NanoEthics: Studies of New and Emerging Technologies

Misconceptions of synthetic biology: Lessons from an interdisciplinary summer school

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Response to Reviewers:	Authors' answers to the reviewers of the manuscript "Misconceptions of synthetic biology: Lessons from an interdisciplinary summer school"

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Thank you for those straightforward comments. You pointed important flaws in the manuscript, allowing us to fix them in this revised version.

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To the editors of the journal NanoEthics

Hawaii, April 25th 2016

Dear Editors,

We have the pleasure to submit a revised version of our manuscript entitled "Misconceptions of synthetic biology: Lessons from an interdisciplinary summer school" for consideration for publication in the journal NanoEthics, as part of the special section edited by Stefanie Seitz and Kristin Hagen.

We found comments from the reviewers to be highly relevant, and consequently addressed their concerns and followed their suggestions. We hope that you will agree that this new version is worthy of publication in your journal.

Many thanks for considering this revised manuscript for publication. We appreciate your time and look forward to your response.

Best wishes,
Cyprien Verseux, on behalf of all the authors.

Response to reviewer's comments
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Misconceptions of synthetic biology: Lessons from an interdisciplinary summer school

Cyprien Verseux[1,*], Carlos G. Acevedo-Rocha[2,3], Fabio Chizzolini[4], and Lynn J. Rothschild[5]

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Abstract

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Introduction

In September 2014, a week-long international summer school entitled "Analyzing the Societal Dimensions of Synthetic Biology" gathered biologists, philosophers, science communicators, and social scientists (Fig. 1). This multidisciplinary group of scholars, at the doctoral and postdoctoral level, discussed critically different approaches to the evaluation of synthetic biology (synbio).

Synbio is an interdisciplinary research field at the interface of biology, engineering, chemistry, physics, mathematics, computer science, and medicine [1]. Many definitions are in circulation[1], one of the most common being "the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems"[2]. Synbio is considered as an emerging technology, among nanotechnology, stem cell research, artificial intelligence, 3D printing, geoengineering, etc. Such technologies are often stated to have the potential of solving global issues pertaining to health, energy security and environment protection, but their premature application is associated with perceived risks. Those risks have to be addressed early to provide an environment which is favourable to the emerging technologies' development.

In this work, we do not intend to detail the points of view of all the summer school's participants on synbio – those are described in a dedicated book [2] – but rather to point out and comment on some challenging issues on the perception of synbio by non-synthetic biologist attendees as noticed by synthetic biologists, as well as some problematic perceptions by synthetic biologists pointed out by non-synthetic biologist attendees (summarized in Table

[1] See for instance http://www.synbioproject.org/topics/synbio101/definition/. Accessed 25 Apr 2016
[2] http://royalsociety.org/page.asp?id=1231. Accessed 25 Apr 2016

1). This necessity stems from i) an observed lack of technical understanding of synbio by several scholars, which lead to biased evaluations and uncritical debates regarding potential risks and benefits of synbio, and ii) an evidently flawed communication from synthetic biologists, coupled to a failure to consider the broader implications of their work. The authors note that the analysis presented here directly results from the experience of this particular summer school and, although the attendees came from a wide range of disciplines (Fig. 1) and countries (mostly European; see Fig. 2), they do not suggest that all their observations can be generalized. This report should rather be seen as a snapshot of a group of interested individuals from a particular time and event.

Synbio seen through its public figures

The view of synbio by most attendees without life sciences background quickly appeared to be based on media extrapolations of the discourse held by public figures in synbio. The synthetic biologists most referred to were, by far, Craig Venter (American biotechnologist, biochemist, geneticist, and entrepreneur known for being one of the first to sequence the human genome, and founder of the J. Craig Venter Institute) and George Church (American geneticist, molecular engineer, and chemist on the faculty of Harvard University). Those two researchers, known in biological sciences as prominent figures in the subfields of synthetic genomics and genome engineering, frequently appear in the international media and popular press[3]. When attempting to illustrate "the point of view of synthetic biologists", attendees usually cited these two high-profile researchers, ignoring most of the less-mediatized scientists. Researchers active in the field and well valued by their peers are, however,

[3] See for instance http://news.nationalgeographic.com/news/innovators/2014/06/140602-george-church-innovation-biology-science-genetics-de-extinction/. Accessed 30 Apr 2015

numerous; for a good representation without bias[4], the reader is referred to a remarkable work by Oldham et al. [3]. Even the remarkable contributions of other famous synthetic biologists, such as Jay Keasling's achievements in metabolic engineering, were seldom mentioned and barely discussed.

