Valencia iGEM Team 2009

Sins, ethics and BIOLOGY

a comprehensive approach

This book is dedicated to our friends and family.
Thank you for supporting us during these crazy months!

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Synthetic Biology is a revolutionary scientific discipline. The ability to design and construct new biological systems with useful properties opens up a challenging scenario for the technological development of humanity. However, new science needs new regulations, and Human Practices dealing with Synthetic Biology must be defined in order to provide an ethical, legal and regulatory framework within which this novel scientific area can develop.

Sins, Ethics and Biology, a Comprehensive Approach, is more than just a review on Human Practices and Synthetic Biology: it encompasses a classical review of scientific reports on HP; the first comparative analysis of previous iGEM HP projects; interviews with well-known experts; and the largest survey on ethics and Synthetic Biology ever made.

The goal of this book is to help researchers and people interested in SB to assess the new risks, possibilities, and ethical issues of this discipline. We hope you will enjoy reading it as much as we enjoyed putting it together!

The Valencia Team

INTRODUCTION

THE REVIEW

In the following pages you will find a review about what has been written in specialized journals about Synthetic Biology and all its ethical implications.

What was and is Synthetic Biology?

Nowadays the term Synthetic Biology is widely used in the scientific community, but its definition and goals differ among scientists. The French chemist Stéphane Leduc was the first to use the term in 1912[1], he was thinking of creating life from inanimate matter and although some might agree (one century later) that this is one of the main goals of the field, there is certainly much more to SB than this.

For a more recent quotation of the term, we have to go back to 1978, when Szybalski and Skalka extended its meaning, bringing it closer to what SB is considered as today:

> *"The work on restriction nucleases not only permits us easily to construct recombinant DNA molecules and to analyze individual genes, but also has led us into the new era of 'Synthetic Biology' where not only existing genes are described and analyzed but also new gene arrangements can be constructed and evaluated."*
>
> Szybalski, W. & Skalka, A.[2]

Nowadays, experts usually agree that there are at least two main ways to look at SB, the Top-Down and the Bottom-Up approaches[3], [4]. The Top-Down approach focuses on designing and creating working biological devices and, to do so, it aims to create a minimal genome (a "chassis") and the standardization of parts of DNA with known function (to make it easier to assemble them). The Bottom-Up approach tries to understand evolution and the origin of life by creating it from inanimate matter, which is why protocells are so important in this new field. But, is Synthetic Biology a new field?

Synthetic Biology...

is a research field that combines the investigative nature of biology with the constructive nature of engineering.

Purnick PE, Weiss R.[6]

Applying Engineering to Biology is not new and, in fact, Synthetic Biology has a lot in common with other branches of science. According to David Deamer[5], both Systems Biology and Synthetic Biology have two common theoretical questions to answer: *How did life begin?* and *Can a lab version of cellular life be made?* For other experts in the field, SB is just an approach to genetic engineering that tries to make it easier and cheaper to genetically modify organisms and can be viewed as an extension of genetic engineering.

Anyway, it seems that the time for a change of paradigm has arrived. The study of biology has traditionally focused on a reductionist way of thinking, where information about single genes and proteins was

gathered with no perspective of the whole cell system. Synthetic Biology and other related disciplines attempt to turn biologists' minds in this new direction.

Re-engineering biology

It is very common to hear this concept when someone tries to define Synthetic Biology, but, what kind of engineering principles are being considered? Are these principles in concordance with the complexity of living matter?

In 2005 Drew Endy wrote a famous article entitled "Foundations for engineering biology" [7] where he tried to explain the engineering principles that need to be applied to Biology: Standardization, Decoupling and Abstraction.

Standards are necessary if we want to design and construct things more easily. We do not need to design every nut and bolt of our genetically modified organism, instead we only have to take the

5 categories of Synthetic Biology:

Bioengineering	Turning biotechnology into a true engineering discipline.
Synthetic genomics	Creating of organisms with a chemically synthesized genome.
Unnatural molecular biology	Creating new kind of molecules chemically simillar to the ones existing in order to replace them (XNA, different genetic code).
Protocells	Constructing artificial cells in vitro.
In silico approaches	Informatic simulation and modelling of the other 4 categories.

Top-Down approach

Bottom-Up approach

Deplazes, A. [8]

"In an ideal world, designing living systems for a practical purpose should be like redesigning a car to make it more efficient, or redesigning a computer with a faster processor. One would have the parts, the right software, the brains and the knowledge about the target system, and 'voilà!' a new bacteria that produces ethanol from water, CO_2 and light has been created."

Serrano, L.[9]

Synthetic Biology...

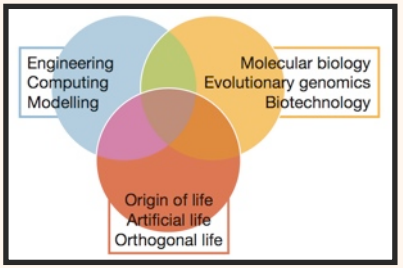
is the design and construction of new biological parts, devices and systems, and the re-design of existing, natural biological systems for useful purposes. (http://www.syntheticbiology.org)

standardized parts we are going to use and combine them, knowing they are going to fit without difficulty. The Registry of Standard Biological Parts was created by the MIT as a place where anyone can find a characterized DNA part that can be mixed and matched to build synthetic biological devices and systems [10].

Decoupling means the division of the different simple tasks of a problem. The separation of design and manufacture is a characteristic of engineering disciplines.

Finally, abstraction is important in order to deal with the complexity of living organisms. The use of abstraction hierarchies in the flow of genetic information enables engineers to work on just one part of the hierarchy without regard for the details of the others. These biological hierarchies have been compared to the ones found in computer engineering, an interesting analogy made in a recent report[11].

Of course, the *in silico* approach is present in every aspect of the field and permits computer modeling and design. Other works also remark the importance of the predictability and reliability of the system. As cells mutate and die, these two parameters should be achieved by either the use of a large number of cells or by synchronization through cell-communication [11].



The pillars of synthetic biology.[14]

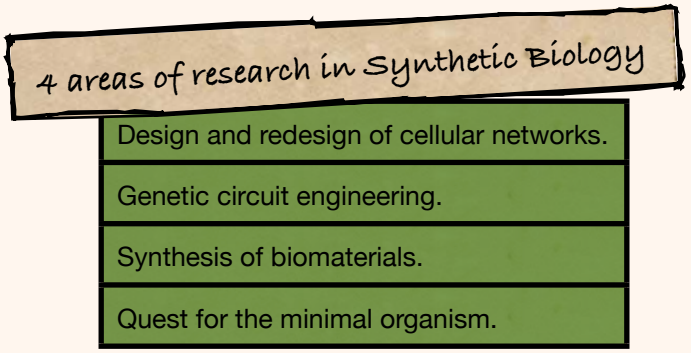
And what do biologists think about all this? They have been studying the molecular complexity of living organisms for more than fifty years and some of them are not so convinced by the idea. Genes are often not interchangeable among organisms and when they are, there is no guarantee that their function remains as it was in a different context. What is more, if we know so little about even the simplest organism known, how are we going to design a new one?[8]. Organisms replicate and evolve and this will certainly affect the stability of any designed system in the long-term. Although an effective solution to this particular problem has yet to be discovered, this is not a problem specific to Synthetic Biology[12]. Computer modeling of cell behavior is discussed in Goethe's dream[13] and discrete and stochastic approaches have been proposed as much more suitable tools than ordinary differential, traditionally and more commonly used equations.

Applications of Synthetic Biology

Which have been the highlights of Synthetic Biology? What new applications has this field made possible? Are these new applications really new?

One of the best known applications of SB is the production of artemisinin, a drug against malaria that only the plant *Artemisia annua* can make, by a genetically modified organism. In 2006, Dae-Kyun Ro managed to genetically engineer yeasts to produce the precursor of artemisinin[15] reducing the cost of cultivating the plants to obtain the drug. But is this amazing achievement really an application of Synthetic Biology? This particular work is far from the engineering principles discussed above, like standardization. Parts taken from different organisms were far from being "plugged and played"[16] and this case is not an exception. One may think that in the future, as the discipline grows, standardization and other engineering principles will become more and more common, revealing, without any doubt, a challenging scenario for the development of new biotechnology.

Designing artificial networks has also yielded some very interesting results like switches[17], [18], which are devices that allow the cell to adopt one of two possible states; oscillators[19] which produce regular fluctuations in the part of networks that allow different cells to communicate and synchronize between each other[20].



Fu, P.[21]

Most of the research on Synthetic Biology has focused on designing this kind of device, but it is not hard to realize that although these are incredibly interesting they have little practical application (unlike the work of Dae-Kyun Ro with artemisinin). They are, instead, basic science, which might be the basis for tomorrow's real synthetic biological applications.

A new chemistry for a new biology

Several attempts have been made to synthesize new molecules able to substitute those found in organisms. In this chapter, we will describe such research and discuss its ethical implications as well.

Instead of using DNA or RNA as information-carrying molecules, Piet Herdewijn and Philippe Marlière[22] have designed new nucleic acids differing only in the sugar present in the backbone of the structure, that is, instead

> **Synthetic Biology...**
>
> aims at making the process of design and construction of many-component, engineered biological systems easier.
>
> Shetty RP, Endy D, Knight TF Jr.[25]

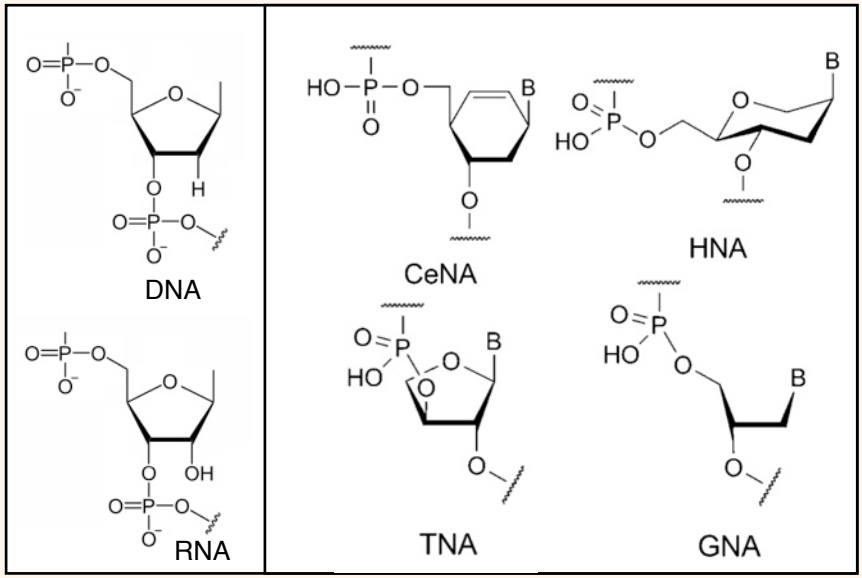
of having ribose or deoxyribose, these new models have threose (TNA), glycerol (GNA), hexitol (HNA) or cyclohexenyl (CeNA). These new structures do not essentially differ from the double helix described by Watson & Crick[23].

This new approach could prevent contamination between genetically modified and natural organisms as their genetic information would not be compatible. This would make biological devices safer.

The minimal genome project[24] poses new ethical questions, which need to be discussed. The creation of a brand-new organism with the only purpose of using them as a chassis for further genetic implementation has very different ethical implications than the idea of modifying naturally occurring organisms. In the latter case, Synthetic Biologists would be creating new life forms instead of modifying them and this is indeed an entirely new way of looking at nature. The ability to create life will certainly lead us to a discussion on the definition of life.

From Asilomar to Synthetic Biology

Ethical questions in Synthetic Biology mostly focus on risks, paying special attention to the need of controlling self-replicating machines that could genetically pollute the environment. This, at first sight, does not differ from the ethical questions discussed more than thirty years ago when the first recombinant DNA techniques were born. So, what's different now?



Piet Herdewijn and Philippe Marlière[22]

In 1975, Paul Berg organized a conference to propose an ethical code for genetically engineering living organisms in Asilomar, California. The chance to obtain genetic hybrid between an *Escherichia coli* (a bacterium) and *SV40* (a virus that can produce cancer in monkeys) raised the alarm of new potential bio-risks (for more information you can check: Summary Statement of the Asilomar Conference on Recombinant DNA Molecules[26]). Certain principles and ground rules for the emerging field were announced, but as years passed, experts started to realize that the technique was not as powerful as first thought. Today all the considerations discussed at the conference have become obsolete. However, Synthetic Biology, which is a more effective way to engineer organisms, may need new regulations as strict as those proposed in Asilomar in 1975.

Although designing and creating new biological machines have become much easier and cheaper with the rise of Synthetic Biology, this scenario can also have negative consequences. For instance, the possibility of non-biotechnologists entering the field and starting to make their own experiments is an evident bio-safety risk. New concepts like bio-hackery (designing and manufacturing biological systems without any kind of regulatory oversight) or Do-It-Yourself biology should be closely watched [27]. Experts usually agree that the risk of accidental harm (which can easily be prevented by introducing weaknesses into our designed organisms) is not as important as intentional harm. Nevertheless, using Synthetic Biology for the purposes of Bio-Terrorism is, at least currently, impractical since it is easier and cheaper to manage other tools like chemicals or natural non-engineered organisms[28].

Scientists' actions may also be driven by their dedication to their work and publications, as Antoine Danchin comments in the fascinating paper 'Not every truth is good'[29]. He recounts how the smallpox virus, which only affects humans, was sequenced instead of being totally destroyed when it was possible. Now, due to that negligence, its sequence is freely available on the Web and thanks to the new, and increasingly cheaper, DNA-synthesis techniques, it is an even greater threat than ever. In fact, proposals to regulate the DNA-synthesis industry have been made by experts[31], their plan serving three purposes: Promoting biological safety and

"SB's vocabuary identifies organisms wiht artifacts, an identification that, given the connection between 'life' and 'value', may in the (very) long run lead to a weakening of society's respect for higher forms of life that are usually regarded as worthy of protection."

Boldt, J. & Müller, O.[30]

security, encouraging the further development of synthetic biological technologies and the wide-world application of these regulations.

Many groups are now working on establishing some ground rules for the practice of Synthetic Biology as a central initiative, like Synbiosafe in Europe, SynBERC in the USA, or the BBSRC (Biotechnology and Biological Sciences Research Council) in the UK. We are at the beginning of a new field and now the right moment seems to have come to start considering all these ethical and risk-related issues seriously.

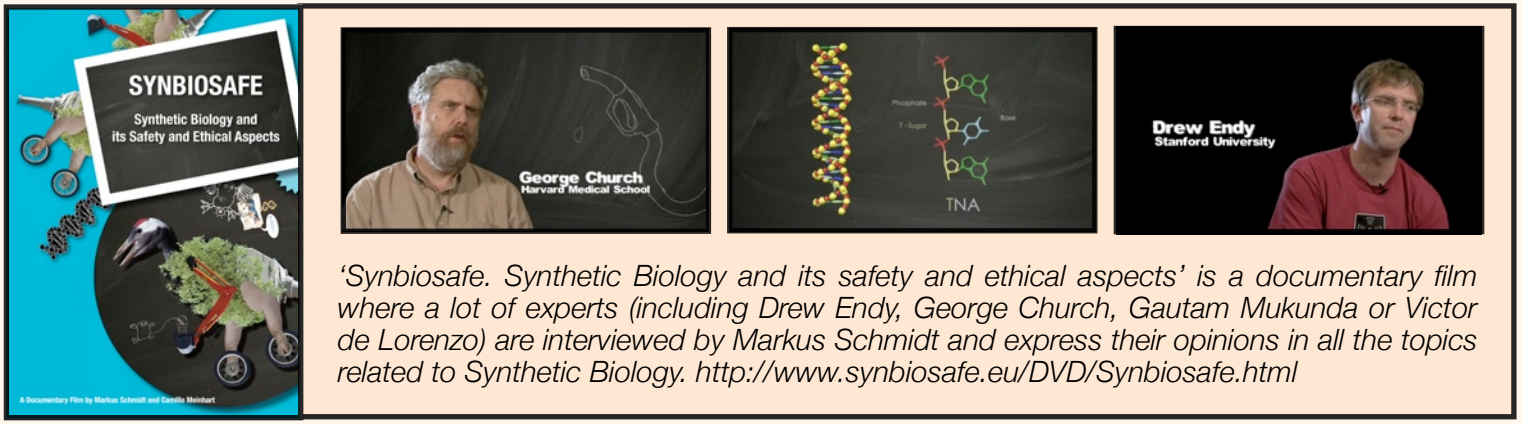
Different worlds

Europe and America are, in fact, two very different places to practice Synthetic Biology. Just a quick comparison shows us that 64% of the publications in the field came from US laboratories[8]. The European Union has already started some initiatives to change this situation by creating a regulatory and scientific infrastructure to support research in this direction, but as Mark Greener[32] points out: "they need to avoid an overly restrictive framework that stifles research".

> **Synthetic Biology...**
>
> ...involves the creation of artificial gene and metabolic networks to program new cell and organism behaviors.
>
> Gerchman Y, Weiss R.[33]

Excuse me, where can I learn some SB?

Synthetic Biology, like every new field in science, is hard to teach and to learn in the usual way for two basic



'Synbiosafe. Synthetic Biology and its safety and ethical aspects' is a documentary film where a lot of experts (including Drew Endy, George Church, Gautam Mukunda or Victor de Lorenzo) are interviewed by Markus Schmidt and express their opinions in all the topics related to Synthetic Biology. http://www.synbiosafe.eu/DVD/Synbiosafe.html

reasons. First, it is hard to define the subject of study because it is being constantly reanalyzed and redefined. And second, the interdisciplinary nature of the field makes it hard to gather and teach to two different kinds of students (basically biologists and engineers) that have such different backgrounds. Instead of typical instruction, Natalie Kuldell[34] describes the possible core structure of studies in Synthetic Biology. This would include (but not be limited to) the following: 1. Students will design biological systems in skillful and responsible ways; 2. Students will design, specify and whenever possible implement their design; 3. Students will conscientiously use materials and 4. Students will define the values, culture, safety practices, and organizational community of the field.

