution or monitor and alert?
- The issue of choice and collective choice vs. individual choice
- Technological promise
- Can humans do better than nature?

Participants concluded with 'How to measure the value of an innovation?'. Asking themselves if 'Artificialised this world is it progress?' They were happy to be involved and imagine the future. They learned many things and felt concerned.

The Observatory of Synthetic Biology and its forum (2013)

The creation of the Observatory of Synthetic Biology (OBS) addresses the wish of public authorities to follow the development of emerging scientific disciplines and facilitate a balanced, reasoned debate within society. It follows the recommendations of three reports:

- *'Synthetic biology: the conditions for a dialogue with the society'*, by the Institute for Research and Innovation in Society (IFRIS), commissioned by the MENESR
- *'Synthetic biology: developments, opportunities and challenges'*, by the working group of the scientific sector 'Bioresources, ecology, agronomy' and animated by the biologist François Képès
- Report on Issues in Synthetic Biology, written by Geneviève Fioraso, deputy for the Parliamentary Office for Scientific and Technical (OPECST) in February 2012

The Observatory, located at the Conservatoire national des arts et métiers (CNAM), is controlled by two entities: the coordination unit and the board of orientation. The Forum Synthetic Biology of the observatory has been designed as a space for open and pluralistic debate, allowing exchange of information, knowledge, and expression/confrontation of different views on synthetic biology.

The first meeting, on April 25th, 2013, was conceived as a dialogue centered on a controversy: does synthetic biology exist (is it new or not)? About 80 people (lay audience) gathered for the debate. Unfortunately, the **debate did not take place because of protests by the activist group 'Pièces et Main d'oeuvre' (PMO),** well-known for its opposition to public debate on nanotechnology. Another debate hasn't been scheduled because the Observatory would rather develop other forms of interactions, such as online forums.

Results

The Observatory of Synthetic Biology provides access to a useful website as an educational resource for tracking news or events.[60] However, it is used by people who are already aware of SynBio.

In France, the **failure of the Observatory's first forum has generated fear of discussing synthetic biology**. This reinforces polarized viewpoints and prevents a more democratic culture in the technical field.

Socio-technical study of the Toulouse White Biotechnology project

Toulouse White Biotechnology (TWB) is a pre-industrial demonstrator that supports the development of innovative biological tools (new enzymes and microorganisms, microbial consortia) to produce chemical molecules, biopolymers, biomaterials and biofuels based on the use of renewable carbon.[61] It integrates an ethics platform led by the Higher School of Science Ethics of the Catholic Institute of Toulouse, with two complementary studies:

- One conceptual study to **better locate nanobiotechnologies**, based on paradigms such as 'natural/artificial' and 'life/living'
- A long-term analysis of **social impact and social acceptability** for all pre-competitive projects developed by the TWB consortium

Moreover, the 'Génotoul' platform[62] directed by a sociologist, Anne Cambon-Thomsen, oversees a study about the actors engaged in the TWB consortium. The study was realised partly in 2013-2014 by students of the Master 2 'Environment management and territorial resources valorization' (GsE-VRT) from Albi University.

Thus, 21 students explored the **representations of scientists, their practices and their visions of the potential consequences of the biological objects** they are building. The approach was a 'constructivist' one able to identify and analyse diverse cognitive, psychological and technical mechanisms and processes engaged in the production of new organisms and biological tools.

The students organised 22 interviews with eight researchers, five managers of experimental platforms, eight administrative people and one industrial representative. Some of them participated to an 80-person meeting on the ethics of life technologies, in November 2013 and 'Genotoul' workshops in 2014. Finally, the students wrote a report entitled 'Socio-technical approach of the relations sciences/nature/society within the actors of SynBio'. It underlines the difficulties researchers face with regard to breaking out of their own logics. For instance, in the researchers' opinions, the environmental risk of SynBio objects is very

[60] http://biologie-synthese.cnam.fr/

[61] http://www.toulouse-white-biotechnology.com/

[62] http://societal.genotoul.fr/index.php?id=275

low since the “news organisms are not made to survive” and therefore “risks are under control”.