Synbio public figures are strong advocates of the field and often describe its potential long-term applications. Scientists active in synbio usually know well what the gap is between the current state-of-the-art and such perspectives. They know that every small step towards such applications requires years of high-quality research[5], where relative successes are commonly outnumbered by failures. But when those visions of potential futures are distorted and relayed to laymen and scholars lacking a clear vision of what is actually happening on today's benches, they are often mistaken for applications on their way. The most utopian and dystopian aspects – where, for instance, Neanderthals can be cloned [4] and anyone can create biological weapons [5] – are relayed and amplified by the media, leading to a fantasized view of the field where all deadly diseases are cured and all cars are fuelled by cheap and eco-friendly microbial products – or where the world ends in a green-goo catastrophe triggered by teenagers playing with DNA in a basement. Even though attendees had a much better knowledge and understanding of synbio than the average layman, several of them expressed deep concerns about imminent, large-scale biosafety or biosecurity catastrophes.

A disconnect between scientific reality and public debate is common in science (see, e.g., [5]), among others because of scientists' communication training and incentives are focused on

[4] Representations are often focused on a specific category of synthetic biologists, such as bioengineers from the US. See for instance http://syntheticbiology.org/. Accessed 30 Apr 2015

[5] The most commonly cited achievement of synbio came with tremendous effort: engineering yeasts to produce a direct precursor of artemisinin, an antimalarial drug [46, 47] took roughly 150 person-years of work [22]. Similarly, engineering them to produce hydrocortisone [48], one of the most important anti-inflammatory molecules in the pharmaceutical industry, took more than 15 years.

peers and ignore the lay public [7, 8], and because of media's use of sensationalism to reach a large audience. This second phenomenon is particularly visible in synbio, where some researchers have an interest in fostering sensationalism and become highly-solicited sources of catchphrases for media. More temperate scientists, who try to fight against over-promising, apparently do not make for appealing headlines. The overrepresentation of some researchers is further amplified by writers under deadlines who tend to go back to the sources they know. Besides, we realized quickly that most communication efforts by synthetic biologists are jeopardized when they overestimate the level of technical knowledge of scholars with no background in life sciences – a common issue in expert-layperson communication [9]. The issue is further exacerbated by the global transition from traditional media to news feeds as primary sources for scientific information for the lay public [10], the decrease in scientific articles in traditional media outlets and, most concerning, the disappearance of trained science journalists [6, 11]. Those observations may partly explain why social scientists among the summer school's attendees, who do not always have the scientific background to understand synbio's original research articles, have difficulties getting an accurate representation of the field in spite of their desire to do so.

Impact of promises on the development of synbio

Interestingly, fantasies initiated or stoked by the media play a major role in the development of synbio: it shows the public where the field could lead us in the long term, and why it is worthwhile investing resources in research whose current outputs are for the most part invisible and unclear to the layman. For the field to flourish, some visionary claims are necessary: funding flows where applications are expected to benefit the society. More generally, imaginative speculation plays a role in shaping the development of innovative technologies. When a new technology emerges, the initial promises of its impact are often very high. Once the right communities (e.g., investors and policy makers) have been convinced of the potential benefits of the technology and have allocated resources to its development, activities can develop that yield more knowledge and accurate information about the potential long-term benefits and risks. Scaled-down and more accurate promises are then formulated. These promises can enter the process again, following the so-called "promise-requirement cycle" [12]. This is particularly true in biology-related innovations.

The downside of unrealistically high technological expectations is that unfulfilled promises lead to disappointment, and often damage the credibility and reputation of scholars working in the field [13, 14]. Lessons should be learned from pharmacogenomics, stem cells, xenografts and other emerging technologies that suffered from unrealistic short-term promises. By monopolizing focus, sensationalistic discourse leads to simplistic views which are problematic when debating practical decisions aimed at framing synbio. As cautioned in the 2010 report of the US Presidential Commission for the Study of Bioethical Issues, *'[t]he use of sensationalist buzzwords and phrases (...) may initially increase attention to the underlying science and its implications for society, but ultimately such words impede ongoing understanding of both the scientific and ethical issues at the core of public debates on these topics"* [15]. A consequence of this sensationalism is that the image of synbio depicted at the summer school was associated with what a future genetic designer might be able to do, rather than on the real-world work of today's synthetic biologists. Part of this real-world work aims at moving towards the very basic – but extremely complex – task of designing tools that could allow us to make challenging applications possible, and at conducting proofs-of-principle studies that offer a glimpse of a future where such technologies might be developed.