The iGEM is also aimed at young undergraduate students who want to know more about Synthetic Biology. In the summer months, they propose and design a project that will be presented in early November. This is a great first step for people who lack the opportunity to study this subject at their own universities. As they present their project, they are also helping to enlarge the Registry of Standard Biological Parts, adding new and characterized gene sequences to the biobrick database.

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More information on social aspects of Synthetic Biology can be found in a special Issue (guest Edited by M. Schmidt) recently published at Systems and Synthetic Biology (http://www.springerlink.com/content/1872-5325).

Synthetic Biology... is a 'field in the making' that combines the expertise and knowledge of biologists and engineers.

Calvert J, Martin P.[35]

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HUMAN PRACTICES

In this iGEM 2009 edition, we have decided to review all the information that other teams have written previously on Human Practices and Synthetic Biology.

We have read and gathered almost thirty reports from more than twenty teams, between 2005 and 2008, and classified these texts into four main topics: Synthetic Biology & iGEM, Biosafety & Risks, Patents and Ethics.

IGEM 2005-2008

Synthetic Biology and the iGEM competition were recurrent topics in all the Wikis and Human Practices reports. A lot of groups tried to define and contextualize Synthetic Biology, the iGEM and the reasons for their participation in the competition.

Definitions of Synthetic Biology are diverse, but the engineering vision of Biology and the interdisciplinary character of the field are common ideas present in all of them. Only the **KuLeuven 2008** team has historically contextualized SB as "a logical step in the development of Biological Science". SB can be classified according to its goals: The main aim of the Bottom-Up approach is to create systems from parts while the Top-Down approach has a much more reductionist vision, which tries to encompass a chemical, physical and mathematical comprehension of biology **(KuLeuven 2008)**. Among potential applications, biofuels and those related to medicine stand out **(Brown 2007, Valencia 2006**). Synthetic Biology is often overrated and it is easy to find sentences like "*SB is one of the most audacious and controversial scientific ideas of the 21st century*" (**KuLeuven 2008**) or "*This is what I always wanted Biology to be*" (Quote from a student, **Brown 2007**).

Brown and **Heidelberg**'s teams did a great job of disseminating SB in their university and informing the general public about the meaning of this new field. Actually, **Heidelberg 2008** (Best Human Practices Advance '08) justified their work in a sociological tone, arguing that the general public's knowledge of Science is democratically necessary for ethical decision-making. That's why they prepared a basic survey for 100 non-scientists to find out their level of scientific knowledge; what is more they addressed a part of their Wiki to this kind of public, where a funny character (Phips the Phage) guided and explained the project. **Calgary 2008** also prepared a survey for adults and high-school students to find out what they knew about SB and the ethical consequences of the field.

Phips The Phage (Heidelberg 08)

An explanation about what SB is and how it works, can be found in **Valencia 2006**. Advantages (like the use of restriction enzymes or modeling) and disadvantages (like the difficulties of applying engineering to living systems) as compared to classic genetic engineering are discussed. Nevertheless, the text is written for scientists and people who are not related to the field may have trouble understanding it.

Regarding the iGEM competition, an explanation of its history can be found at **Berkeley 2008**, this extensive text starting with the donation of American funds and ended with the 2008 edition. Likewise, a lot of teams often refer to the Austin-Texas' Bio-Film but with different intentions: **Berkeley** brands it as "infamous" and **Brown 2006** as a successful work born in the iGEM.

HUMAN PRACTICES

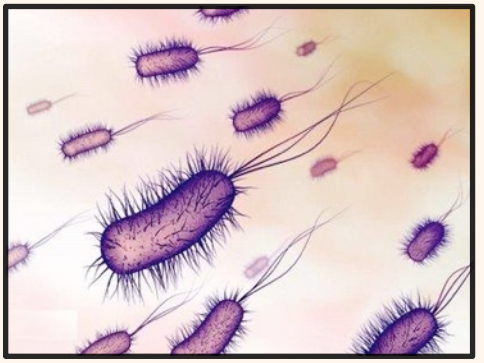
Since the beginning of the iGEM competition at an international level in 2005, Biosafety concerns have been one of the most widely discussed issues. Like most reports on this topic, we will hereafter consider Biosafety and Risk as separate terms. Biosafety refers to good practices in the laboratory, whereas Risk is related to the consequences that a genetically modified organism could have when released into the environment. Certainly both terms are intimately related because incorrect lab practices might result in the uncontrolled spreading of genetically engineered microorganisms, which might disturb the ecological balance.

Many teams have indeed taken into account the importance of Biosafety in Synthetic Biology, as demonstrated by the "training" that some students have received before starting working on the wetlab **(Purdue 2007, Slovenia 2008)**; the supervision of their lab practices by an expert **(Zurich 2008, Pavia 2008, Slovenia 2008, TUDelft 2008)** or university department **(Washington 2008)**; or the establishment of different levels of "biological danger" with the appropriate security measures **(Zurich 2008, Slovenia 2008, Edinburgh 2008, Bologna 2008)**.

One of the main topics discussed in Biosafety is the importance of working in sterile conditions as stated in the first report on Biosafety issues in the iGEM competition **(MIT 2005)**. Since then, two more teams **(KULeuven 2008, Valencia 2008)** have continued gathering information and highlighting the key role of maintaining sterility on the bench. The idea of lab safety is also supported by focusing on different physical and chemical agents commonly used in Molecular Biology: EtBr, UV light **(Pavia 2008, Bologna 2008)**, dry ice, liquid nitrogen **(Purdue 2007)** etc, as well as some warnings about their use or storage.

And what about the Risks? Just a few examples to have been forecasted involve unexpected mutations when a gene is introduced inside an organism **(KULeuven 2008)**, the mixture of natural and artificial gene pools, the unpredictability of synthetic organism proliferation **(Freiburg 2008)**, and the use of microorganisms as "bioweapons" **(Valencia 2008)**. The growth of Risks with the advance of massive sequencing techniques, free distribution of DNA, etc. was discussed by **TUDelft 2008** and **Freiburg 2008** teams that also recognized the difficulty of building effective barriers, and concluded that stopping technical advance is obviously not the solution to checking

IGEM 2005-2008



Risks. Finally, a very interesting classification of different types of risks was proposed by **KULeuven** in **2008** and different perceptions about risk by **TUDelft 2008**.

As previously mentioned, Biosafety and Risks are closely related, so choosing the safest "chassis" for a Synthetic Biology project is an extremely important task in terms of Biosafety because of the associated risks. This is probably the reason why most iGEM teams implement control strategies for their GM microorganisms. The most commonly proposed systems to avoid the release and spread of synthetic microorganisms are: using non-pathogenic bacteria **(Edinburgh 2008)**; inserting a gene for automatic self-destruction under certain conditions **(Freiburg 2008, Slovenia 2008)**; replacing an essential gene **(KULeuven 2008)**; using toxin-antitoxin systems **(Valencia 2008)** and using lab-specific strains free of toxin- or resistance-containing plasmids **(Pavia 2008)**.

The importance of improving synthetic circuits and ensuring their safety and suitability to fulfill their final function been also highlighted **(KULeuven 2008, Edinburgh 2008, Caltech 2008)**.

HUMAN PRACTICES

Since the iGEM 2007 competition, several teams have pointed out the need to examine ethical considerations on Synthetic Biology related to the open-source character of the technology and its relationship with commercialization of ideas and patent laws. **UCSF 2008** raised this simple point: do we need patents? They detailed the advantages and disadvantages of patenting and compared patenting with an alternative: keeping trade secrets (like the Coca Cola formulation).

In our society, scientific research on patented applications is possible without licenses. However, license fees have to be paid when an investigated application is subsequently commercialized (**TUDelft 2008**).

The iGEM competition ideal is a community sharing parts, devices, systems and ideas. BioBricks are the best example of this spirit (**UCSF 2008**). The idea is that BioBricks are added to a database in a completely open-source setting. However, the free-market environment, academic and company interests, the possibility of deliberate misuse (**TUDelft 2008**), economic viability and information safety have to be considered. On the other hand, basic tools and knowledge for the use of these Units should be available to researchers in other areas (**Valencia 2008**).

The particular use of different parts (the basic element) on integrated systems and devices does not imply ownership of parts already present in nature, but a new and unique way of putting them into use for purposes other than the original (**Valencia 2008**). Furthermore, the application must be both novel and non-obvious over the prior (**Berkeley UC 0207**).

Debate about the intellectual property of Parts is a very important issue, to which not enough attention has been paid (**Valencia 2008**). But, could a Biobrick-based device be patented? After outlining the terms of the legal OpenWetWare archive, **UCSF 2008** concluded that open source parts that are further developed should be “patentable” whereas the original parts used must remain open source.

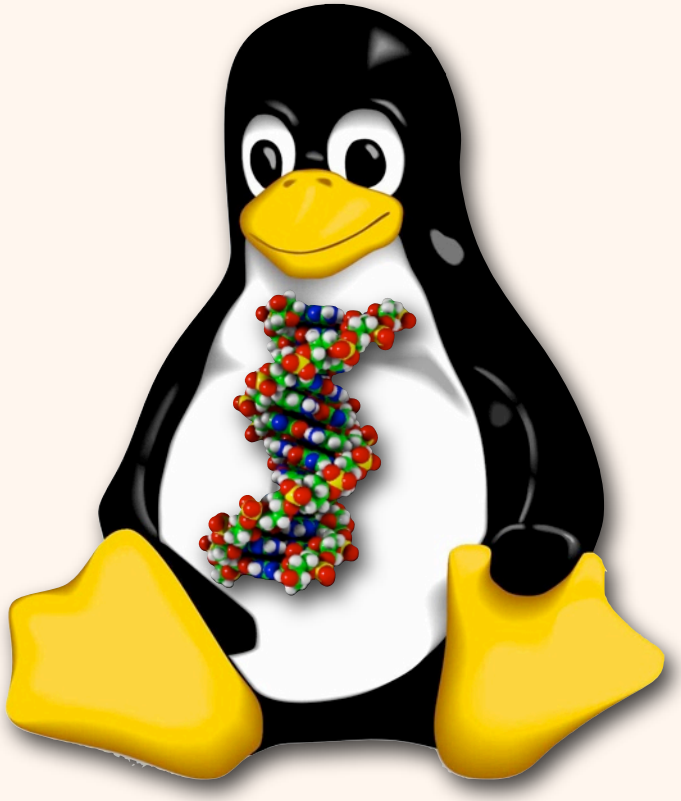
Aspects such as use, composition and methods should be included as a claim or a set of claims in the application. Thus each aspect might be separately patentable. Moreover, the time line for the patent application would not start when the part is listed in the register. Instead, it would start when the application of the part has been publicly disclosed. (**Berkeley UC 2007**)

IGEM 2005-2008

Regarding iGEM projects, a few teams have focused on the patentability of their projects (**UCSF 2008**, **Berkeley UC 2007**), or made a statement claiming to have released their research into the public domain (**Edinburgh 2008**). However, it has to be noted that if a company improves the process they have developed, it could not be prevented from patenting that innovation.

A different and novel approach to this issue was proposed by **Edinburgh 2007**, who organized a presentation on Intellectual Property laws and how these might apply to Synthetic Biology. This team highlighted existing similarities between Synthetic Biology and the Linux-based open source code.

Finally, **Berkeley UC 2007** raised three important questions: the limitations on part and device definitions, research protocols design, and Synthetic Biology as a driver for inventing new modes of industrial practices and partnerships.



HUMAN PRACTICES

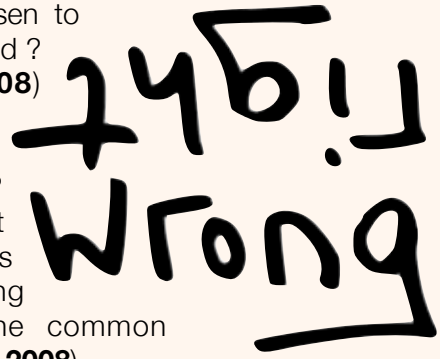
The quality of our lives is determined by the quality of our thinking. The quality of our thinking, in turn, is determined by the quality of our questions. This is Linda Elder's view[1], and it is also ours. In this sense, many iGEM teams have recently raised interesting bioethical questions. This chapter summarizes all these questions. And a few answers.

What can we expect from Synthetic Biology? (**KULeuven 2008**) Is society ready for this new, extreme form of genetic engineering? (**TUDelft 2008**) Which practical implementations are possible? (**KULeuven 2008**) Should recombinant DNA techniques be the solution to all the world's problems? (**TUDelft 2008**) **Freiburg 2008** and **Valencia 2008** declare that synthetic biological approaches promise to fight some of these problems and **KULeuven 08** aims at proving to the reader that synthetic biology is in fact a logical step in the continuous development of Biological Sciences.

Are there any new ethical issues related to Synthetic Biology? (**KULeuven 2008**). Under the "banner" or flag of Synthetic Biology, should research be allowed so much further than that of genetic modification in classical bioengineering? (**TUDelft 2008**). Should the fear to new deleterious biological devices stop scientific development? (**Valencia 08**). Is it morally acceptable to change the nature of life on earth to better suit man's desire? (**KULeuven 2008**). What would happen if human beings disappeared and left behind a population of Synthetic Biological systems? (**Valencia 2008**).

What properties and traits do we want to give to our new organisms? Are there differences between the creation of more complex, for instance multi-cellular systems, and organisms? (**KULeuven 2008**). Bio-engineers even start to cross the thin line between manipulating life and creating life. (**Freiburg 2008**) When does a natural system become a mechanical structure? (**TUDelft 2008**) Do we have to look at synthetic organisms as just ordinary life forms or should they have the same value as machines? (**KULeuven 2008**).

How is Synthetic Biology presented in the media, is it just another *hype*? (**TUDelft 2008**) What politics are involved and which "societal sufferings" are chosen to be remedied? (**UCBerkeley 2008**) Should science always depend on public involvement? Scientists can't make decisions without considering the opinion of the common people. (**KULeuven 2008**)



IGEM 2005-2008

How does the research being done by the students in the iGEM lab relate to other projects being pursued under the banner of Synthetic Biology? What does it mean to be a human practices member of an iGEM team? Doing Synthetic Biology (experimenting, designing projects, situating findings within it, making decisions about what projects are important, etc.) is a human practice. (**UCBerkeley 2008**). In its Code, **Valencia 2008** exposed three general commitments regarding bioethics: research on Synthetic Biology must not be directed by economic interests, animal dignity must be assured in every synthetic biology-related research program and common sense should be followed.

Moreover, there have been several discussions among terms, as shown in: "ethics of consequences" vs. "ethics of principles" (**KULeuven 2008**), "standardized BioBricks" or "standardized science" (**TUDelft 2008**) and "bottom-up approach" vs. "top-down approach" (**KULeuven 2008**).

Furthermore, **KULeuven 2008** also cited the "Three laws of Robotics" (Isaac Asimov, 1942) and postulated justice, autonomy and culture as the three central ideas that are present in all debates concerning ethics and Synthetic Biology. Meanwhile, **TUDelft 2008** stated that ethical decisions have to be made throughout the entire project development.

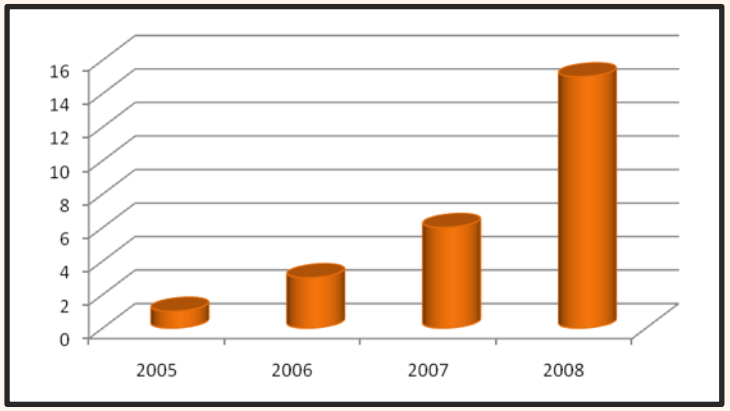
Finally, **Calgary 2008** prepared two online surveys, one written for high-school students and the other for adults, to better understand the level of knowledge of Synthetic Biology, what was forecast about its future, implications and advances and which framework of governance Synthetic Biology should have. **Valencia 2008** was the first to propose what they called the Concentric Units of Ethical Issues whereas **UCBerkeley 2008** enumerated the proposals from SynBERC and used a blog, a notebook and the ArsSynthetica web to follow the development of their ethical study.

And among all these questions, the one that might be the ultimate question: Is the world prepared for Synthetic Biology? (**Calgary 2008**).

HUMAN PRACTICES

CONCLUSIONS

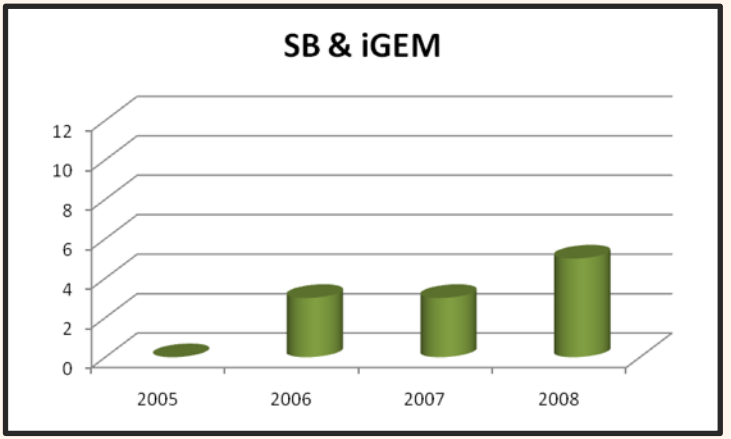
Human Practices are becoming more and more important in the iGEM competition. In the first international edition, in 2005, only the **MIT** team wrote a very brief reference to Biosafety issues in its project. However, since then, there has been an exponential increase in the number of teams dealing with this issue, including a Human Practices report.