From our point of view, such a specific process is interesting from a public participation perspective. Indeed, it **emphasises a general perception of science** as a closed world which decides its own alliances. Contrary to what people might think, it is probably not a voluntary ideological attitude on the part of scientists that determines this partition, but a network of complex relationships, behaviours and habitus. Thus, public participation can be considered a force which can help shape the reflexivity of the science world and open it to society, no longer acting as a force definitively exterior to scientific and technological logics. Of course, this is not an argument that can motivate people towards involvement; however, it can be helpful for the organisers of public participation events.

Conclusions

The VivAgora process was carried out according to three steps:

- State of play with a small circle of people involved
- Shares in various forms of information to a wider audience, as opportunities
- Mobilisation of citizens by an imaginary projection into the future

This process is based on the idea that **information is not pre-existing and not only forged by synthetic biology’s actors**. It designs diffusion as a natural process, using the usual channels of propagation of new ideas into society. It allows the initiation of contradictory and pluralistic debate. It depicts a fictional projection into the future to capture the perceptions and questions of an uninformed public.

The tracking of problems was conducted from civic issues in a continuous interaction to metabolise **cross-cutting issues** (legal, ethical, societal). The result was the **building of a common culture** among a small number of people. The evaluation of this informal stage is difficult.

Mobilising virgin citizens (picked from the phone book at random) was a hard job but it is the condition to gather a representative overview of emotions (attraction, repulsion, etc.).

Ultimately, these initiatives have given some **visibility to SynBio in the public arena**. They created an **initial dialogue between academic and industrial players**. They played a role in foresight, for instance, through contact with the Centre for Strategic Analysis, which published two papers on SynBio – partly from the findings presented at the VivAgora’s 2009 cycle.

The **four challenges expressed** in the introduction will be considered for each process in terms of four criteria of assessment:

1) **Public interest** (quantity and quality) to provide benchmarks of understanding of what is happening. Here, we pay attention to the diversification of information media (websites, blogs, citizen watches, etc.) and the fluidity of keywords and emerging themes

Criteria for success: The audience should have an active attitude in order to build information as a landscape of meanings. The diversity of mobilised stakeholders and their interactions are the condition for prioritising the scenarios

2) **Imagining the future and the alternatives** with all the stakeholders and considering their perceptions of the SynBio world. Considering all issues in terms of rupture, value, risk, state of mind, etc.

Criteria for success: Contrasting views, opinions and controversies, unknowns and uncertainties, understanding complexity, independent judgments. Are they made visible?

3) **Identifying the different actors and their interests, and mapping of the projects** (understanding the priorities of each group of stakeholders).

Criteria for success: Balanced involvement of all stakeholders; alternatives building capacities; clarification of investments and costs

4) **Influencing the innovation and governance of synthetic biology processes**; sustaining responsible practices and policies integrating the commons; preventing non-constructive conflict and increase trust

Criteria for success:

Respect of the social contract between participants; clarifying roles and interests; characterisation of the leeway regarding alternatives; producing opinions, positions or guidance on responsible innovation.

The various approaches embody **different priorities for the public**. They can be analysed according to the **degree of stakeholder participation**. Confrontation with an unknown field forces us to propose a gradual increase in public engagement, starting from an information process, (questioning, crossing issues) to cooperative forms like workshops scenarios. The question of the **extent of government commitment** is essential: the public can be motivated to learn, but they only engage in sustained participation if their **contributions are guaranteed to have some impact**; but only a **process mandated by policies** can assume that dimension. This is the case of the CNAM Synthetic Biology Forum ...but the only meeting was spoiled. The authorities could establish a culture of dialogue by giving the dynamics of interactions to non-partisan and pluralistic entities, not just from academics. For example, The NanoForum (2007-2009), with its pluralist steering committee, which was able to build pragmatic relevant dialogues, was welcomed by the sociologist Pierre Benoit Joly (Conditions for dialogue with society). In France, there is a great distrust of political acceptability proceeding by manipulating people towards a specific vision of the future. For many NGOs, the humanities are manipulated to make acceptability.