Creating life from scratch?

Most of the summer school's attendees clearly overestimated our abilities to understand and control life. In particular, synthetic biologists were often viewed as scientists creating – or about to create – a repertoire of new life forms from scratch. Even though this endeavour is often presented as a long-term goal of synbio (see, e.g., [16]) and steps are taken in this direction (see for instance [17]), we are still great challenges away from being able to design and create, from basic chemistry blocks, new life forms (according to any widely used definition of life) as complex as the "simplest" bacterium. Besides, creating life from scratch is not a day-to-day preoccupation of most synthetic biologists [18], who are rather focusing on modifying existing life forms or creating molecular systems that are capable of mimicking simple cellular functions. Some of the attendees were also under the impression that "biological parts" could be assembled and interchanged as easily as electronic components on a breadboard ("since they are standardized"), and be inserted in any cell ("as the genetic code is quasi-universal"). Such a view is not surprising, as it matches a discourse often held by highly visible synthetic biologists. But while the standardization of biological parts, devices and systems is one of the main objectives of bioengineers who shaped the development of synbio in the US (e.g., [19, 20]), we are very far from interconnecting molecular processes as we assemble screws and bolts. Even simple parts which have been extensively characterized often behave in an unexpected way when conditions (cell type, laboratory conditions, direct genetic environment, selection marker, etc.) are changed (e.g., [21, 22]). Likewise, assembling a new construct from parts to reach a target function is an uncertain and laborious process, involving much trial-and-error [22]. The fact that assembling parts is becoming straightforward does not make their behaviour easy to predict: as pointed out by Gardner [23], "*[n]atural selection is Nature's method of trial and error (...). Simplifying principles are generally rare, and exceptions to rules are far more abundant than the rules themselves*". Progress is being made, but biology is still hard to engineer.

This gap between reality and beliefs on our ability to manipulate life seemed to stem from a reliance on media-inspired claims, as described above. Indeed, when questioned, such beliefs were generally justified by quoting catchphrases on biology standardization from Drew Endy (Professor of Bioengineering at Stanford University), on the creation and "faxing" of life from Venter, or on cloning from Church. We, biologists, should be more aware of the impact that such bold claims can have on people who don't have the background to interpret them as they are: analogies, theoretical potentials, or futuristic visions.

Irrelevant fears

The lack of knowledge about real-life work of synthetic biologists created not only unrealistic expectations but also irrelevant fears. A question asked to one of our peers illustrated this fact. After describing how his team assembled an artificial protocell, made up of a lipidic vesicle containing DNA and the factors needed for its expression (for details, see Lentini et al. [24]), he was asked how, "given that his construct contains DNA and that DNA is the way Nature uses to reproduce", he could be sure that the system wouldn't multiply and spread. The given answer was, in short, that a piece of DNA outside the cell machinery and with no amplification-related information won't be replicated – and certainly not lead to replication of the vesicle around it. As an analogy, a motor in a shoe box will not drive itself along the highway. Besides, most concerns of the attendees assumed a technological level that does not exist yet. For instance, unrealistic fears about the potential use of synbio by bioterrorists, due to the will to make it easier to engineer, matched those described by Jefferson et al. [5]. While these fears might be useful to take biosecurity and biosafety measures ahead of time, too much resources seem to be allocated to what might happen in the future, creating confusion about, and driving attention from, what is actually happening today.

Synthetic biology and genetically modified organisms

The relationship between synbio and genetically modified organisms (GMOs) seemed unclear to most of the participants. When the term "GMO" was introduced, the debate took a new turn, even though the terms "genetic engineering" or "synthetic biology" had been used until then, in the same conversation, for designating the exact same processes.