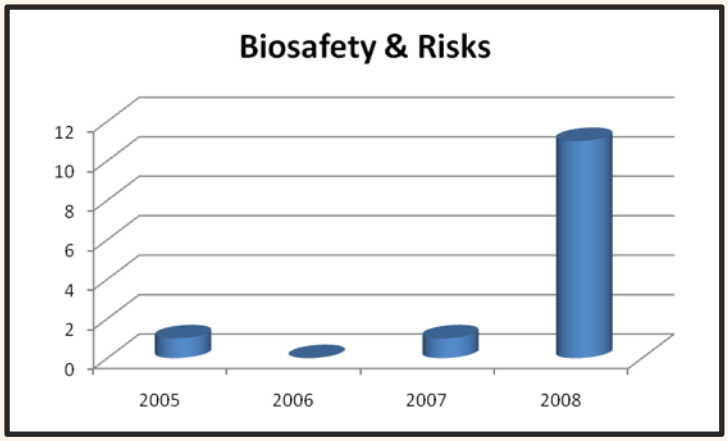
In 2008, a "Best Human Practices Advance" was recognized for the first time in the iGEM competition as a special prize. The **Heidelberg** team won this award for a report on Synthetic Biology and scientific communication, in which they discussed the role of the media in scientific dissemination as well as people's opinion and knowledge about Synthetic Biology. They also included surveys and an interview of a Nobel Prize winner.

The four topics listed in our review (SB & iGEM, Biosafety & Risks, Patents and Bioethics) have had different relative importance in each iGEM edition.

SB & iGEM was mentioned for the first time in three reports in 2006. The number of teams which included this topic in their work was the same in 2007 but increased in 2008 from three to five reports.



IGEM 2005-2008

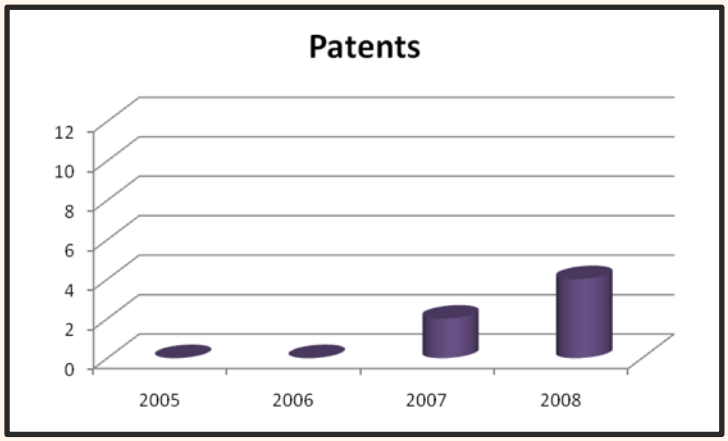


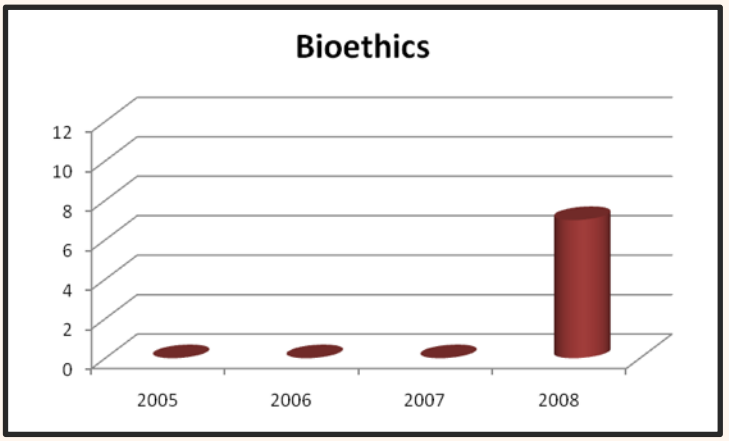
CONCLUSIONS

Despite being the only topic cited in 2005, **Biosafety & Risks** was not included in any of the 2006 reports and just in one of the 2007 edition. However, it has been the most widely discussed issue in 2008 (eleven reports) and also in the whole iGEM competition (a total of thirteen).

In 2007, two teams introduced a new issue: **Patents**. The number of reports on intellectual property doubled in the following iGEM edition.

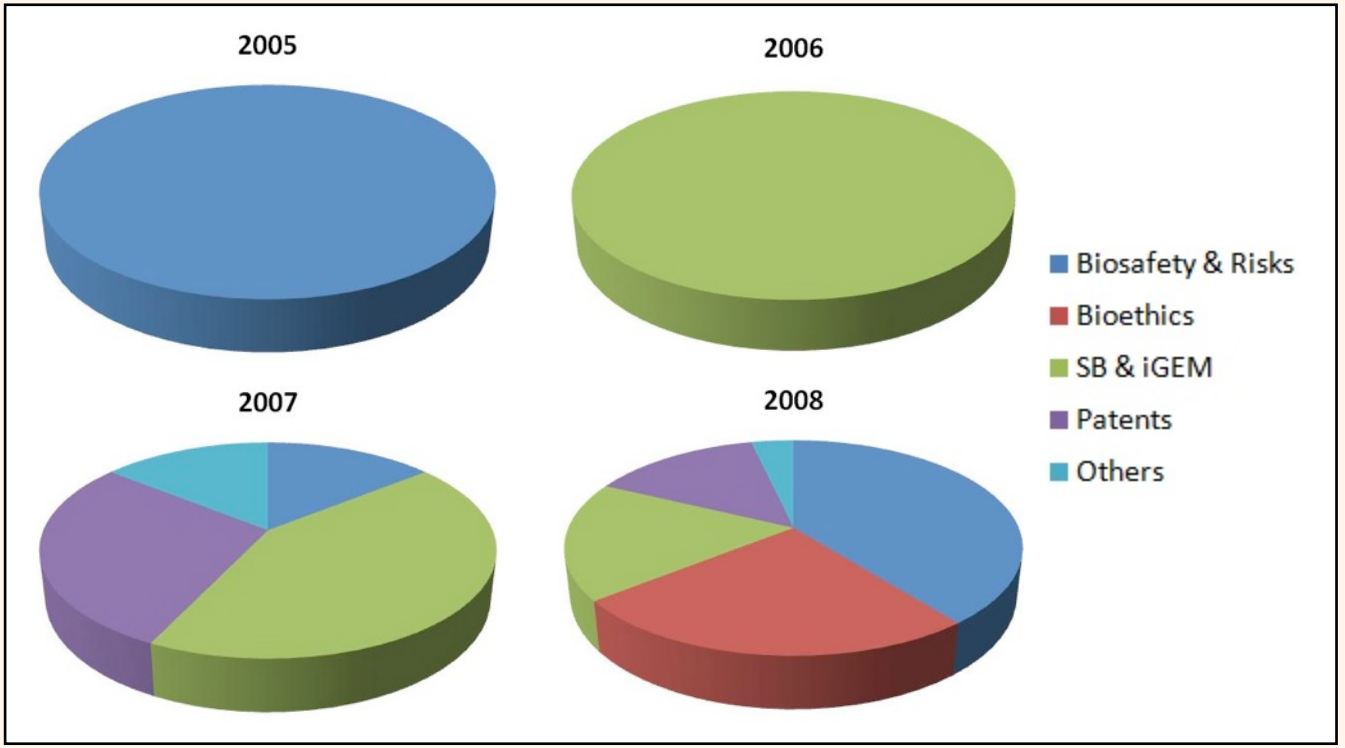
The iGEM community had to wait until 2008 to read some reports on another new topic: **Bioethics**, which became the second most-discussed issue of that year (seven reports).





HUMAN PRACTICES

The variety of topics included in Human Practices reports has increased every year:

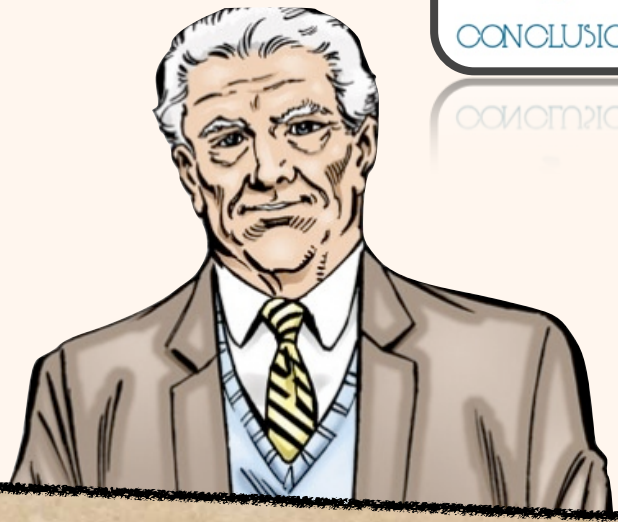


IGEM 2005-2008

CONCLUSIONS

Furthermore, iGEM teams have tried to make Synthetic Biology closer to non scientists by including surveys addressed to the general public (Heidelberg, TUDelft and Calgary 2008); developing a glossary in which terms like Synthetic Biology, Systems Biology, Biotechnology, Metabolic Engineering, System, etc. are defined and briefly explained (Valencia 2008); or by designing a part of the Wiki for people without a strong biological background (Heidelberg 2008).

Finally, one of the funniest points of Human Practices reports are quotations, often referring to contemporary science fiction heroes' ethics, which are used as metaphors of today's SB challenges.



"With great power comes great responsibility"

Spiderman's uncle Ben (**Valencia 2008**)

"Fear leads to anger. Anger leads to hate. Hate leads to suffering"

Master Yoda (**KULeuven 2008**)

[1] : *The Art of Asking Essential Questions.* By Linda Elder and Richard Paul. 48 pages. The Foundation for Critical Thinking. 2006.

THE SURVEY

Hello,

We, the iGEM 2009 Valencia Team, invite you to participate in our survey, that will be included in our project for the present year. In this survey, people from a variety of educational levels and professional areas will be asked to complete some questions about Synthetic Biolgy. It will take approximately five minutes to complete the questionnaire, but please consider your answers ;)

Your survey responses will be strictly confidential. If you have questions at any time about the survey or the procedures, you may contact us by email at the address specified below.

Thank you very much for your time and support. It is very important for us to know your opinions.

You can start with the survey now by clicking on the Continue button below.

Valencia Team 2009
Human Practices
Valencia2009iGEM@gmail.com

Age

-- Select --

Sex

- Man
- Woman

Degree Level

-- Select --

Field

- Life Science
- Engineering
- Others

Where have you found this survey?

- E-mail
- Facebook
- iGEM Wiki
- Other

Do you know about the iGEM competition?

- Yes
- No

Are you a member of a 2009 iGEM Team?

- Yes
- No

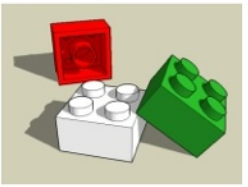
Which one?

-- Select --

Do you know what Synthetic Biology is?

- Yes
- No

Would you be able to define it in just a few words? Come on!



Here you have a short explanation:

Synthetic Biology is a kind of Genetic Engineering in which different parts of an organism (such as genes) are supposed to behave like independent ´modules´. You can interchange these modules between the organisms, creating a novel artificial system.

Have you understood it?

- Yes, loud and clear
- No :(I'm sorry, but let's go on!

THE SURVEY

Now, without looking at Wikipedia ... select the 5 words you feel are most closely related to Synthetic Biology.

- [ ] Plastic
- [ ] DNA
- [ ] System
- [ ] Abstraction
- [ ] Anthrax
- [ ] Destruction
- [ ] BioBrick
- [ ] Infection
- [ ] PCR
- [ ] Modelling
- [ ] Transgenics
- [ ] Creation
- [ ] Standards

Knowing that parts of the genetic information can be isolated, do you think these pieces should be ... ?

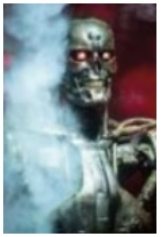
- ( ) Patentable
- ( ) Open Source
- ( ) Sorry, I don't know it.

Let´s assume that humans can create artificial life. Do we have the right to do it?

- ( ) Yes
- ( ) No
- ( ) Sorry, it's too hard for me.

Do you think is possible a situation such as many science-fiction movies as "I, Robot", "Terminator", etc, in which humans go a step too far in their need for improving themselves?

- ( ) Let's hope human ethics can set a brake before that
- ( ) Uh? OK, ban people from creating life



Do you think eating a transgenic vegetable is harmful for your health?

- Yes
- No
- It depends. I would agree with the Golden Rice, not with "Roundup Ready" strains

Do you think eating a drug produced in a genetic modified organism (GMO) is dangerous for your health?

- Yes
- No

Do you think there are significant ethical differences between Classic Genetic Engineering and Synthetic Biology?

- Yes
- No
- What?

THE SURVEY

Great we are almost done! Just two more questions:

From 1 (nothing) to 5 (completely) how ... do you think Synthetic Biology is?

	1	2	3	4	5
Beneficial	○	○	○	○	○
Dangerous	○	○	○	○	○

And the last one, do you think we should continue research in Synthetic Biology?

- ○ Yes
- ○ No

Please visit our Valencia Team wiki

Thank You for completing this survey

THE SURVEY

With this survey, we wanted to know people's opinion on several topics related to Synthetic Biology. That's why we prepared a short questionnaire which was addressed to both iGEM members as well as other people. We tried to write the questions in a clear language, avoiding the use of technical words.

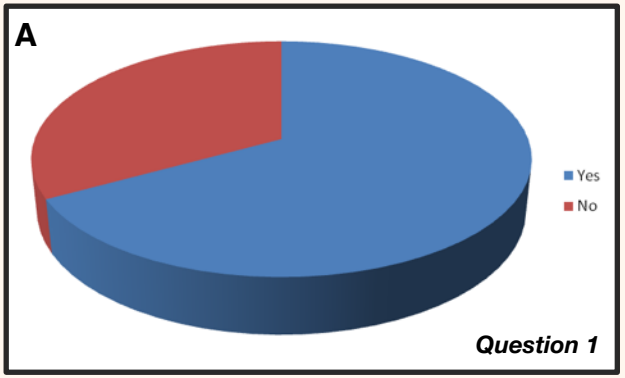
Our survey was available from July 29th to October 12th in our Wiki. We also sent personalized mails to all 2009 iGEM teams inviting them to fill it in, we posted the survey in some important websites such as www.synbiosafe.eu or www.syntheticbiology.org, and also in well-known social networks like Facebook.

We got 1288 answers, which made our survey the biggest one ever made (to the best of our knowledge, the ¿¿Royal Academy of Engineering?? survey, with 1005 participants, was the biggest one ever made before). 643 answers came from members of 101 iGEM 2009 teams. We acknowledged their collaboration by designing gold (100% of members have responded), silver (75%) and bronze medals (50%) for their Wikis (see page 43). The other 645 answers came from people belonging to many different social groups (for more details you can see page 69 of our Appendix).

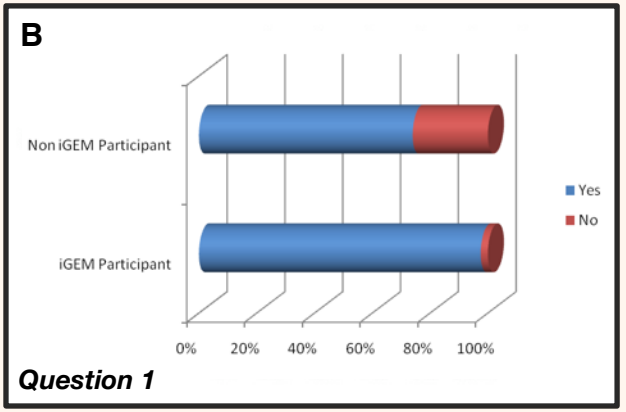
Besides considering all the participants' results in our analysis, different groups of people were also distinguished: people who know about SB vs. people who do not know about SB (hereon "informed" vs. "uninformed"), and iGEM members vs. non iGEM members. Exceptionally, other groups like those informed vs. uninformed about the iGEM competition, and engineers vs. life scientists will be differentiated in some questions.

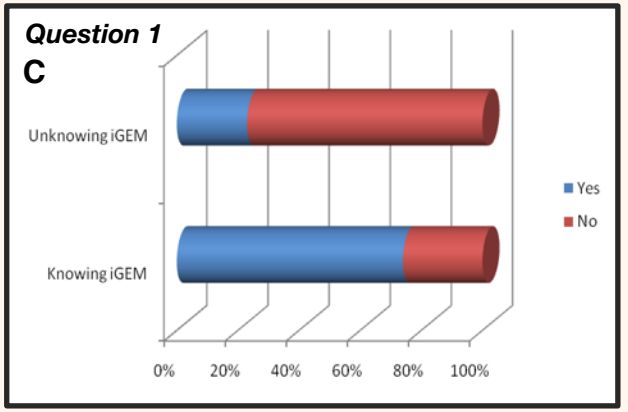
These are the main results of our survey:

Question 1. **Do you know what Synthetic Biology is?**



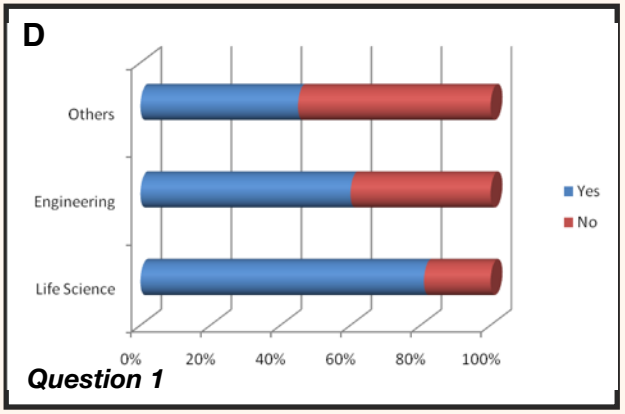
A total of 864 people out of the whole 1288 participants (67%), asserted they knew what SB is and gave their own definition (these definitions are analyzed in page 48). Obviously, almost all iGEM members (98%) were able to define SB, whilst the percentage of non iGEM members who knew what SB is was substantially lower 36% (see B).