Finally, as for the challenges mentioned in order to make public participation on SynBio possible and desirable, based on well- analysed processes, the approaches described can be summarised in the following table.

CHALLENGES FOR PUBLIC PARTICIPATION	Making SynBio projects comprehensible	Exploring SynBio stakes without bias	Describing the stakeholder scene	Making SynBio a public affair: a political sense
APPROACHES AND TOOLS	**Perceptions, representations, information tools**	**Pluralistic contributions, time, clear rules of functioning**	**Cartography of roles and responsibilities, social contract**	**'Giving life' to the field: SynBio representations of scientists and artists**
Cycle of debates	++: A lot of key questions made visible	+/-: Diversity of points of views but difficulty to present all of them	+: General description of the actors	**+/-**: can be if the cycle is organized for that purpose
Conferences and workshops event	+: Some key questions and new concepts made visible	+/-: Mobilise NGOs but difficulty to present all of sensibilities; bias possibly perceived	+/-: Some actors appear; cartography possible if dedicated tools are used	+: appear as "*res-publica*" with an international tonality
Narrative scenarios workshops	++: Cross-awareness of the issues; lot of concepts raised and discussed	++: No 'formatting' of the participants	-: not dedicated to that	++: imaginative situation where participants can identify applications and can freely question the field
SynBio Observatory	++ Monitoring the news	+ Diversity of points of views but a focus on academics	-: not dedicated to that	-: not dedicated to that
Socio-technical study of SynBio projects	-: not dedicated to that	-: not dedicated to that	+/-: interviews of different representatives of a SynBio project	+: underlines the own logics of the SynBio community; public participation as a force to shape the reflexivity of the science world

5. Conclusion

Synthetic biology (SynBio) represents the latest phase in the development of biotechnology. The SynBio approach allows the **construction of new biological parts, functions, and, in the future, entire organisms** by redesigning existing ones or building them from scratch. The development of this new field is fostered by an increasing knowledge gained by the study of natural micro-organisms, the development of computer modelling, and the reduction in price of DNA sequencing technologies.

Large **public databanks** now offer information about individual gene sequences that can be thought of as 'building blocks'. Engineering principles are used to combine these building blocks into complex systems, creating new biological systems with the aim of providing news functions and answers to some societal issues. SynBio-based biological systems could have applications in the production of biosensors, biofuels, pharmaceuticals or biomaterials. Thus, the field of **SynBio seems to have potential to address some of the greatest challenges of facing today's societies.**

However, SynBio **also raises crucial ethical, legal, and social aspects**. Although many regulations around biotechnologies already exist, **revising them in response to** SynBio is essential. Besides the great benefits SynBio could bring to society, **potential risks must be considered and evaluated**.

The fair allocation of the benefits and burdens of synthetic biology, the aggravation of existing inequalities at a global level, the accidental or intentional release of uncontrollable organisms developed with SynBio, are just some of the issues raised by the new field. Among them, some risks and misconceptions especially target specificities of the SynBio field. For instance, the 'playing with God' metaphor is a powerful phrase that is often used by media to describe activities linked to SynBio, in relation to the fact that scientists potentially create new organisms. Additionally, the variety of stakeholders involved in SynBio developments can be a concern, as SynBio is not only developed within scientific institutions. Indeed, the accessibility of DNA sequencing tools and data on gene sequences have allowed the development of movements that involve amateurs, like DIYbio or the iGEM competition. Diversity is a positive driver of scientific development, but misunderstanding about what these different communities are doing and how their activities are regulated can lead to negative perceptions from society. Finally, arguments persist about fixing an official definition of SynBio. This can make understanding the field difficult for the public.