There again, lack of technical knowledge led to an evaluation of risks that was disconnected from current synbio research and impaired constructive discussions. For instance, the safety of GMOs was treated either as a philosophical or social issue rather than the result of empirical science, or in a generalized way: attendees argued over properties of GMOs (such as whether or not they were detrimental to health) without mentioning a specific gene modification. Results of a study described by an attendee and showing the effects of a given gene modification was generalized to GMOs in general. Such generalizations are irrelevant since, as stated by Nobel Peace Prize 1970 laureate, Norman E. Borlaug, "*[t]he risk posed by foods are a function of the biological characteristics of those foods and the specific genes that have been used, not of the processes employed in their development*" [25]. Whether editing genomes is desirable or not, whether a given genetic construct should be inserted in a given host, or how the resulting GMOs should be handled, are worthy debates, but generalizing a given property to GMOs in general is irrelevant when the studied effects come from the specific gene which has been modified or inserted. It is worth noting that although the public is often stated to have un-nuanced opinions on GMOs, a study from the Public Acceptance of Agricultural Biotechnologies (PABE) project of CSEC, Lancaster University, showed that the general public discriminates between different types of GMOs [26]. Here, however, no discrimination was heard in debates before biologists pointed it out. It is possible, though, that clear-cut judgement were expressed louder than more nuanced opinions.

After further discussions, it appeared that most of the attendees understood – when thinking about it – that an organism modified using synbio tools and methods is, technically, a GMO. But naming it as such first raised vivid debates, ground to aprioristic ideological positions. In a discussion with a reduced group, the opinion of several scientists was received with suspicion when perceived as favourable to a given GMO while any opposite position, even with a much weaker scientific background, was easily approved. This reflected emotion- rather than fact-driven opinions, as is often reported around the GMO debate [27, 28]. Such opposition to GMOs in the context of agriculture (which is was what most attendees first had in mind when talking about GMOs) is not uncommon. Opposition is easy to trigger among the general public due to health and environmental concerns related to GMO's perceived unnaturalness: led by "*philosophical traditions*" and "*cosmological myths*", the layman "*holds that human artifacts, including GMOs as their most transgressive avatars, have the inherent and fatal character of destroying natural harmony*" [29]. In addition, past food scandals in Europe led to a loss of confidence in the governments' abilities to ensure safe use of agricultural biotechnologies [30]. When communicating about synbio, semantics matter a lot.

Context matters, too: when reminded that GMOs could find applications outside agriculture, such as studies on gene function or the production of pharmaceuticals, opinions were more ambivalent. When talking about engineering a GM microbe to produce a life-saving drug, for example, most attendees agreed that direct benefits could outweigh potential risks.

Interestingly, attendees were aware that gene variants have been selected and combined into populations of crop-plants and animals since the onset of agriculture and farming, 10,000 years ago, through traditional breeding. In this Darwinian process, varieties of plants and animals displaying the desired phenotypic traits have been selected from generation to generation; for example, cows producing more milk or corn that has larger content of carbohydrates were selected by farmers. When this was pointed out, an attendee answered that those modifications were different, as happening naturally and merely selected. It seemed that the feeling of unsafety associated with GMOs came in large part from their perceived unnaturalness, an aspect known to be particularly sensitive when it comes to food [31]. A biologist's explanation that the consequences of a given base modification (be they desirable, undesirable or neutral) are independent from its cause was received with scepticism. Yet it should be noted that another reason for the concerns associated with GMOs was the fear of further industrialization of plants and animals. One of the participants reminded the others that the increasing use of pesticides in industrial agriculture (e.g., neonicotinoids) affects not only the soil and water resources around, but also damages insects crucial in the natural food supply. Another attendee pointed out the indiscriminate practice of industrial farming, which brutalizes animals that live in reduced spaces and that are treated with large amounts of antibiotics, thus triggering antibiotic-resistance in bacteria, a huge health concern worldwide. These examples reminded synthetic biologists of the need to be aware of the context in which they are working, as well as of the broader concerns that their discoveries can raise.

Synth-ethics?