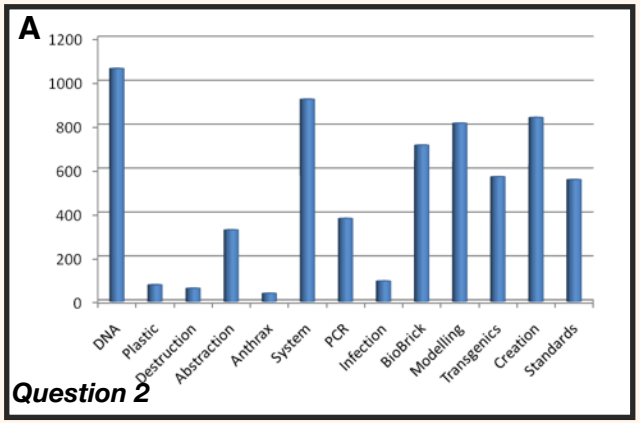


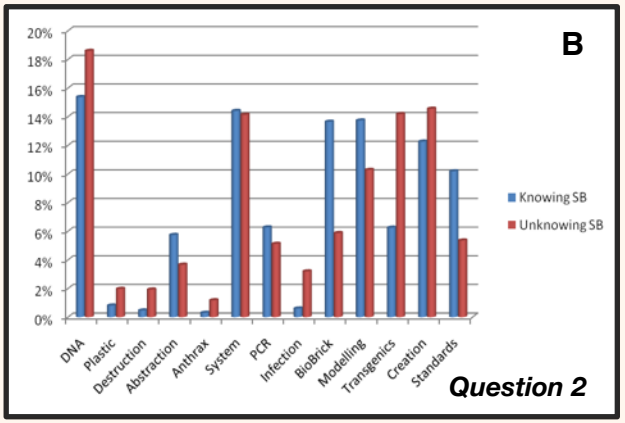
It has to be noted that considering the people who are not members of iGEM, the percentage of them who can give a definition of SB was higher (74% vs. 23%) when they also knew about this competition. That shows the important role iGEM plays in the diffusion of this emerging field (see C).

Finally, the number of life scientists who knew about SB was higher (81%) than engineers (60%). Regarding people from other fields, less than half (45%) were able to define SB (see D).



THE SURVEY





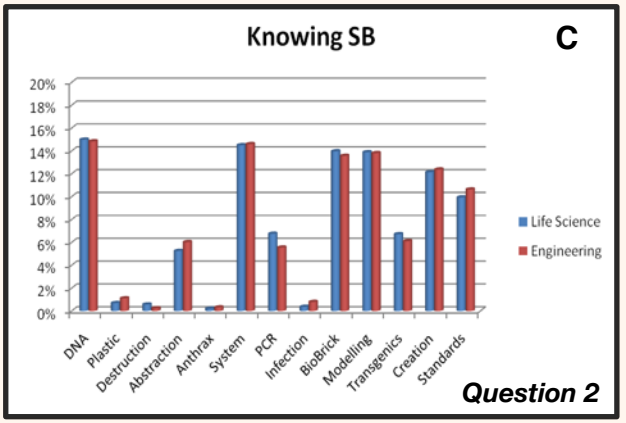
Question 2. Now, without looking at Wikipedia… select the 5 words you feel are most closely related to Synthetic Biology

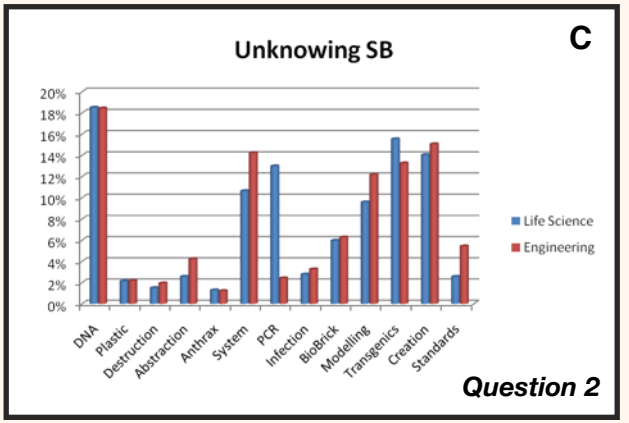
DNA, **System**, **BioBrick**, **Modelling**, **Standards** and **Creation** are by far the words that people consider more related to SB, followed by **Abstraction**, **PCR** and **Transgenics** (See A).

However, there are some differences between SB informed and uninformed people: the latter don't recognize BioBrick and Standards as SB-related terms, and point out another word: Transgenics. (See B).

This fact can be due to their incapacity to distinguish SB from other similar disciplines such as Biotechnology or classical Genetic Engineering when they are not clearly defined. SB can be used for creating transgenics, but so too could the other disciplines mentioned above. On the other hand, Modeling, Standards or BioBrick specifically refer to SB.

It is important to highlight that very few people, even SB uninformed, propose words like Destruction, Anthrax or Infection. This means that currently people don't immediately associate fear or mistrust with the term Synthetic Biology. Furthermore, another difference between SB informed and uninformed is the following: if answers from life scientists and engineers are compared, there are no significant differences when they know what SB is, as it is a deeply interdisciplinary science; however, when SB is unknown, engineers and



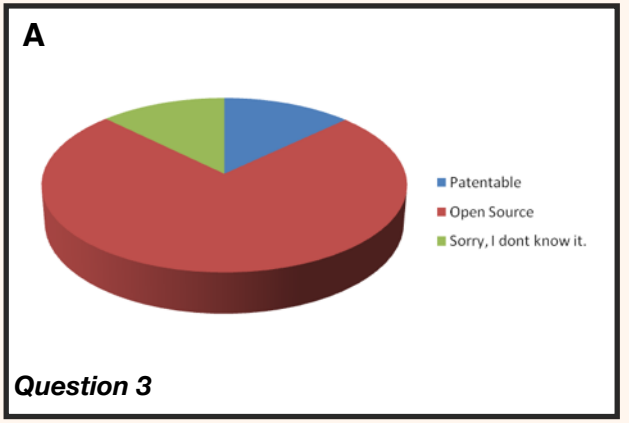


life scientists choose the words more closely related with their own fields. Words such as PCR, System, Modelling and Standards are good examples (see C).

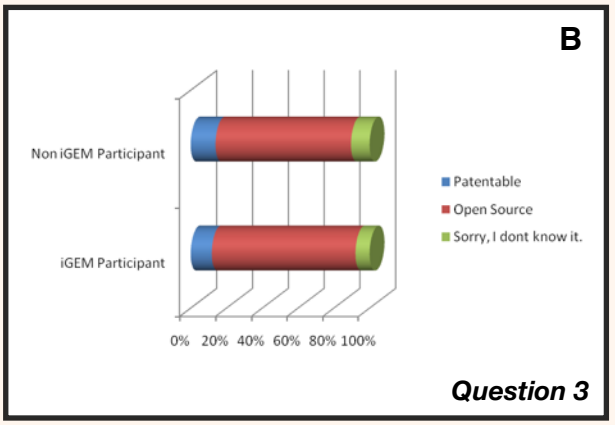
Question 3. **Knowing that parts of genetic information can be isolated, do you think these pieces should be patentable or open source?**

Regarding intellectual property, people agree (74%) in considering that parts of genetic information should be open source. Only 13% of participants think that they should be patentable (see A).

Comparing iGEM members and not iGEM members, there is a difference of opinions. A higher percentage of iGEM participants (80% vs. 68%) asserted that parts should be open source. This result agrees with the iGEM



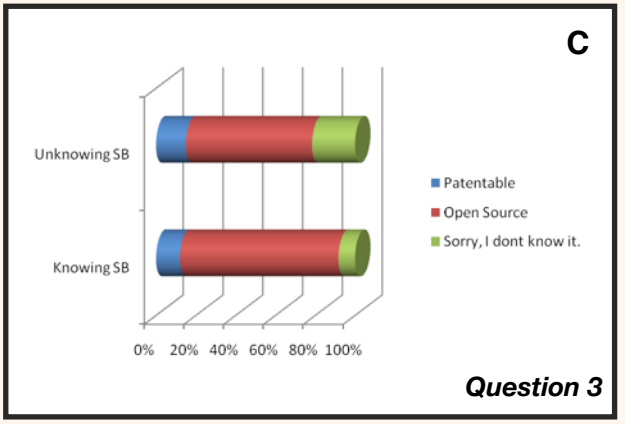
THE SURVEY

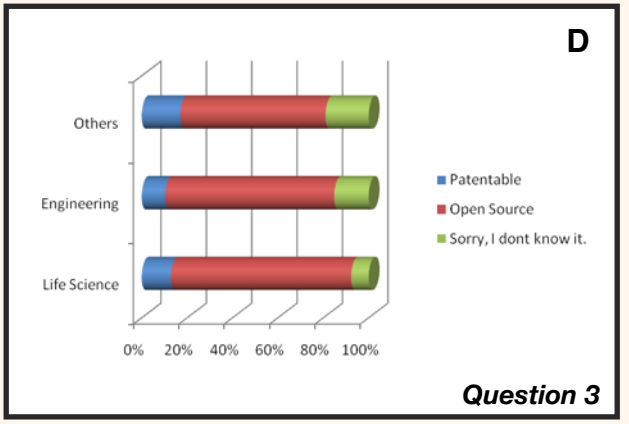


ideals on this topic, for instance, the creation of the Registry of Parts, in which anyone can find lots of free standardized parts (see B).

The idea of open source is better supported by SB informed (79%) than by SB uninformed (63%). However, it has to be noted that a significant percentage (22%) of the latter ones did not have a clear opinion (see C).

No significant differences were found between life scientists and engineers. However, the percentage of people from other fields who believed that genetic parts should be open source was lower (64% vs. 80% and 75%) (see D).



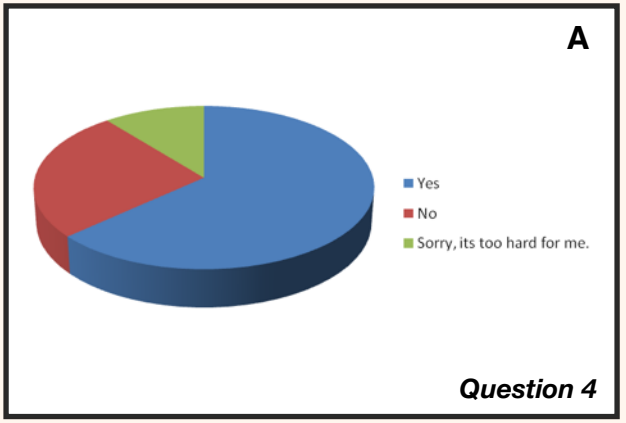


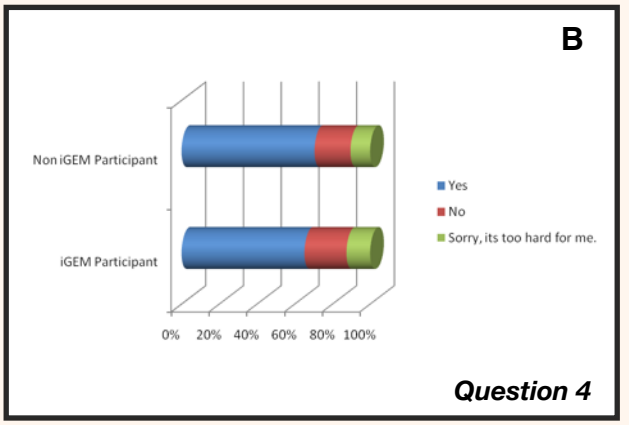
***Question 4.* Let's assume that humans can create artificial life. Do we have the right to do it?**

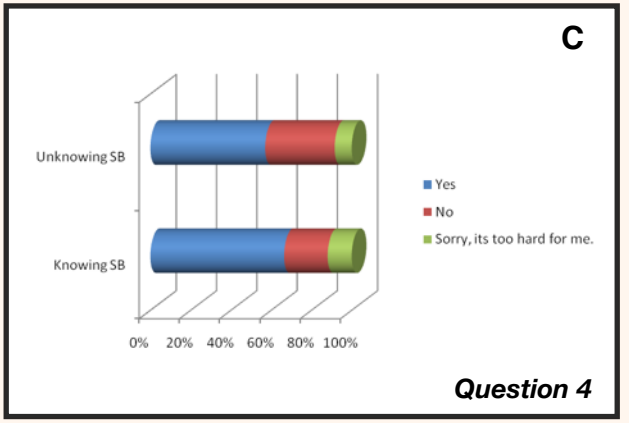
The creation of artificial life is a more controversial issue. Although most people (63%) assert that human beings have the right to create life in the laboratory, 26% do not approve. Interestingly, a significant 11% of participants were unable to give an answer because of the transcendence and the moral and religious implications of this topic (see A).

There are no significant differences between iGEM members and non iGEM members (see B).

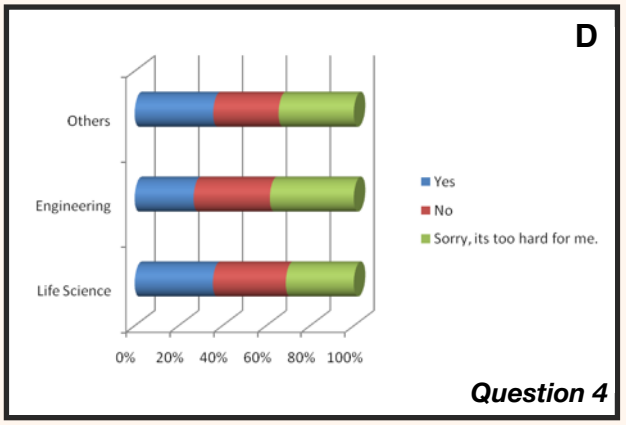
But there is a difference on comparing SB informed and uninformed. The percentage of the latter that agree with the creation of artificial life is not as high (57%) as the former (66%) (see C).







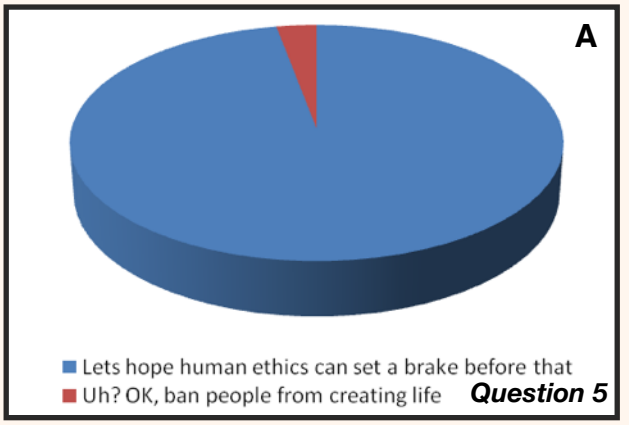
THE SURVEY



Furthermore, the percentage of life scientists who approve of the creation of artificial life (67%) is slightly higher than the one of engineers (62%) and other fields (58%) (see D)

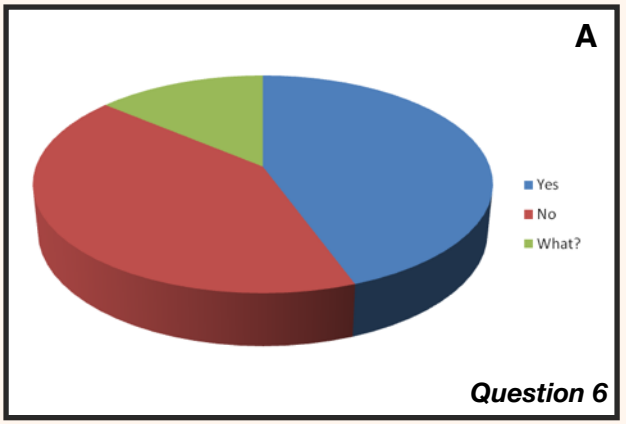
Question 5. Do you think is possible a situation such as many science-fiction movies as "I, Robot", "Terminator", etc, in which humans go a step too far in their need for improving themselves?

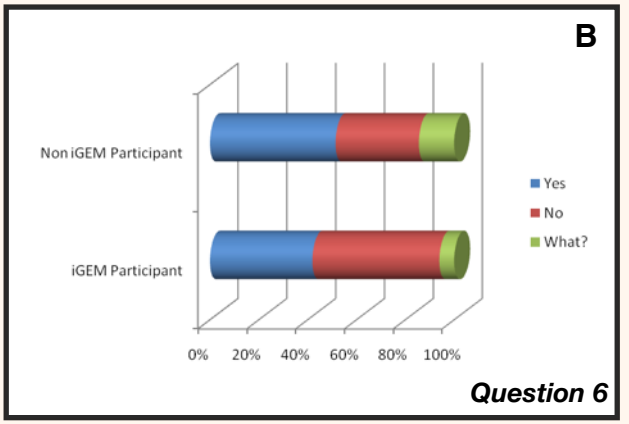
The vast majority of people (97%) who agree with the creation of artificial life don't believe that this hypothetical power could lead us to the irrational situation that many science-fiction movies show.



Question 6. Do you think there are significant ethical differences between Classic Genetic Engineering and Synthetic Biology?