There is currently a real convergence between the need for developing policies around SynBio and **anticipating the reactions and expectations from society**. The opportunity for public engagement provides a unique case of anticipatory governance. Citizens are given the opportunity to learn about SynBio, discuss its potentials, tradeoffs, and risks, and can get involved in assessing policy before the field gets wider public attention and the regulations are decided.

Discussions about SynBio may be carried out in various ways. However, involving lay audiences in public engagement activities implies a variety of challenges will be met, such as making SynBio understandable, exploring stakes of SynBio without bias, identifying the stakeholders involved, and making SynBio challenges a public affair. The public can be involved in activities at different levels, depending on the intentions and objectives adopted by the organisers. **Choosing a clear rationale** to address SynBio is essential: is the aim of the activity informing, forming opinions, or fostering participation in public decisions? As described in the present toolkit, there are lots of different formats to approach SynBio.

In projects like Synenergene, **mutual learning processes are at the center** of these public engagement activities. By understanding each other, and sharing ideas and knowledge, participants in science communication activities will learn from and with each other. The public acquires a better understanding of SynBio and develops an opinion. Such activities can result in fostering responsible research and innovation within the field.

To ensure public engagement in SynBio is successful, it is useful to look back and learn from each other's initiatives. As an emerging field, few public engagement activities about SynBio took place before 2015. The VivAgora processes give some examples and results of completed initiatives. These projects highlight some key questions raised by SynBio in non-expert communities such as: what are the differences between SynBio products and GMOs? What are natural and synthetic lives? Is it science or engineering? A great diversity of opinions and representations appeared to profile SynBio as a very diverse field that can be debated through its different fields of implication (economic, technical, scientific, or social). Methods were identified as an essential key for reaching specific objectives of public engagement. Still, direct and active participation of the public can be difficult and organisers need to be aware of the challenges they face and share the lessons they learn.

Exchanges of practices and the development of innovative forms of public engagement in SynBio are foreseen in the **Synenergene project until 2017**. Science centres and museums, in collaboration with universities and other science communication organisations, will **develop and test some innovative events and activities** about SynBio. Alongside the knowledge discovered by stakeholders, evaluation of the project will be a precious resource with which to improve the way SynBio is communicated to the public.

6. Glossary

Entry	Definition	Source
Bio-bricks	Standardised 'biological building blocks' used for the construction of components that carry out specific tasks, which can in turn be used to construct more complex biological systems.	The Health Council of the Netherlands 2008
Biosafety	Biosafety refers to the development and implementation of administrative policies, microbiological practices, facility safeguards, and safety equipment to prevent the transmission of potentially harmful biologic agents to workers, other persons, and the environment. Containment is used to describe safe methods, facilities, and equipment for managing infectious materials in the laboratory where they are being handled or maintained	OSTP n.d.
Biosecurity	The term biosecurity refers to the protection, control of, and accountability for high-consequence biological agents and toxins, and critical relevant biological materials and information within laboratories to prevent unauthorised possession, loss, theft, misuse, diversion, or intentional release	OSTP n.d
DNA synthesis	A technology that enables the de novo generation of genetic sequences that specifically program cells for the expression of a given protein	The National Academies 2011
Do-It-Yourself	Do-It-Yourself Biology, or DIYbio, is a global movement spreading the use of biotechnology beyond traditional academic and industrial institutions and into the lay public. Practitioners include a broad mix of amateurs, enthusiasts, students, and trained scientists, some of whom focus their efforts on using the technology to create art, to explore genetics, or simply to tinker	Grushkin et al. 2013
Dual use	Dual use goods are products and technologies normally used for civilian purposes but which may have military applications	European Commission n.d.
Ethical, Legal, and Social Aspects (ELSA)	The acronym ELSA refers very broadly to research on the ethical, legal, and social issues that accompany scientific and technical change	Thompson 2010