Ethics in synbio seemed like an entirely new branch of bioethics when listening to talks and statements from several attendees. One may argue that some ethical issues raised by synbio are new and distinct from those raised, for instance, by genetic engineering, since the former area aims in the long term at creating, and not just manipulating, living organisms [18]. Some ethical aspects may be new, or pushed to a new level (see for instance work on human germline, or vector gene drive engineering, using genome editing tools [1]). However, as pointed out by Parens et al. [32], ethical questions raised by synbio *"are virtually identical to the ethical questions that have arisen in the past. Failing to recognize that fact can lead to reinventing the bioethical wheel for each new technology and, thus, squandering scarce resources. Instead of lovingly listing the ethical questions that arise over and over, we need to dig deeper. We need to test intuitions, arguments, and responses developed in previous contexts against new fact patterns"*. Overlaps between the different subareas of synbio (e.g., synthetic genomics) and disciplines which have already been extensively debated by ethicists (e.g., genetic engineering [33]) are obvious to the biologist but, as it appeared, not necessarily to the philosopher or scholar of the social sciences. We were somewhat surprised that some attendees, who proved to be very familiar with the literature on the debates surrounding genetic engineering when we specifically pronounced those words, were building arguments almost from scratch when it came to genetic modifications performed by synthetic biologists. Could this issue be due to the specific semantics used in synbio, coupled to a lack of technical understanding? Terms used in synbio are often distinct from those used in fields falling under its umbrella, such as protocell research, metabolic engineering, genome engineering, genome editing, and synthetic genomics [1]. It seems plausible that without an extensive molecular biology background, this is a common source of confusion and that connections are hard to draw.

We also had stimulating debates with colleagues calling themselves biocentrist ethicists (see for instance [34]) who deemed unethical the use of microbes, including engineered microbes, for human purposes. Even though discussing this around a glass of (yeast-fermented) beer was somewhat amusing, this opinion is worthy of consideration. On one hand, our moral intuition is that living beings should be considered as having an intrinsic value, and we share without nuance our colleagues' view that unnecessary harm to animals must be avoided. But what does this imply for microorganisms that lack the biological bases for sentience? We definitely agree that protecting at least some microorganisms owing to their practical value, notably their importance in the biosphere (see [35]), makes sense. Is it, though, unethical to use microbes for applied purposes? Answers to this question are beyond simple theoretical philosophy, as deciding – as a society – against the use of microbes would have tremendous implications. One can doubt that microbes will replace many fossil fuel-based processes for the industrial production of polymers, materials, medicines, vaccines, pharmaceuticals, biofuels, vitamins, additives and many other products that are essential for our daily lives in a technology-driven society. But as a simple mind experiment can make anyone aware of, human activity is extensively dependent on microbe-processed goods – and has been so for millennia. Setting aside functions necessary for survival of any animal or plant species on this planet (e.g., nitrogen fixation), microbes are used to recycle our waste products and offer us delicious fermented foods (bread, dairy products, sauerkraut, etc.) and beverages (beer, wine and tequila cocktails), as well as vaccines, antibiotics and other therapeutic compounds, fertilizers, industrial solvents, additives, and so on. A similar line of reasoning could be followed about plants (and consequences may be more obvious), but plants were not mentioned in the debate. Is, as our colleagues implied, a future where microbes modified by synbio can suit increasingly-demanding human needs undesirable? One may argue that it depends on how efficiently we want to fight diseases, and how independent we want to be from fossil fuels in a growing population whose demand in energy and food keeps increasing.

What is life?

A question was asked about whether or not a given synthetic construct was alive; passionate discussions about the definition of life followed. Attempts at finding a universal definition for life have led to vivid debates for centuries, at least since Aristotle. Most proposed definitions have been based on observable features used to recognize life, and all have faced issues (mostly as counter-examples; among the troublemakers are mules, which cannot reproduce and thus not undergo Darwinian evolution, dead bodies, viruses, and artificial intelligence). But it was interesting to listen to arguments about what life is or is not in absolute – as if life had an absolute definition, independently from any human definition, to be looked for. In addition, several attendees were categorical about the mentioned construct being alive or not. It was an interesting illustration of the fact that, as once written in an editorial of the journal Nature, "*[t]here is a popular notion that life is something that appears when a clear threshold is crossed*" [36]. On the other hand, synthetic biologists generally take for granted that there is no clear border between life and non-living chemistry, besides what is arbitrarily defined. This continuum between life and non-life was actually accepted well before the term synbio was coined, notably in the field of prebiotic chemistry, which deals with the natural transition between chemistry and life (see, e.g., [37, 38]).

In most fields, what is life and what is not has no ambiguity: animals, plants, fungi, bacteria, and archaea are (before death) alive, and any definition of life that includes them while excluding anything else can be used for most purposes. However, when working in fields where subjects of studies are at life/non-life borders, as in synbio or astrobiology[6], no definition can be based solely on an intuitive and universal idea of what life is. The possibility that life is a "natural kind" [39], and that advances in biology will one day yield a deep understanding of its nature and allow us to formulate a precise theoretical identity, could be considered [40].