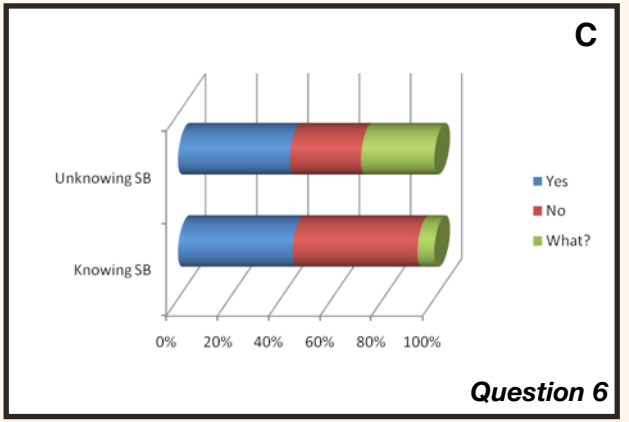
On the differences between classic GE and SB, we can conclude that there is a maximum parity between both views. However, 179 people out of 1288 did not understand the meaning of the question (see A).





An interesting finding is that iGEM members and non members have opposite opinions: more than half (52%) of the iGEM members consider that there are no significant ethical differences between SB and classic GE, whilst only the 31% of non iGEM members agree with that (see B).

Another finding is that, despite the number of "What?" responses rate is 22 points higher for those who claim not to know what synthetic biology is, the "Yes" percentage has practically remained the same in both groups (see C).



THE SURVEY

Question 7. Do you think eating a transgenic vegetable is harmful for your health?

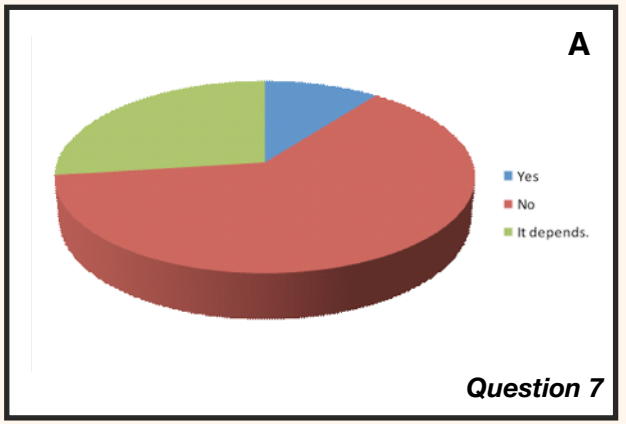
Regarding eating transgenic vegetables, more than 60% of interviewed people believe that they are not harmful for their health, whilst 362 out of 1288 relate their response to a particular case of modified food (see A).

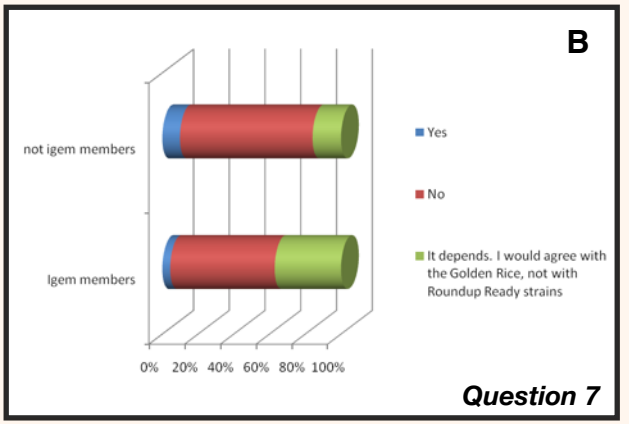
A surprising result is the high percentage of iGEM members and SB informed who chose the third option ("It depends. I would agree with the Golden Rice, not with Roundup Ready strains"), as there is no reason for these vegetables to be more dangerous than other transgenic products. However, the percentage of iGEM members that consider transgenic food dangerous is slightly lower (5%) than for non iGEM participants (17%) (see B).

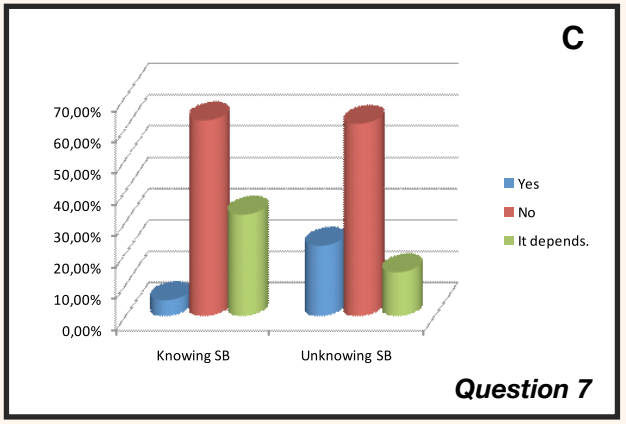
Similarly, there is a difference of 17 percent between SB informed vs. uninformed who assert that eating a transgenic vegetable is harmful, which means that people knowing about synthetic biology distrust GM food less (see C).

The percentage of participants that consider transgenic food dangerous changes among fields: Only 5% of life scientists do not trust these products, whilst the percentage of engineers and people from other fields with this opinion is more than twice and four times higher, respectively (see D).

Question 8. Do you think eating a drug produced in a genetic modified organism (GMO) is dangerous for your health?





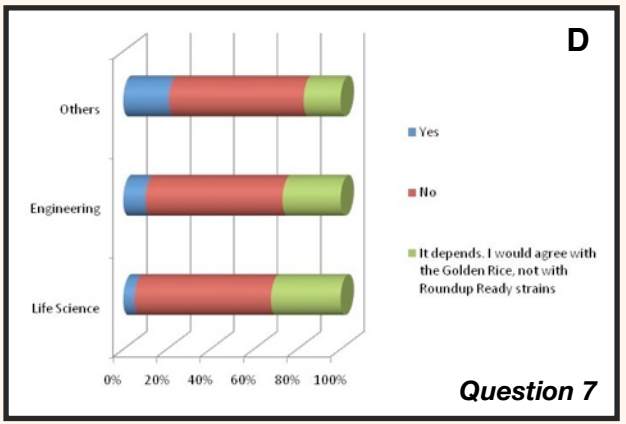


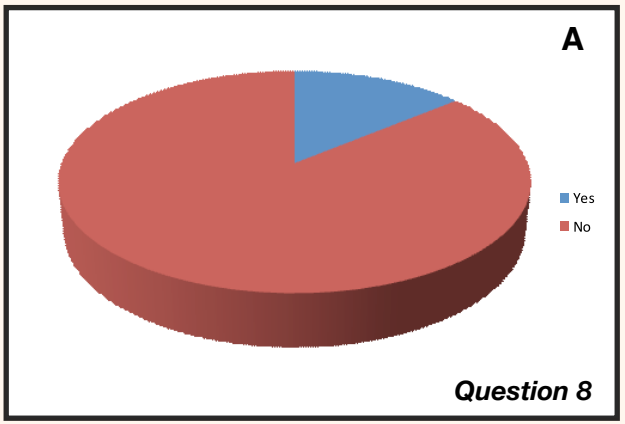
Similarly, the majority argues that there is no problem in eating a drug produced in a genetically modified organism. Interestingly, there is a slightly higher percentage (4%) of people against drugs produced in GM than against transgenic vegetables (see A).

The results reveal an increased confidence in GMO products (difference of 10%) by those who are iGEM participants compared with those who are not (see B).

The same conclusion can be reached on comparing SB informed and uninformed people (see C).

Once again, there is no agreement between people from different fields. Drugs produced in GMOs are rejected less by life scientists (8%) than by engineers (17%).





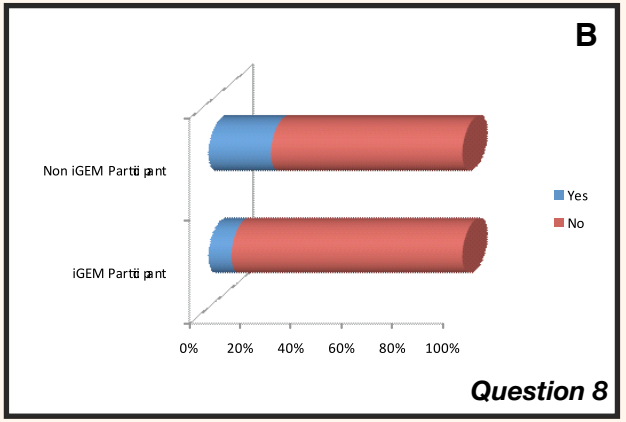
THE SURVEY

Participants from other fields distrusting this type of drugs was higher (28%):

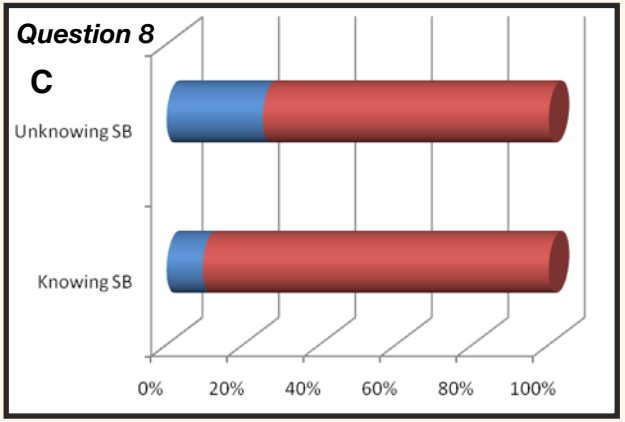
Question 9. From 1 (nothing) to 5 (completely) how dangerous or beneficial do you think Synthetic Biology is?

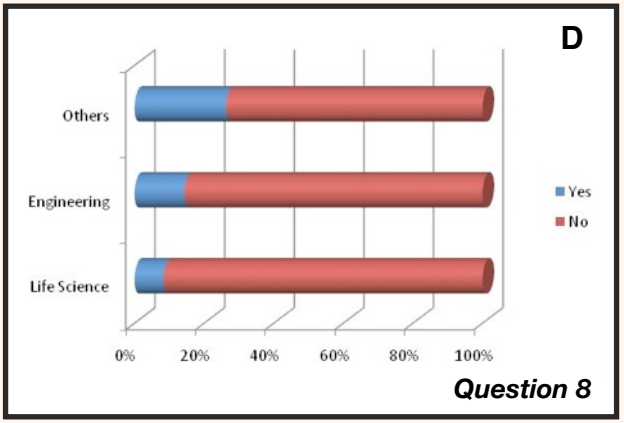
Only 36 out of 1288 think that Synthetic Biology is a little or not beneficial at all. But, on the other hand, more than 82% of the opinions see this new area as highly or completely beneficial.

Analyzing hazard, we can see that almost 35% have chosen the more neutral option. But if we study the more extreme options, 306 responses out of 1288 say that Synthetic Biology is very or completely dangerous whilst 42% of interviewees consider it not at all or a bit hazardous.

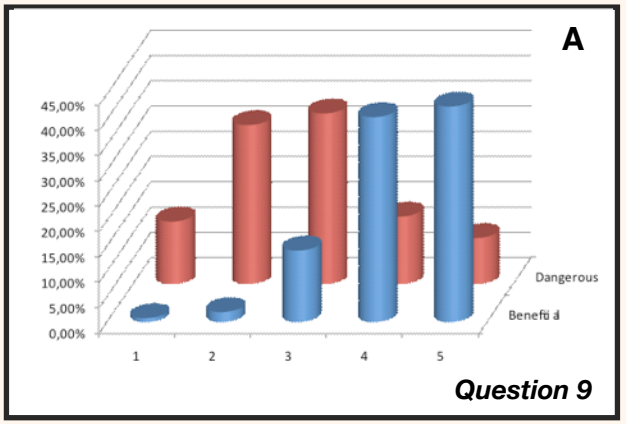


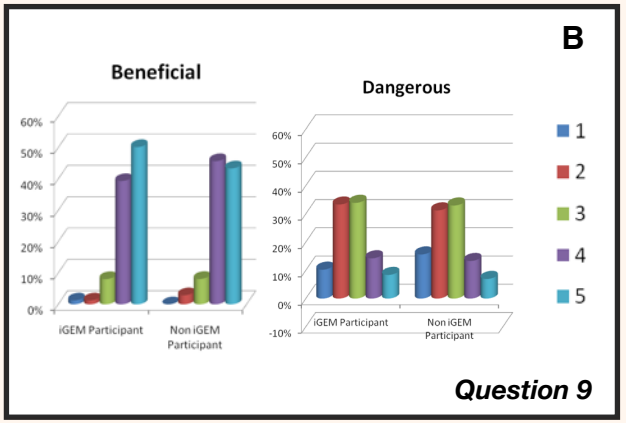
Disaggregating the responses by groups in each ranking, we must point out a clear trend: people with a greater awareness of Synthetic Biology believe that it is potentially more beneficial and less dangerous than

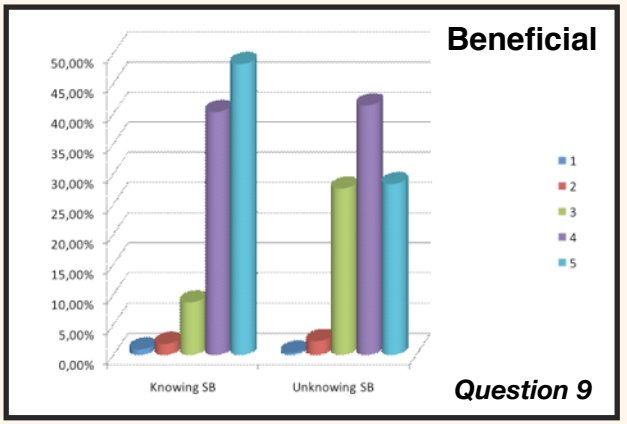


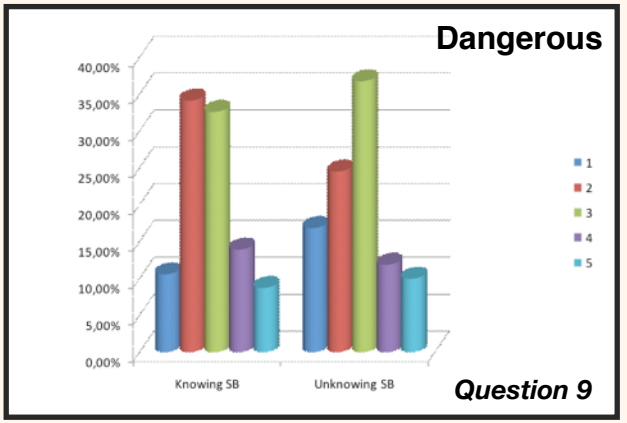


uninformed people. A similar conclusion can be obtained when iGEM members and non members are compared.





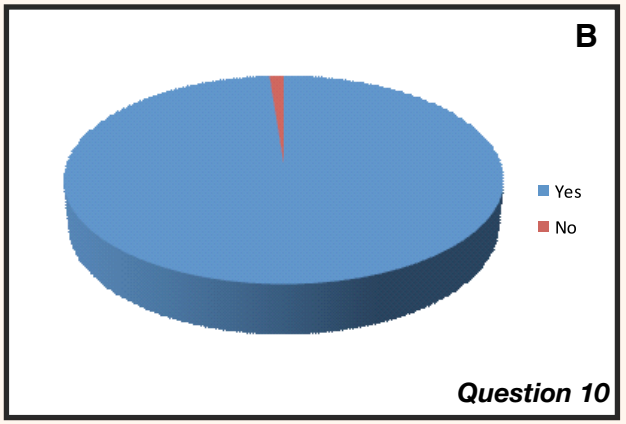


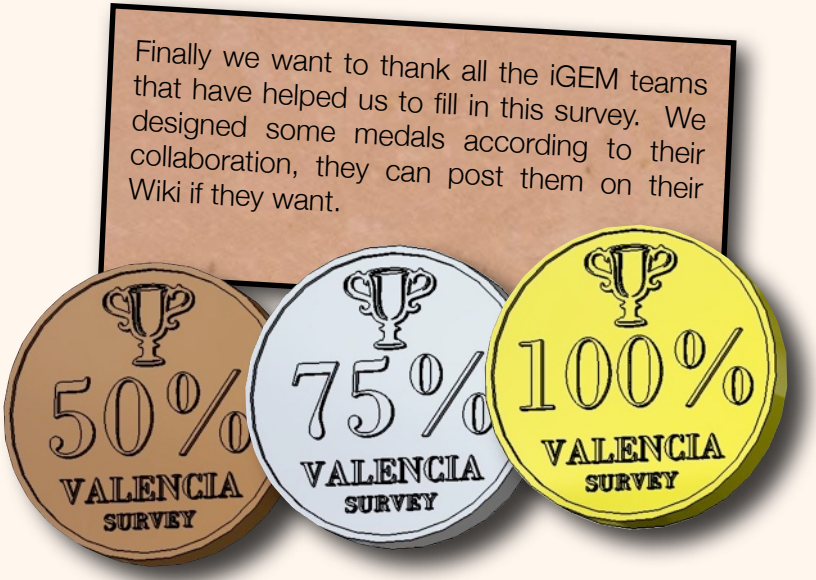


THE SURVEY

Question 10. Do you think we should continue research on Synthetic Biology?

The last question has revealed a virtually total approval to continue research in Synthetic Biology. Only 19 out of 1288 disagree with the development of this new discipline.





Gold (100% of the team members have filled our survey): Imperial College London, Paris, Minnesota, Chiba, Harcard, SupBiotech-Paris, NTU Singapore, IPN.UNAM Mexico, Sheffield, Heidelberg, DTU Denmark, KU Leuven, Virginia Commonweath, TorontoMaRSDiscovery, UAB Barcelona, Southhampton, Slovenia, SDU Denmark, British Columbia, Wisconsin Madison, Edinburgh, Groningen, Freiburg Bioware, Freiburg Software, UCL London, TU Delft, Calgary, LCG-UNAM Mexico, UQ Australia, Art Science Bangalore, IT Bombay India, Brown, Berkeley Software, BCCS Bristol.