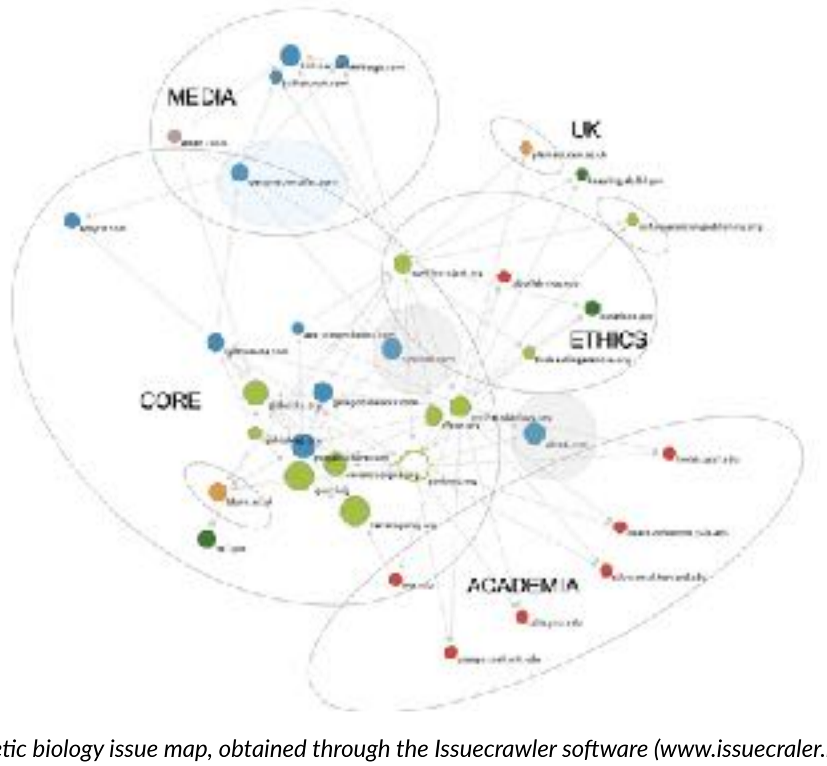
Entry	Definition	Source
Framing	A mode of interpreting and, thereby, co-constructing SynBio, to make it accessible for debate. Typical frames in case of SynBio are: risk, ethics, economics, and societal aspects	
iGEM	The International Genetically Engineered Machine competition (iGEM) is an undergraduate Synthetic Biology competition. Student teams are given a kit of biological parts at the beginning of the summer from the Registry of Standard Biological Parts. Working at their own schools over the summer, they use these parts and new parts of their own design to build biological systems and operate them in living cells	iGEM n.d.
Patent	A patent is an exclusive right granted for an invention. Generally speaking, a patent provides the patent owner with the right to decide how – or whether – the invention can be used by others. In exchange for this right, the patent owner makes technical information about the invention publicly available in the published patent document	WIPO n.d.
Public engagement	A broad range of mechanisms and activities aimed at involving individual members of the community in making decisions about management of economic, environmental, and health risks and benefits.	Besley 2010
	Public engagement describes the myriad ways in which the activity and benefits of higher education and research can be shared with the public. Engagement is, by definition, a two-way process, involving interaction and listening, with the goal of generating mutual benefit and realised a public assessment of research and innovation (including thus SynBio).	publicengagement.co.uk
Responsible innovation	Responsible innovation means taking care of the future through collective stewardship of science and innovation in the present	Stilgoe et al. 2013

7. Annexes

1. SynBio's ELSA in the Web

Which are the websites communicating about the development of synthetic biology that are most linked to each other? Considering web discussions on SynBio is a vital source of information for science communication practitioners.

The map below shows four main clusters of websites around the synthetic biology issue, building up a network because they co-link: a **core** part of the network, with reference to the iGEM competition and private companies in the SynBio business, a **media** cluster consisting in websites of journalistic coverage of synthetic biology (like techcrunch.com, wired.co.uk, theverge.com, and – more central to the network – nytimes.com) an **ethics** cluster, with websites such as bioethics.gov and thehastingcenter.org, and the **academic** websites (.edu domains). Is it relevant to note that most present European websites in the network are in the UK.