But as there is currently no consensus on the definition of life (see, e.g., [40, 41]), an absolute answer to whether a given construct is alive cannot be given; arguing about the nature of life is dealing with the wrong question. That being said, one can use a working description, as suggested by Oliver and Perry [42]. Tell us what you mean by life and we can tell you whether, *according to this definition*, this synthetic construct (or a virus, for that matter) is alive or not. Before employing the word "life", scientists could specify what definition they are referring to. Arguing about the absolute nature of life can be of interest in a philosophical discourse, and whenever argumentation matters more than the answer itself. However, when decisions are to be taken and laws to be written, an arbitrary threshold between life and non-life must be defined. Again, probably not in absolute: the relevance of a given definition depends on the use that one wants to make of it. But this is not an issue, as far as the running definition is made clear.

[6] See for instance http://www.nasa.gov/vision/universe/starsgalaxies/life's_working_definition.html. Accessed 25 Apr 2016.

Clarifying what one means by "life", or even replacing it when possible by a proposition based on the life-associated features which are dealt with (e.g., "self-replicating and evolving systems"), may also help avoiding overreactions to bold statements from some synthetic biologists – in particular those implying that "scientists" are close to creating life. A common argument among opponents of synbio was several times mentioned during the summer school: by creating life, synthetic biologists can lead to a decrease in its perceived value and to its "banalization". Interestingly, a similar – albeit less pronounced – opposition is sometimes heard against prebiotic chemistry. A comment from Luisi [43] about the misgivings encountered by this latter field may be relevant to synbio as well: it *"comes from the unconscious and confusing equivalence between life and 'spirit'"*. The idea of life is often associated with intelligence, consciousness and various properties shared by all known natural life forms; but we are far from creating life forms having such features. Creating a construct which is living according to, e.g., the 'chemical Darwinian' definition of life adopted by NASA's Exobiology program ("a self-sustaining chemical system capable of Darwinian evolution" [44]) does not necessarily mean creating an entity to which ethics, moral or religious beliefs should be applied. Because of the connotations it conveys, synthetic biologists should be very careful about their use of the word "life".

Conclusion

Our general impression is that non-biologist attendees of the summer school working on synbio were generally focused on speculations of what synbio *might lead to*, rather than on what it actually *is* today. Although this attitude may help in assessing the value of synbio in the long term and in taking measures against catastrophic scenarios well in advance, it hinders constructive debates about the real-world synbio and how it can benefit the society in the short and medium-term. While keeping in mind very long-term objectives and risks, we suggest that oversight should be given more extensively be to today's synbio.

Those observations are particularly disturbing given that most attendees were highly educated and showed a genuine wish to understand even technical details of the field. It suggests a critical shortage of documents depicting the current state-of-the art of synbio and its plausible short-term scenarios in a way that can be understood by non-scientists, and a strong influence of sensationalistic journalists and researchers. This might explain the lack of rational analyses of the field from non-life sciences points of view. Such analyses exist (see, e.g., Aldrich et al. [45]) but are outnumbered by analyses of far-future and unlikely scenarios.

Conversely, attendees with background in social sciences seemed surprised by the lack of knowledge, among synthetic biologists, of the societal debates surrounding their research. We learned much from them and they made us consider our own field from perspectives we never had before.

Taken as a whole, those issues point out an urging need for enabling direct communication between synthetic biologists on one side, and journalists or scholars from other areas working on synbio on the other. This would help make synthetic biologists more aware of the broader implications of their work, while giving the others a more accurate understanding of the field. The 2014 summer school "Analyzing the Societal Dimensions of Synthetic Biology" successfully served those purposes, and we suggest that such events should become commonplace.