Silver (75% of the team members have filled our survey): PKU Beijing, Lethbridge, SJTU Biox Shangai, Upsala Sweden, Victoria Australia.

Bronze (50% of the team members have filled our survey): Cambridge, Missouri Miners, Wash U, Victoria BC, NYMU Taipei, EPF Lausanne, Yeshiva NTC, Mo Western Davidson, Virginia U Chicago, Bay Arka RSI, Michigan, Queens, Johns Hopkins Bagm Bologna, USTC, Biotec Dresden, USTC Software, IIT Madras, Washington, ULB Brussels, UC Davis.

*643 Members from all iGEM Teams have answered to our survey (58% of the total)

CONCLUSIONS

In our opinion, Synthetic Biology is a novel discipline that is beginning to be well-known among society. The general public does not seem to be afraid of SB, even though it is a revolutionary area. However, a lot of people do not have a clear idea of what it is, so more efforts should be addressed to disseminating this new field.

Similar answers were found among different groups when we asked them about creating life in the laboratory and problems regarding intellectual property. We think that these profound issues are strong convictions formed early in life and are hard to change. This contrasts with questions related to transgenics. One can clearly see how different answers may be in terms of participants' biotechnological knowledge and the field they are working on. When we asked about ethical differences between Synthetic Biology and classic Genetic Engineering, we also found diverging answers depending on the social group. According to this information, we may classify ethical questions in two blocks; when positions are extreme and a debate is usually futile we have "insurmountable issues", on the other hand, when opinions change depending on knowledge of the topic we consider these as "relaxed issues".

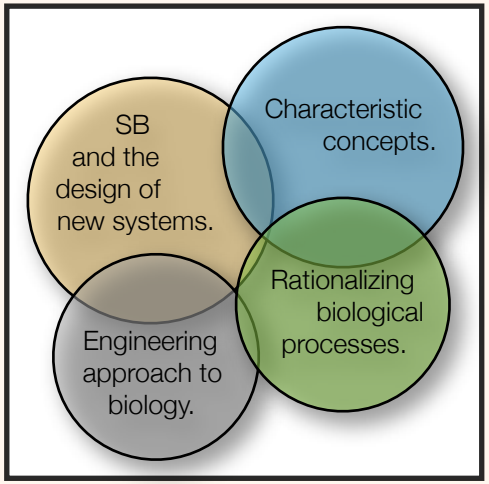
Other works with a similar goal have been published this year[1], [2]. In their surveys, fewer people participated (16 personally and 1005 interviewed by telephone[1], and 1001[2]) and they were only addressed to UK[1] and USA[2]. Synthetic Biology: public dialogue on Synthetic Biology[1] is the first UK's public dialogue of Synthetic Biology that explores people's views and attitudes towards this discipline. It was carried out by The Royal Academy of Engineering (www.raeng.org.uk). Its objectives were to determine public awareness of SB, explore uninformed and informed public attitudes to SB, identify particular hopes, expectations and concerns relating to the development of the technology, and identify issues that merit further research and/or dialogue activity.

Finally, Nanotechnology, Synthetic Biology, & Public Opinion[2] is a report of findings based on a survey. It was conducted on behalf of The Woodrow Wilson International Center for Scholars. This is the fourth year of the study, but since the second year it included Synthetic Biology. They basically asked about public awareness of SB (with similar results to [1], not a lot of people know about it), the impression of its risks and benefits, and concerns about biofuels. Like us, they concluded that there should be more information for the general public about new technologies.

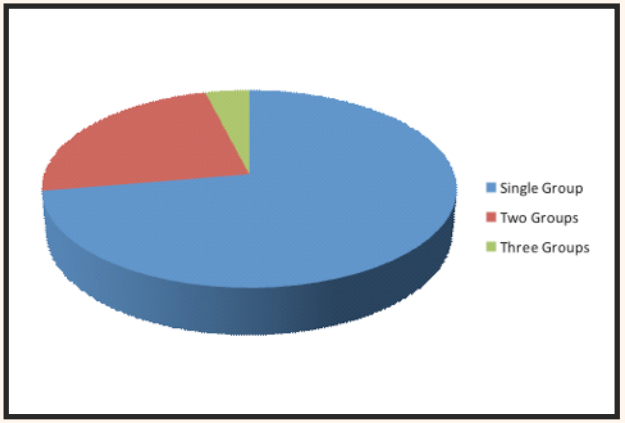
THE SURVEY

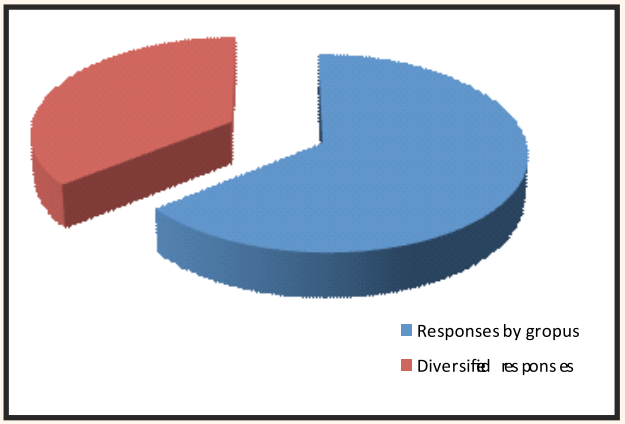
DEFINITIONS

After considering and comparing all definitions received (864) they were classified into four different groups.



Thus, over 65% of the responses have been included in one or more of these segments. Obviously, groups are not mutually exclusive and one definition may fall into more than one group. However, 66% of the definitions were classified in a single group, 22% into two main groups, and only 4% were considered to correspond to three of the divisions established. We were not able to find any definition that referred to the four criteria.





You can check all the 863 definitions at http://2009.igem.org/Team:Valencia/All_Definitions

In a more detailed analysis, more than half of the answers dealt with the design and creation of new systems (58%); 48% on the relationship between Synthetic Biology and Engineering; 19% were descriptive definitions listing some of the basic features of this new discipline such as “standardization” and “abstraction”; and 8% included the importance of Synthetic Biology in “understanding” biological systems. Words used to define SB among each of the four groups are listed below.

Synthetic Biology and the design of new systems.

Within this section, participants have defined Synthetic Biology as creation (38%), designing (33%), engineering (32%), building (14%), modifying (13%), making (8%) and assembling (2%) new biological systems (56%), parts (28%), organisms (18%), devices (17%), functions (16%), life forms (12%), components (7%) and machines (4%).

The best definitions

“A new interdisciplinary field that involves the design, construction and standardization of new biological parts, devices, and systems, and the re-design of existing, natural biological systems for useful purposes.”

Female, undergraduate student, under 20 years old

“Application of engineering principles (modularity, abstraction) to rationalize the art of genetic modification, increasing the complexity of systems that can be designed and constructed reliably.”

Male, doctoral degree, 31-40 years old

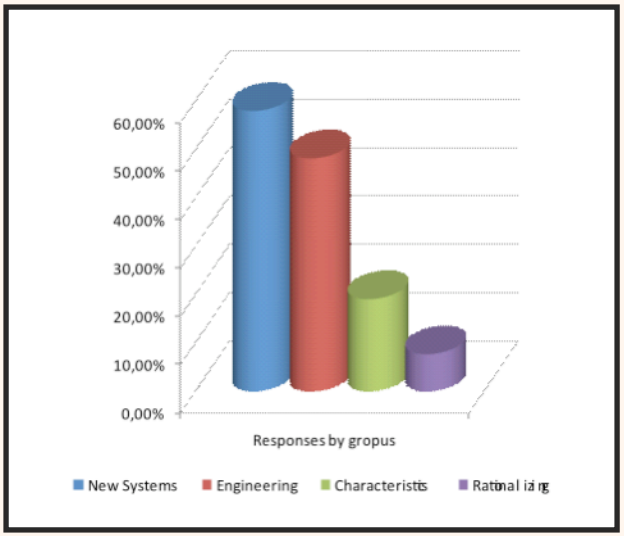
“Synthetic biology is a new discipline of life sciences focused on bringing engineering into biology. It uses engineering concepts like modeling and standardization to create biological devices with new capabilities that do not exist in nature.”

Male, graduate student – Ph, 21-30 years old

Engineering approach to Biology.

This group includes definitions referring to Synthetic Biology as a new interdisciplinary field where

THE SURVEY



engineering principles are applied to Biology (69%), Biological Systems (39%), Science (7%), Genetic Manipulation (6%) and Life Sciences (5%).

Characteristic concepts of Synthetic Biology.

This group includes definitions which state that Synthetic Biology involves standardization (72%), abstraction (16%), modularity (14%), modeling (12%), characterization (5%), interchangeability (3%), automation, insulation, transferability, hierarchy, acceleration and simulation of biological systems (2%).

Rationalizing biological processes.

The last group corresponds to those definitions that consider Synthetic Biology as a field of knowledge that aims to further understand biological systems (70%), the basis of life (18%) and complex biochemical pathways (12%).

The most original definitions

"Engineering + Cell Biology - World Domination."

Male, graduate student – Ph, 21-30 years old

"Decouple life, Construct life."

Male, undergraduate student, under 20 years old

"Synthetic Biology is Systems biology in reverse - obtaining in vivo results by in silico prediction."

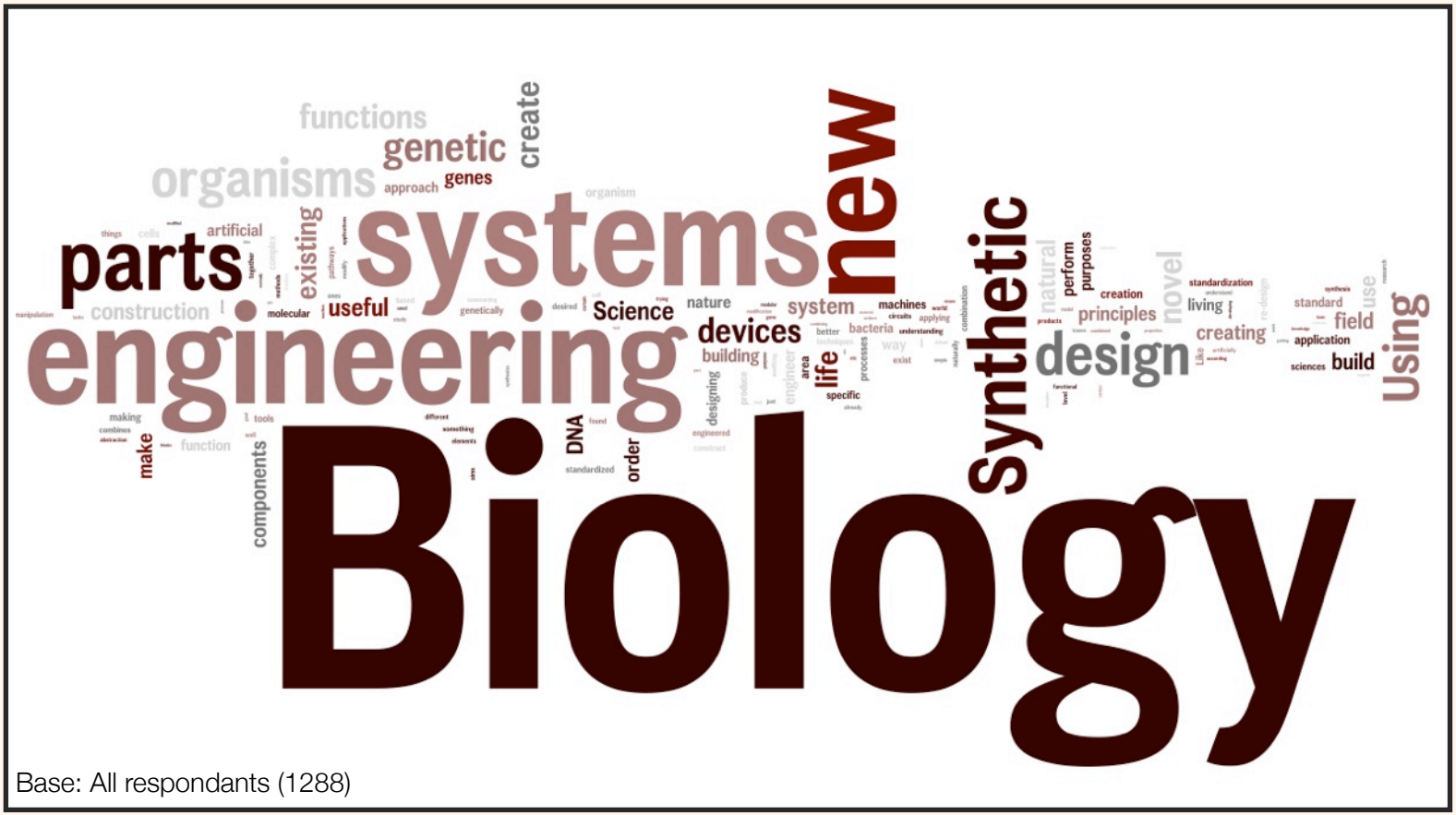
Male, undergraduate student, 21-30 years old

"Abstracting biology concepts with an engineering framework to introduce standards into the field. Like lego."

Male, undergraduate student, under 20 years old

"Thinking like an engineer and doing like a molecular biologist."

Female, doctoral degree, 31-40 years old

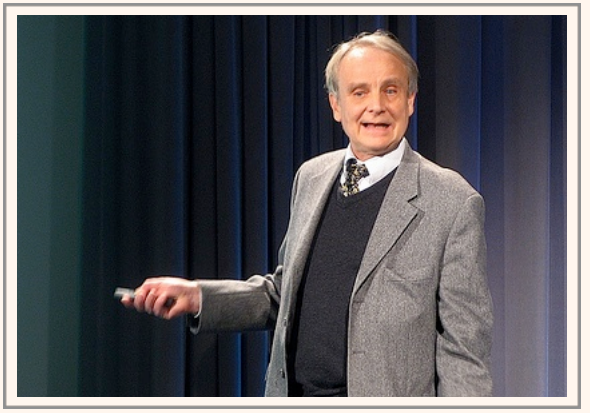


The most repeted words in all of our 863 definitions. Size according to its repetition. “Biology” refers to both “biology and “biological” terms. This word cloud was created by http://www.wordle.net/

[1] : *Synthetic Biology: public dialogue on synthetic biology.* The Royal academy of Engineering. 60 pages. 2009.
[2]: *Awareness of and Attitudes Towards Nanotechnology and Synthetic Biology*, Peter D Hart Research Associates. Inc. 17 Pages. Woodrow Wilson International Center for Scholars. 2009.

THE EXPERTS

Markus Schmidt



Antoine Danchin

Markus Smicht is an Austrian biosafety scientist. His research interests include plant genetic resources, risk assessment, public perception, communication, and technology assessment (TA) of novel bio- and nanotechnologies, including Synthetic Biology. His interest in SB is beyond doubt and he has interviewed many experts in the field (http://www.synbiosafe.eu/index.php?page=expert-interviews)

With more than three hundred publications in forty years, Antoine Danchin is nowadays, one of the most popular scientists developing theoretical reflections and experiments in the domain of Synthetic Biology. Trained as a mathematician and a physicist, his work with Adenylate cyclase is well known, but he has also focused on Bioinformatics and Philosophy of Science.

Both of them have kindly answered an interview about Synthetic Biology. First, we have asked them to fill in our survey. If you answered it too, you may be interested in comparing your answers with the ones of our experts. Finally, we have asked several additional questions on Ethics, Biosafety and the Regulatory frameworks of Synthetic Biology.

ANSWERS TO OUR SURVEY

Markus

Question: Do you know what Synthetic Biology is? Please, define it!

Answer: *Yes, Synthetic biology is the design and construction of new biological systems not found in nature. It aims at creating novel organisms for practical purposes but also at gaining insights into living systems by re-constructing them. SB is an interdisciplinary field, involving microbiology, genetic engineering, information technology, nanotechnology, and biochemistry. SB as a scientific and engineering field includes the following subfields:*
(A) Engineering DNA-based biological circuits, including but not limited to standardized biological parts;
(B) Defining a minimal genome/minimal life (top-down approach);
(C) Constructing so-called protocells, i.e. living cells, from scratch (bottom-up approach);
(D) Creating orthogonal biological systems based on a biochemistry not found in nature (e.g. non-DNA, non-RNA nucleic acids); and
(E) Gene and Genome DNA synthesis

Question: Do you know what Synthetic Biology is? Please, define it!

Answer: *Yes, is the process to reconstruct life from the chemical world.*

Antoine

As they are experts, Markus and Antoine don't like to follow the rules! They have extended their answers further than requested in the survey. But since we think their ideas are particularly valuable, we have included them for all of you to read.

THE EXPERTS

Markus

Q: Now, without looking at Wikipedia, select the 5 words you feel are most closely related to Synthetic Biology. (Answers in bold)

A: DNA, Plastic, Destruction, **Abstraction**, Anthrax, **System**, PCR, Infection, **BioBrick**, Modelling, Transgenics, **Creation**, **Standards**.

Q: Knowing that parts of the genetic information can be isolated, do you think these pieces should be ... ?

A: Patentable // **Open Source** // Sorry, I don't know.

Q: Let´s assume that humans can create artificial life. Do we have the right to do so?

A: **Yes** // No // Sorry, it's too hard for me.

Q: Do you think the situation shown in many science fiction movies is possible, like "I, Robot", "Terminator", etc, in which humans go a step too far in their need for improving themselves?

"SB tries to much more rational than Genetic Engeneering." (Markus)

Q: Now, without looking at Wikipedia, select the 5 words you feel are most closely related to Synthetic Biology. (Answers in bold)

Antoine

A: DNA, Plastic, Destruction, **Abstraction**, Anthrax, System, PCR, Infection, **BioBrick**, **Modelling**, Transgenics, **Creation**, **Standards**.