Synthetic biology issue map, obtained through the Issuecrawler software (www.issuecraler.net)

2. ELSA concepts in the social sciences

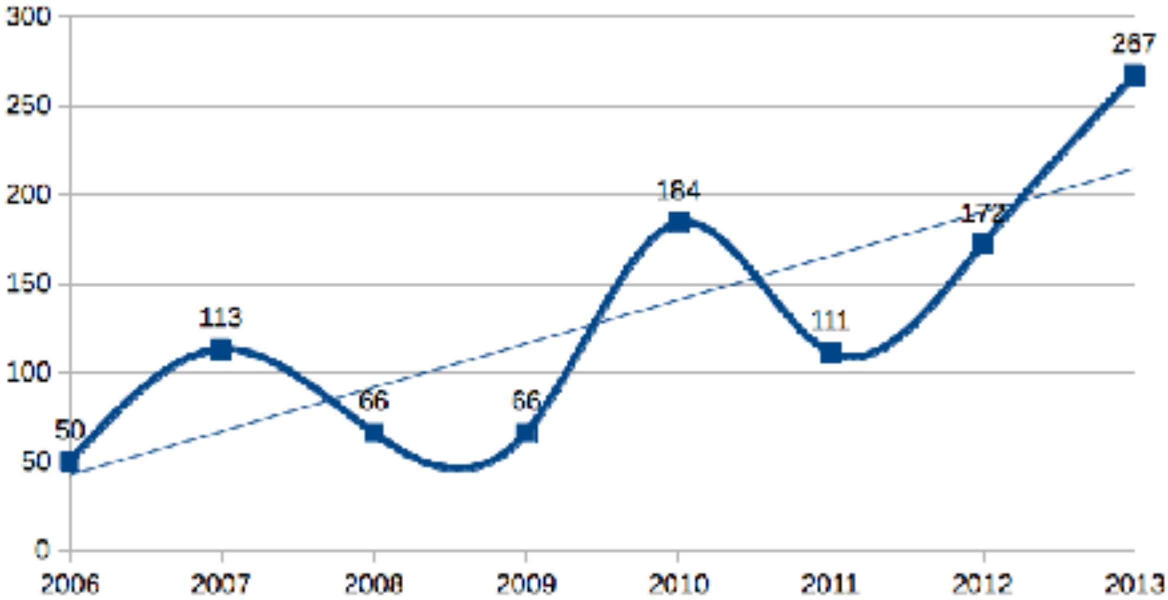
One of the most fruitful ways to reflect on Ethical, Legal, and Social concepts for public engagement in synthetic biology is to consider the keywords used by social scientists for synthesising the content of their papers.

The table below displays some of the keywords referring to ethical, legal, and social issues used by social scientists; their frequency (under parentheses) has been gathered through the Scopus database, social science subject area, years 1989-2015.

Keywords generated by authors of papers cited in social science & humanities literature about synthetic biology (Source: Scopus database).
Biotechnology (39)
Biology (23)
Design (19)
Artificial life (11)
Biofuels (11)
Assessment (7)
Governance (6)
Education (6)
Standards (6)
Bioethics (5)
Creation (4)
Reflexivity (3)
Biological weapons (2)
Precautionary principle (2)
Science policy (2)
Bio-bricks (2)
Collaboration (2)
Human practices (2)
Imaginaries (2)

3. Synthetic biology in newspapers, a growing attention

Even if synthetic biology is not much considered a trending topic in the mass media (and it's certainly not at the levels of previous controversial technologies such as GMOs), if we analyse coverage of the issue, an increasing trend in newspaper attention is visible over the



years.

The chart below displays the number of newspaper articles on synthetic biology that are listed by the comprehensive Lexis/Nexis database for each year in the period 2006-2013. 2013 was the year with the highest coverage, with 267 articles published in the English language press.

Relevant ethical, legal, and social aspects have however peaked coverage in the media in 2010, when reports announced 'creation of artificial life' by Craig Venter, and the prominence of keywords such as 'risk', 'regulation', 'playing god', 'dual-use', 'do-it-yourself', 'biological weapons', 'bioethics', and 'artificial life'.