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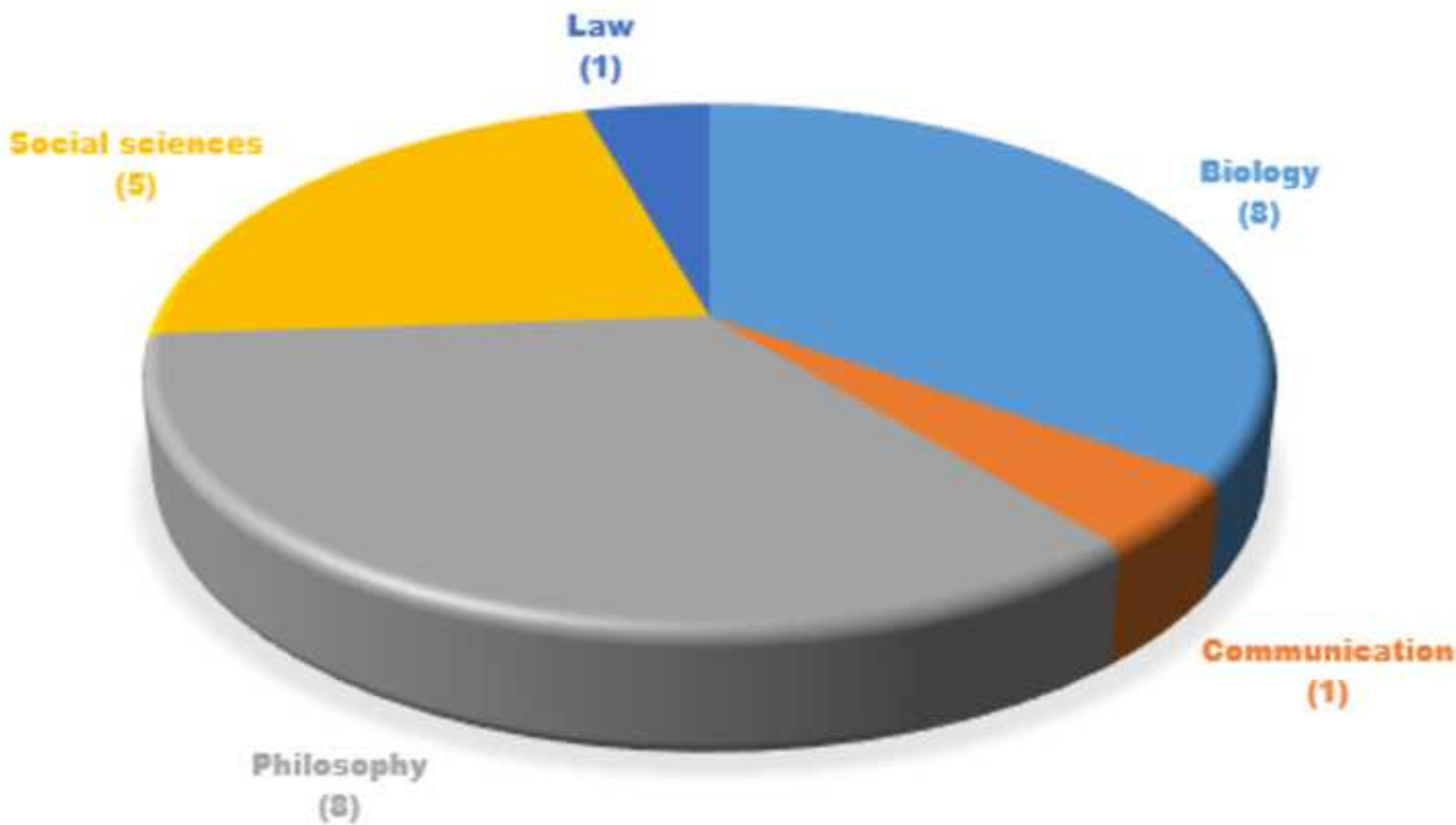
Figure legends

Fig. 1. Backgrounds of the attendees of the 2014 summer school "Analyzing the Societal Dimensions of Synthetic Biology". Numbers in brackets represent the number of attendees having a background (Bachelor's degree or more advanced degree) in the corresponding field. External experts who gave talks but were absent from most of the summer school are not taken into account.