Q: Knowing that parts of the genetic information can be isolated, do you think these pieces should be ... ?

A: Patentable // Open Source // Sorry, I don't know.

One can only patent the result of inventive activity. Therefore isolated genetic information cannot be patented as such, but only coupled to some kind of inventive activity.

Q: Let´s assume that humans can create artificial life. Do we have the right to do so?

A: **Yes** // No // Sorry, it's too hard for me.

Q: Do you think the situation shown in many science fiction movies is possible, like "I, Robot", "Terminator", etc, in which humans go a step too far in their need for improving themselves?

Markus

A: Let's hope human ethics can set a brake before that // Uh? OK, ban people from creating life.
I Robot and Terminator are not good examples, both are robots, not enhanced humans.
I think humans will use the tools to improve themselves in a variety of different ways in the future. One day – when the tools are available - it will be uneconomic, irrational and inhuman not to do so.

Q: Do you think there are significant ethical differences between Classic Genetic Engineering and Synthetic Biology?
A: No // Yes // What?
Can be, but not so much with the biobricks subfield. But the more radical approaches such as the protcells or the non-DNA non-RNA genomes could well pose some new ethical questions.

Q: Do you think eating a transgenic vegetable is harmful for your health?

"The more radical approaches such as the protcells or the non-DNA non-RNA genomes could well pose some new ethical questions." (Markus)

Antoine

A: Let's hope human ethics can set a brake before that // Uh? OK, ban people from creating life
This is not science fiction. The important ethical issue, as in all applications of science, is the use we make of what we create. A knife can be used to make surgery, cut meat or plants, but it can also kill. This does not mean that we should not have created knives. Yet, some of our constructs are clearly meant to do harm: this is the case of landmines, or explosive parcels. The problem is not, therefore, creation of life, but the goal of that particular creation. We may be in a situation somewhat similar to that of the time when scientists conceived the taming of nuclear power. We cannot escape creating knowledge, yet, unless we can be certain to control all sources of that particular creation, we should not try to stop that creation, but, rather, make it "common knowledge", which is the only way to have some kind of dissuasion against unethical use. Note that, if we know of some type of knowledge which could be used in a wrong way, and which exists only in one or a few places and can be destroyed there, then we should probably destroy this source of knowledge, and never get it, but this is a very rare situation.

"The problem is not creation of life, but the goal of that particular creation." (Antoine)

THE EXPERTS

Markus

Yes // No // It depends, I would agree with the Golden Rice, not with "Roundup Ready" strains
A: *Depends on the transgenic vegetable. Once it has gone through the biosaftey testing I think it is even safer than other foods are. Or do you know what genes there are in a Kiwi?*

Q: Do you think eating a drug produced in a genetically modified organism (GMO) is dangerous for your health?
A: Yes // **No**

Q: From 1 (nothing) to 5 (completely) how ... do you think Synthetic Biology is?
A:Beneficial 1 2 3 4 **5**
Dangerous 1 2
3 4 5

"SB will have a tremendous impact in a all kinds of sectors, but if that is in 10, 20 or 50 years I can't say." (Markus)

Q: Do you think we should continue research in Synthetic Biology?
A: **Yes** // No

Antoine

Q: Do you think there are significant ethical differences between Classic Genetic Engineering and Synthetic Biology?
A: **No** // Yes // What?

Q: Do you think eating a transgenic vegetable is harmful for your health?
Yes // No // It depends, I would agree with the Golden Rice, not with "Roundup Ready" strains
A: *No, unless in contains toxic products (you could purposely make poisonous plants).*

Q: Do you think eating a drug produced in a genetically modified organism (GMO) is dangerous for your health?
A: Yes // **No**

Q: From 1 (nothing) to 5 (completely) how ... do you think Synthetic Biology is?
A: Beneficial 1 2 **3** 4 5
Dangerous **1** 2 3 4 5, except for the chemical part of DNA synthesis, which could be **5** (complete synthesis of dangerous viruses)

Q: Do you think we should continue research in Synthetic Biology?
A: **Yes** // No

ANSWERS TO OUR SURVEY/THE INTERVIEW

Markus

One of the aims of SB is the standardization of biological parts but, do you believe that this standardization could be as successful as shown to be in classical engineering?

I think it is a great idea to try out if standardization works on a gene level, just like in engineering. But I have my doubts if it will work exactly that way. The examples used from mechanical engineering and electronic engineering are analogies. It is nice to use these analogies but they certainly have their limits. The nut and bolt example of standards that made mechanical engineering so much easier, or the plug and play of electronic parts is still very different from how an organism works.
I think it is necessary to come up with a new kind of engineering that takes the particularities of organisms into account, before a similar success can be achieved.

Do you think that the increasing availability of DNA synthesis services will necessarily result in an enhanced risk of dangerous constructs?

Well yes it definitely creates a new risk that someone constructs the DNA of a pathogen that could be harmful for humans or the environment.

Antoine

One of the aims of SB is the standardization of biological parts but, do you believe that this standardization could be as successful as shown to be in classical engineering?

No, I do not believe in the way we consider standards, for a very specific reason, that of internal consistency of the organism. Typically, beside the identified function of an object, there are a great many constraints dealing with time and space where this object has to be put in place and in action. As a consequence the shape of the object, for example, should differ in different organisms. The standardization is only real at the conceptual level. For example one could think of specific functions carried out by different objects (see the degradosome in different bacterial clades).

Do you think that the increasing availability of DNA synthesis services will necessarily result in an enhanced risk of dangerous constructs?

"One can only patent the result of inventive activity." (Antoine)

Yes, and this is a real problem, but not linked to Synthetic Biology per se. It is, in fact a problem of synthetic chemistry. This is similar to the making of

THE EXPERTS

Markus

If any, which regulatory framework do you think SB should have?

It is already bound to regulatory frameworks! However, as the field develops several aspects will have to be re-negotiated or completely renewed.

What do you expect about SB results in the near and long-term future? Do you think expectations will be met?

"The plug and play of electronic parts is still very different from how an organism works." (Markus)

Hard to say, the big impact will certainly take some time. But finally I think SB will have a tremendous impact in a all kinds of sectors. But if that is in 10, 20 or 50 years I can't say.

How do you think the iGEM competition contributes to SB development?

A lot, it has created a venue for SB where ideas, approaches and viewpoints are transported to the

Antoine

explosives, with the additional problem that living organism can multiply. By contrast, living organisms have built-in defenses that are very difficult to implement against chemicals such as explosives. This is why I think that terrorists will still go on with chemistry (or, if they can, nuclear power).

If any, which regulatory framework do you think SB should have?

Standard law: it is forbidden to kill !

What do you expect about SB results in the near and long-term future? Do you think expectations will be met?

"Easily available dangerous constructs are a real problem, but not linked to synthetic biology per se. It's a problem of synthetic chemistry." (Antoine)

My position is fairly simple. I think that SB will succeed in terms of creating cell factories working at a fairly small scale. Scaling up will be difficult but perhaps not impossible, if we can find ideas to harness the intrinsic

Markus

younger generation. Someone has to test the claim if it is possible that you can use standardized bioparts! Also iGEM got a lot of attention by the media and helped to spread the word. Also it is a great educational event!

Do you think that there are significant differences between Genetic Engineering and SB in...

Concept?

Yes it tries to be much more rational than GE. In SB, engineering is used as a methodology, in GE it was just a metaphor.

Bioethics?

The more radical approaches such as the protocells or the non-DNA non-RNA genomes could well pose some new ethical questions.

Biosafety?

When SB delivers what it promises now, there will be several new biosafety challenges. Biosafety, is the prevention of unintentional exposure to pathogens, toxins and otherwise harmful or potentially harmful

Antoine

inventive power of life to the goals we have. In short, either we will make cell factories which will age and need to be replaced regularly, or we will keep the inventive power of life (what I named "Maxwell's demon's genes") but, then, the goal of the cell will generally differ from that of engineers...

How do you think the iGEM competition contributes to SB development?

Essentially as a teaching enterprise, which attracts young students to biology. I think this is great, as it is really very useful to have a lively community of enthusiastic young scientists !

Do you think that there are significant differences between Genetic Engineering and SB in...

Concept?
Considerable differences; in fact I think that combination of nuts and bolts will not work.

Bioethics?
Yes: I think that there was no ethical problem in Genetic Engineering

THE EXPERTS

Markus

biological material, or its accidental release. So, what is new?

New methods in risk assessment SB requires new methods of risk assessment to decide whether a new SB technique or application is safe enough (for human health, animals and the environment) for the use in restricted and/or less restricted environments. The following cases warrant a review and adaptation of current risk assessment practices:

(A) DNA-based biocircuits consisting of a larger number of DNA 'parts'.

(B) The survivability and evolvability novel minimal organisms -used as platform/chassis for DNA based biocircuits– in different environments;

(C) Exotic biological systems based on an alternative biochemical structure, e.g. genetic code based on novel types of nucleotides, or an enlarged number of base pairs.

"Careful attention must be paid to the way SB skills diffuse (Do-it-yourself biology, amateurs, biohackers)." (Markus)

Biosafety?
Not at this point.

Antoine

Thank you very much for your time Antoine!

Markus

Synthetic safety systems (biosafety engineering)

An important task of a safety discussion is to explore how SB itself may contribute towards overcoming existing and possible future biosafety problems by contributing to the design of safer biosystems, for example:

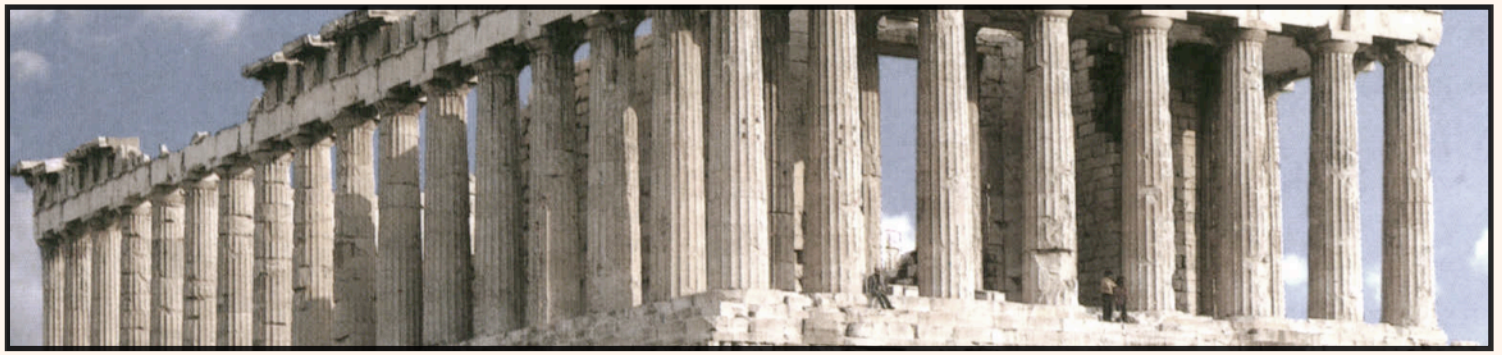
(A) Design of less competitive organisms by changing metabolic pathways;
(B) Replacing metabolic pathways with others that have an in-built dependency on external biochemicals;
(C) Design of evolutionary robust biological circuits;
(D) Use of biological systems based on an alternative biochemical structure to avoid e.g. gene flow to and from wild species;
(E) Design of protocells that lack key features of living entities, such as growth or replication.

Diffusion of SB to amateur biologists

Careful attention must be paid to the way SB skills diffuse (e.g. Do-it-yourself biology, amateurs, biohackers). The consequences of further deskilling biotechnology are not clear and should be investigated. In particular:
(A) Care must be taken to ensure that everyone using the resources of SB does so safely and has sufficient awareness of and training in relevant biosafety techniques and approaches;
(B) Proper mechanisms such as laws, codes of conduct, voluntary measures, access restrictions to key materials, institutional embedding and mandatory reporting to Institutional Biosafety Committees [IBCs], need to be in place to avoid unintentional harm.

Thank you very much for your time Markus!

CONCLUSIONS



This book was conceived to contribute to helping the reader understand the complex Synthetic Biology scenario by studying people's opinions (mainly students and researchers, but also experts and the general public) on SB-related conceptual, biosafety, ethical and legal issues.

Trying to define SB is not an easy task. After revising all the definitions of our survey (more than ---), gathering all the information in every Human Practices report at the iGEM; interviewing Markus Schmidt and Antoine Danchin; and reading a lot of serious articles, the only thing we can conclude is that, like the Heisenberg uncertainty principle, SB principles and goals depend on the observer. For instance, iGEM participants, who are assumed to be very close to the real SB, mainly focus on the engineering principles of SB, not paying attention to other aspects of the field. Their vision is closer to that of the engineering fathers of SB like Drew Endy or George Church. On the other hand, biologists usually consider SB as a bottom-up approach to the creation of life in a test tube. Regarding the general public, and as shown by our survey, although precise definitions were provided, again, only a few included all three main principles (creation of novel systems, engineering principles of SB, and the understanding of biological systems through SB).

When Biosafety & Risks were considered, a wide range of opinions was found. Interestingly, the general public did not consider SB as harmful as some experts in scientific journals declare. However, the innocuousness of SB is far from being accepted unanimously by the whole scientific community. Comparing the answers of our interviewed experts reveals a good example of this, this topic being the one where they diverged the most.

We were not surprised to notice that there is a general distrust in genetically modified organisms, although this is certainly not a specific problem of SB but of Genetic Engineering approaches in general. Despite this, young students participating in iGEM are strongly concerned about the risks of GMOs and propose several solutions to make them safer in their Human Practices reports.

It was not easy to select controversial questions about the good and evil of SB in the questionary our experts answered. Only protocells and creating life from inanimate matter provoked a strong discussion about human rights and duties. This differs to the results of our survey, where the majority of participants approved the creation of artificial life. Once again, well-informed people seem to be more concerned than the general public. Patents and intellectual property were also controversial. In previous iGEM reports, studies revealed a lack of consensus on the legal framework a genetic part should be governed by. In contrast, our survey indicates a clearly favorable tendency towards open source. We have found very few solutions or framework proposals to the problem on specialized journals.

Many questions have yet to be answered, but since the development of SB needs a transparent public dialogue, we consider that the first step is to face and discuss the problems of any new field in life. If the bases of the dialogue are properly set, answers will start to come. As a Greek proverb states:

"Αμαρτία 'ξομολογημένη, η μισή συγχωρεμένη."

"A confessed sin is half a sin."

APPENDIX (1)

iGEM edition	Team	Topics discussed
2005	MIT	Biosafety & Risks
2006	Brown	SB & iGEM
	Freiburg	SB & iGEM, Others (Constructive Biology, BioFab)
	Valencia	SB & iGEM
2007	Berkeley_UC	Patents
	Brown	SB & iGEM
	Edinburgh	SB & iGEM, Patents
	Ljubljana	Others (AIDS)
	Michigan	SB & iGEM
	Purdue	Biosafety & Risks

iGEM edition	Team	Topics discussed
2008	Bologna	Biosafety & Risks
	Calgary	SB & iGEM, Bioethics
	Caltech	Biosafety & Risks
	Edinburgh	Biosafety & Risks, Bioethics, Patents
	Freiburg	Biosafety & Risks, Bioethics
	Heidelberg	SB & iGEM, Others (Science Communication)
	KULeuven	Biosafety & Risks, Bioethics, SB & iGEM
	Slovenia	Biosafety & Risks
	TU delft	Biosafety & Risks, Bioethics, Patents, SB & iGEM
	UC Berkeley	Bioethics, SB & iGEM
	UCSF	Patents
	Unipv_Pavia	Biosafety & Risks
	Valencia	Biosafety & Risks, Bioethics, Patents
	Washington	Biosafety & Risks
	Zurich	Biosafety & Risks

APPENDIX (2)

Survey Statistics	
Viewed	931
Started	820
Completed	648
Completion Rate	100%
Drop Outs (After Starting)	79%
Average time taken to complete survey : 6 minute(s)	

Because of technical issues, the results of the survey are s eparated in function of the language used,Spanish or English.