Opinions matter: awareness, attitudes and the public debate

Knowing peoples' opinions and attitudes is crucial when planning and implementing engagement exercises.

Surveys on synthetic biology (Hart 2008, 2009, 2010, 2013) offer some instructive insights on at least a few of the factors that can be relevant in public debates and can affect the public opinion: information available and provided to the participants to the debate, arguments that are used in the discussion.

Results show a rather constant scenario over time, as shown in table 1 below, with around 25% of people informed on synthetic biology thinking that benefits will outweigh the risks, 35% thinking that risks will outweigh the benefits, and a growing percentage of people, from 29% in 2008 to 38% thinking that benefits and risks and benefits are equal.

	Benefits outweigh risks	Risks outweigh benefits	Risks and benefit are equal	Not sure
2008	28	35	29	8
2009	25	35	34	6
2010	26	33	37	4
2013	24	33	38	5

Informed opinions on risks and benefits of synthetic biology, percentage values (Source: Hart 2008, 2009, 2010, 2013)

These public opinion data thus show us that the majority of people equals risks and benefits, and that there's a little prevalence (10%) of the public thinking that risks will outweigh benefits.

Not only information as such, but also what piece of information is given has relevance in shaping public attitudes. In the UK survey implemented by the Royal Society,[63] over six out of ten (63%) respondents agreed with the statement "creating new man-made micro-organisms that will produce medicines or biofuels should be supported", with a third of respondents (33%) agreeing strongly. Yet, using a statement absent of any context or purpose regarding possible applications, 41% of the same pool of respondents said that "the idea of man-made microorganisms is worrying", a significant proportion (28%) neither agreed nor disagreed, and a similar number disagreed (about 13% disagreed strongly).

Drawing on the data of the Euro-barometer survey on biotechnology,[64] discovers that 52 per cent of European citizens opt for a governance of synthetic biology based on advice from experts and on scientific evidence about the risks and benefits involved, instead of on the general public's view and on the moral issues involved. These results distinguish synthetic biology from other fields (e.g. for animal cloning, respondents choosing deliberation are some 10 per cent fewer and 9 per cent more opting for moral deliberation). However, a plurality of about 25% of respondents in EU27 takes the opposite view: it is the public, not experts, and moral concerns, not risks and benefits, that should dictate the principles of governance for such technologies (the principle of 'moral deliberation').

A 2013 survey in the US provides some information on the related issue of regulation. Data show that nearly equal proportions of adults say that synthetic biology research should be regulated by the federal government (45%) and that voluntary research guidelines should be

[63] The Royal Academy of Engineering, Synthetic Biology, *Public dialogue on synthetic biology*, London, UK, 2009.

[64] George Gaskell, Sally Stares, Agnes Allansdottir, Nick Allum, Paula Castro, Yilmaz Esmer, Claude Fischler, Jonathan Jackson, Nicole Kronberger, Jürgen Hampel, Niels Mejlgaard, Alex Quintanilha, Andu Rammer, Gemma Revuelta, Paul Stoneman, Helge Torgersen and Wolfgang Wagn, Europeans and Biotechnology in 2010. Winds of change?, Brussels, European Commission, 2010.

developed jointly by industry and government (43%).[65] This most recent survey sees the support for government intervention down from the past, when in 2008 52% believed that synthetic biology research should be regulated by the federal government.[66]

[65] Hart Research Associates, Awareness & Impressions of Synthetic Biology, a report of findings based on a national survey among adults, conducted on behalf of: Synthetic Biology Project The Woodrow Wilson International Center For Scholars, USA, March 6, 2013.

[66] Hart Research Associates, Awareness of And Attitudes Toward Nanotechnology And Synthetic Biology. a report of findings based on a national survey among adults, conducted on behalf of: project On Emerging Nanotechnologies The Woodrow Wilson International Center For Scholars, USA, September 24, 2008.

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