Frequency Analysis (Age)		
Answer	**Count**	**Percent**
<20	175	2.688%
21-30	**418**	**6.421%**
31-40	41	630%
41-50	15	230%
51-60	2	31%
>60	0	0%
Total	**651**	**100%**

Key Analytics (Age)	
Mean	1.849
Confidence Interval @ 95%	[1.799 - 1.900] n = 651
Standard Deviation	655
Standard Error	26

SURVEY RESULTS (ENGLISH)

Frequency Analysis (Sex)		
Answer	**Count**	**Percent**
Man	**398**	**6.114%**
Woman	253	3.886%
Total	**651**	**100%**

Key Analytics (Sex)	
Mean	1.389
Confidence Interval @ 95%	[1.351 - 1.426] n = 651
Standard Deviation	488
Standard Error	19

Frequency Analysis (Degree Level)		
Answer	**Count**	**Percent**
Undergraduate student	**417**	**6.406%**
Bachelors degree	63	968%
Graduate student (Masters)	56	860%
Masters degree	28	430%
Graduate student (Phd)	34	522%
Doctoral degree	53	814%
Total	**651**	**100%**

Key Analytics (Degree Level)	
Mean	2.014
Confidence Interval @ 95%	[1.888 - 2.139] n = 651
Standard Deviation	1.636
Standard Error	64

APPENDIX (2)

Frequency Analysis (Field)		
Answer	**Count**	**Percent**
Life Science	**352**	**5.407%**
Engineering	189	2.903%
Others	110	1.690%
Total	**651**	**100%**

Key Analytics (Field)	
Mean	1.628
Confidence Interval @ 95%	[1.570 - 1.686] n = 651
Standard Deviation	757
Standard Error	0,030

Frequency Analysis (Where have you found the survey)		
Answer	**Count**	**Percent**
E-mail	**488**	**7.496%**
Facebook	20	307%
iGEM Wiki	101	1.551%
Other	42	645%
Total	**651**	**100%**

Key Analytics (Where have you found the survey)	
Mean	1.535
Confidence Interval @ 95%	[1.460 - 1.609] n = 651
Standard Deviation	973
Standard Error	38

SURVEY RESULTS (ENGLISH)

Frequency Analysis (Do you know the iGEM competition?)		
Answer	**Count**	**Percent**
Yes	**629**	**9.662%**
No	22	338%
Total	**651**	**100%**

Key Analytics (Do you know the iGEM competition?)	
Mean	1.034
Confidence Interval @ 95%	[1.020 - 1.048] n = 651
Standard Deviation	181
Standard Error	7

requency Analysis (Are you a member of any iGEM team?)		
Answer	**Count**	**Percent**
Yes	**596**	**9.490%**
No	32	510%
Total	**628**	**100%**

Key Analytics (Are you a member of any iGEM team?)	
Mean	1.051
Confidence Interval @ 95%	[1.034 - 1.068] n = 628
Standard Deviation	220
Standard Error	9

APPENDIX (2)

Frequency Analysis (Do you know what Synthetic Biology is?)		
Answer	**Count**	**Percent**
Yes	**615**	**9.462%**
No	35	538%
Total	**650**	**100%**

Key Analytics (Do you know what Synthetic Biology is?)	
Mean	1.054
Confidence Interval @ 95%	[1.036 - 1.071] n = 650
Standard Deviation	226
Standard Error	9

Frequency Analysis (Have you understood the explanation?)		
Answer	**Count**	**Percent**
Yes, loud and clear	**30**	**8.571%**
No :(Im sorry, but lets go on!	5	1.429%
Total	**35**	**100%**

Key Analytics (Have you understood the explanation?)	
Mean	1.143
Confidence Interval @ 95%	[1.025 - 1.260] n = 35
Standard Deviation	355
Standard Error	60

SURVEY RESULTS (ENGLISH)

Frequency Analysis (Select the 5 words you feel are more related to Synthetic Biology)		
Answer	**Count**	**Percent**
DNA	**512**	**1.575%**
Plastic	16	49%
Destruction	19	58%
Abstraction	179	551%
Anthrax	4	12%
System	443	1.363%
PCR	208	640%
Infection	19	58%
BioBrick	486	1.495%
Modelling	440	1.354%
Transgenics	193	594%
Creation	370	1.138%
Standards	361	1.111%
Total	**3250**	**100%**

Key Analytics (Select the 5 words you feel are more related to Synthetic Biology)	
Mean	7.887
Confidence Interval @ 95%	[7.752 - 8.022] n = 3250
Standard Deviation	3.919
Standard Error	69

APPENDIX (2)

Frequency Analysis (Knowing that parts of the genetic information can be isolated, do you think these pieces should be ... ?)		
Answer	**Count**	**Percent**
Patentable	80	1.235%
Open Source	**516**	**7.963%**
Sorry, I dont know.	52	802%
Total	**648**	**100%**

Key Analytics (Knowing that parts of the genetic information can be isolated, do you think these pieces should be ... ?)	
Mean	1.957
Confidence Interval @ 95%	[1.922 - 1.991] n = 648
Standard Deviation	450
Standard Error	18

Frequency Analysis (Let´s assume that humans can create artificial life. Do we have the right to do it?)		
Answer	**Count**	**Percent**
Yes	**416**	**6.420%**
No	155	2.392%
Sorry, its too hard for me.	77	1.188%
Total	**648**	**100%**

Key Analytics (Let´s assume that humans can create artificial life. Do we have the right to do it?)	
Mean	1.477
Confidence Interval @ 95%	[1.423 - 1.531] n = 648
Standard Deviation	698
Standard Error	27

SURVEY RESULTS (ENGLISH)

Frequency Analysis (Do you think is possible a situation such as many science-fiction movies as "I, Robot", "Terminator", etc, in which humans go a step too far in their need for improving themselves?)		
Answer	**Count**	**Percent**
Lets hope human ethics can set a brake before that	**403**	**9.688%**
Uh? OK, ban people from creating life	13	312%
Total	**416**	**100%**

Key Analytics (Do you think is possible a situation such as many science-fiction movies as "I, Robot", "Terminator", etc, in which humans go a step too far in their need for improving themselves?)	
Mean	1.031
Confidence Interval @ 95%	[1.015 - 1.048] n = 416
Standard Deviation	174
Standard Error	9

Frequency Analysis (Do you think there are significant ethical differences between Classic Genetic Engineering and Synthetic Biology?)		
Answer	**Count**	**Percent**
Yes	277	4.275%
No	**331**	**5.108%**
What?	40	617%
Total	**648**	**100%**

Key Analytics (Do you think there are significant ethical differences between Classic Genetic Engineering and Synthetic Biology?)	
Mean	1.634
Confidence Interval @ 95%	[1.588 - 1.680] n = 648
Standard Deviation	597
Standard Error	23

APPENDIX (2)

Frequency Analysis (Do you think eating a transgenic vegetable is harmful for your health?)		
Answer	**Count**	**Percent**
Yes	33	509%
No	**355**	**5.478%**
It depends. I would agree with the Golden Rice, not with Roundup Ready strains	260	4.012%
Total	**648**	**100%**

Key Analytics (Do you think eating a transgenic vegetable is harmful for your health?)	
Mean	2.350
Confidence Interval @ 95%	[2.306 - 2.395] n = 648
Standard Deviation	574
Standard Error	23

Frequency Analysis (Do you think eating a drug produced in a genetic modified organism (GMO) is dangerous for your health?)		
Answer	**Count**	**Percent**
Yes	75	1.157%
No	**573**	**8.843%**
Total	**648**	**100%**

Key Analytics (Do you think eating a drug produced in a genetic modified organism (GMO) is dangerous for your health?)	
Mean	1.884
Confidence Interval @ 95%	[1.860 - 1.909] n = 648
Standard Deviation	320
Standard Error	13

SURVEY RESULTS (ENGLISH)

From 1 (nothing) to 5 (completely) how ... do you think Synthetic Biology is?		
Question	**Count**	**Score**
Beneficial	648	4.341
Dangerous	648	2.772
	Average	**3.556**

Frequency Analysis (From 1 (nothing) to 5 (completely) how Beneficial do you think Synthetic Biology is?)		
Answer	**Count**	**Percent**
1	7	108%
2	11	170%
3	52	802%
4	262	4.043%
5	**316**	**4.877%**
Total	**648**	**100%**

Key Analytics (From 1 (nothing) to 5 (completely) how Beneficial do you think Synthetic Biology is?)	
Mean	4.341
Confidence Interval @ 95%	[4.281 - 4.402] n = 648
Standard Deviation	786
Standard Error	31

APPENDIX (2)

Frequency Analysis (From 1 (nothing) to 5 (completely) how Dangerous do you think Synthetic Biology is?)		
Answer	**Count**	**Percent**
1	70	1.080%
2	210	3.241%
3	**221**	**3.410%**
4	92	1.420%
5	55	849%
Total	**648**	**100%**

Key Analytics (From 1 (nothing) to 5 (completely) how Dangerous do you think Synthetic Biology is?)	
Mean	2.772
Confidence Interval @ 95%	[2.688 - 2.856] n = 648
Standard Deviation	1.090
Standard Error	43

SURVEY RESULTS (ENGLISH)

Frequency Analysis (Do you think we should continue research in Synthetic Biology?)		
Answer	**Count**	**Percent**
Yes	**642**	**9.907%**
No	6	93%
Total	**648**	**100%**

Key Analytics (Do you think we should continue research in Synthetic Biology?)	
Mean	1.009
Confidence Interval @ 95%	[1.002 - 1.017] n = 648
Standard Deviation	96
Standard Error	4

APPENDIX (2)

Frequency Analysis (Age)		
Answer	**Count**	**Percent**
<20	79	1.234%
21-30	**413**	**6.453%**
31-40	86	1.344%
41-50	38	594%
51-60	19	297%
>60	5	78%
Total	**640**	**100%**

Survey Statistics	
Viewed	977
Started	831
Completed	640
Completion Rate	100%
Drop Outs (After Starting)	77%
Average time taken to complete survey : 6 minute(s)	

Key Analytics (Age)	
Mean	2.250
Confidence Interval @ 95%	[2.180 - 2.320] n = 640
Standard Deviation	909
Standard Error	36

SURVEY RESULTS (SPANISH)

Frequency Analysis (Sex)		
Answer	**Count**	**Percent**
Hombre	**356**	**5.562%**
Mujer	284	4.438%
Total	**640**	**100%**

Key Analytics (Sex)	
Mean	1.444
Confidence Interval @ 95%	[1.405 - 1.482] n = 640
Standard Deviation	497
Standard Error	20

Frequency Analysis (Degree Level)		
Answer	**Count**	**Percent**
Estudiante de diplomatura (primer ciclo)	112	1.750%
Diplomado o equivalente	38	594%
Estudiante de licenciatura (segundo ciclo)	**253**	**3.953%**
Licenciado o equivalente	120	1.875%
Estudiante de doctorado	67	1.047%
Doctor	50	781%
Total	**640**	**100%**

Key Analytics (Degree Level)	
Mean	3.222
Confidence Interval @ 95%	[3.112 - 3.332] n = 640
Standard Deviation	1.422
Standard Error	56

APPENDIX (2)

Frequency Analysis (Field)		
Answer	**Count**	**Percent**
Ciencias Naturales	**231**	**3.609%**
Ingeniería	219	3.422%
Otros	190	2.969%
Total	**640**	**100%**

Key Analytics (Field)	
Mean	1.936
Confidence Interval @ 95%	[1.873 - 1.999] n = 640
Standard Deviation	809
Standard Error	32

Frequency Analysis (Where have you fund this survey)		
Answer	**Count**	**Percent**
E-mail	209	3.266%
Facebook	86	1.344%
iGEM Wiki	28	438%
Otros	**317**	**4.953%**
Total	**640**	**100%**

Key Analytics (Where have you fund this survey)	
Mean	2.708
Confidence Interval @ 95%	[2.602 - 2.813] n = 640
Standard Deviation	1.361
Standard Error	54

SURVEY RESULTS (SPANISH)

Frequency Analysis (Do you know the iGEM Comptetition?)		
Answer	**Count**	**Percent**
Sí	191	2.984%
No	**449**	**7.016%**
Total	**640**	**100%**

Key Analytics (Do you know the iGEM Comptetition?)	
Mean	1.702
Confidence Interval @ 95%	[1.666 - 1.737] n = 640
Standard Deviation	458
Standard Error	18

Frequency Analysis (Are you a member of any iGEM team?)		
Answer	**Count**	**Percent**
Sí	50	2.618%
No	**141**	**7.382%**
Total	**191**	**100%**

Key Analytics (Are you a member of any iGEM team?)	
Mean	1.738
Confidence Interval @ 95%	[1.676 - 1.801] n = 191
Standard Deviation	441
Standard Error	32

APPENDIX (2)

Frequency Analysis (Do you know what Synthetic Biology is?)		
Answer	**Count**	**Percent**
Sí	249	3.891%
No	**391**	**6.109%**
Total	**640**	**100%**

Key Analytics (Do you know what Synthetic Biology is?)	
Mean	1.611
Confidence Interval @ 95%	[1.573 - 1.649] n = 640
Standard Deviation	488
Standard Error	19

Frequency Analysis (Have you understood the explanation?)		
Answer	**Count**	**Percent**
Sí, alto y claro	**354**	**9.054%**
No :(Lo siento, ¡pero sigamos adelante!	37	946%
Total	**391**	**100%**

Key Analytics (Have you understood the explanation?)	
Mean	1.095
Confidence Interval @ 95%	[1.066 - 1.124] n = 391
Standard Deviation	293
Standard Error	15

SURVEY RESULTS (SPANISH)

Frequency Analysis (Select the 5 words you fell are more closely related to Synthetic Biology)		
Answer	**Count**	**Percent**
ADN	**550**	**1.719%**
Plástico	61	191%
Destrucción	42	131%
Abstracción	148	462%
Anthrax	34	106%
Sistema	479	1.497%
PCR	171	534%
Infección	75	234%
BioBrick	227	709%
Modelado	373	1.166%
Transgénicos	376	1.175%
Creación	469	1.466%
Estándares	195	609%
Total	**3200**	**100%**

Key Analytics (Select the 5 words you fell are more closely related to Synthetic Biology)	
Mean	7.595
Confidence Interval @ 95%	[7.455 - 7.734] n = 3200
Standard Deviation	4.028
Standard Error	71

APPENDIX (2)

Frequency Analysis (Knowing that parts of the genetic information can be isolated, do you think these pieces should be ... ?)		
Answer	**Count**	**Percent**
Patentables	87	1.359%
De libre acceso	**442**	**6.906%**
Lo siento, no lo sé.	111	1.734%
Total	**640**	**100%**

Key Analytics (Knowing that parts of the genetic information can be isolated, do you think these pieces should be ... ?)	
Mean	2.038
Confidence Interval @ 95%	[1.994 - 2.081] n = 640
Standard Deviation	555
Standard Error	22

Frequency Analysis (Let´s assume that humans can create artificial life. Do we have the right to do it?)		
Answer	**Count**	**Percent**
Sí	**399**	**6.234%**
No	179	2.797%
Lo siento, es demasiado para mí	62	969%
Total	**640**	**100%**

Key Analytics (Let´s assume that humans can create artificial life. Do we have the right to do it?)	
Mean	1.473
Confidence Interval @ 95%	[1.422 - 1.525] n = 640
Standard Deviation	666
Standard Error	26

SURVEY RESULTS (SPANISH)

Frequency Analysis (Do you think is possible a situation such as many science-fiction movies as "I, Robot", "Terminator", etc, in which humans go a step too far in their need for improving themselves?)		
Answer	**Count**	**Percent**
Esperemos que la ética humana pueda impedirlo	**388**	**9.724%**
Uh? De acuerdo, prohibamos la creación de vida artificial	11	276%
Total	**399**	**100%**

Key Analytics (Do you think is possible a situation such as many science-fiction movies as "I, Robot", "Terminator", etc, in which humans go a step too far in their need for improving themselves?)	
Mean	1.028
Confidence Interval @ 95%	[1.011 - 1.044] n = 399
Standard Deviation	164
Standard Error	8

Frequency Analysis (Do you think there are significant ethical differences between Classic Genetic Engineering and Synthetic Biology?)		
Answer	**Count**	**Percent**
Sí	**295**	**4.609%**
No	206	3.219%
¿Qué?	139	2.172%
Total	**640**	**100%**

Key Analytics (Do you think there are significant ethical differences between Classic Genetic Engineering and Synthetic Biology?)	
Mean	1.756
Confidence Interval @ 95%	[1.695 - 1.817] n = 640
Standard Deviation	787
Standard Error	31

APPENDIX (2)

Frequency Analysis (Do you think eating a transgenic vegetable is harmful for your health?)		
Answer	**Count**	**Percent**
Sí	113	1.766%
No	**425**	**6.641%**
Depende. Aceptaría el Arroz Dorado pero no las variedades resistentes a Roundup.	102	1.594%
Total	**640**	**100%**

Key Analytics (Do you think eating a transgenic vegetable is harmful for your health?)	
Mean	1.983
Confidence Interval @ 95%	[1.938 - 2.028] n = 640
Standard Deviation	580
Standard Error	23

Frequency Analysis (Do you think eating a drug produced in a genetic modified organism (GMO) is dangerous for your health?)		
Answer	**Count**	**Percent**
Sí	128	2.000%
No	**512**	**8.000%**
Total	**640**	**100%**

Key Analytics (Do you think eating a drug produced in a genetic modified organism (GMO) is dangerous for your health?)	
Mean	1.800
Confidence Interval @ 95%	[1.769 - 1.831] n = 640
Standard Deviation	400
Standard Error	16

SURVEY RESULTS (SPANISH)

From 1 (nothing) to 5 (completely) how ... do you think Synthetic Biology is?		
Question	**Count**	**Score**
Beneficiosa	640	4.042
Peligrosa	640	2.833
	Average	**3.438**

Frequency Analysis (From 1 (nothing) to 5 (completely) how Beneficious do you think Synthetic Biology is?)		
Answer	**Count**	**Percent**
1	3	47%
2	15	234%
3	143	2.234%
4	**270**	**4.219%**
5	209	3.266%
Total	**640**	**100%**

Key Analytics (From 1 (nothing) to 5 (completely) how Beneficious do you think Synthetic Biology is?)	
Mean	4.042
Confidence Interval @ 95%	[3.978 - 4.106] n = 640
Standard Deviation	828
Standard Error	33

APPENDIX (2)

Frequency Analysis (From 1 (nothing) to 5 (completely) how Dangerous do you think Synthetic Biology is?)		
Answer	**Count**	**Percent**
1	74	1.156%
2	185	2.891%
3	**222**	**3.469%**
4	92	1.437%
5	67	1.047%
Total	**640**	**100%**

Key Analytics (From 1 (nothing) to 5 (completely) how Dangerous do you think Synthetic Biology is?)	
Mean	2.833
Confidence Interval @ 95%	[2.745 - 2.921] n = 640
Standard Deviation	1.135
Standard Error	45

SURVEY RESULTS (SPANISH)

Frequency Analysis (Do you think we should continue research in Synthetic Biology?)		
Answer	**Count**	**Percent**
Sí	**627**	**9.797%**
No	13	203%
Total	**640**	**100%**

Key Analytics (Do you think we should continue research in Synthetic Biology?)	
Mean	1.020
Confidence Interval @ 95%	[1.009 - 1.031] n = 640
Standard Deviation	141
Standard Error	6