Fig. 2. Nationalities of the attendees of the 2014 summer school "Analyzing the Societal Dimensions of Synthetic Biology". Numbers in brackets represent the number of attendees coming from the corresponding country. External experts who gave talks but were absent from most of the summer school are not taken into account.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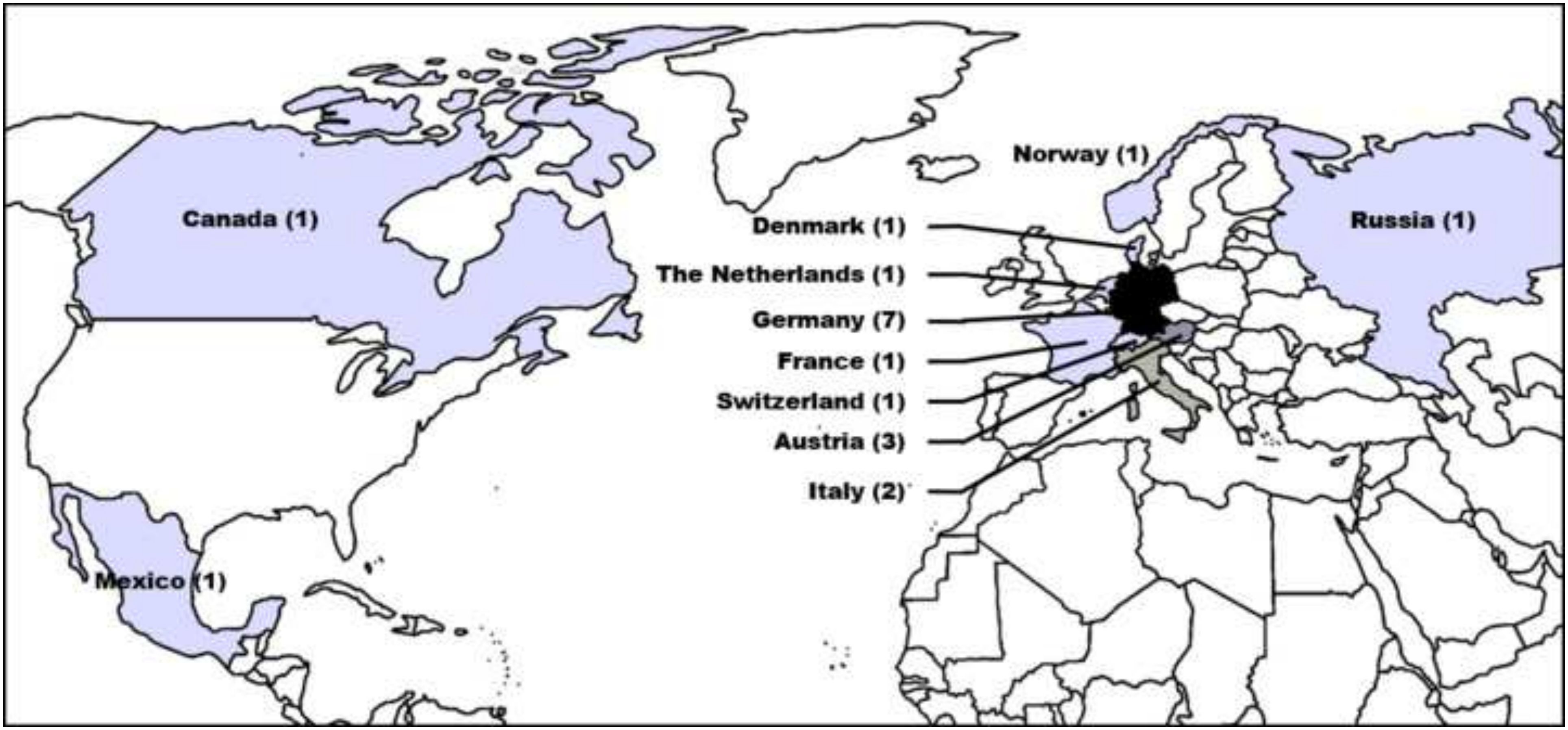

Table 1. Issues identified during the summer school, and suggested improvement strategies.

Identified issue	***Improvement strategies for biologists***	***Improvement strategies for non-biologists***
Synthetic biology is seen through its public figures and sensationalistic media, leading to unrealistic expectations and fears.	• Communicating with the public, to avoid being represented by a handful of people. • Avoiding overpromising.	• Paying more attention to less mediatized scientists.
Synthetic biologists' abilities to manipulate life tend to be overestimated.	• See above • Avoiding or explaining ambiguous catchphrases and metaphors.	• Basing judgements on peer-reviewed work rather than on unsupported, bold claims.
Specific terms (e.g., GMO) trigger emotional reactions, sometimes irrelevant to the specific aspects being debated.	• Writing documents explaining the terms related to synthetic biology, being accurate and detailed but legible and appealing to non-biologists.	• Obtaining the level of understanding necessary to know what can be generalized and what cannot.
Ethics in synthetic biology are often treated as an entirely new branch of bioethics.	• Better explaining the relationships between terms specific to synthetic biology and older terms. • Avoiding coining or using new terms when unnecessary.	• Building on the work done in other bioengineering disciplines rather than "reinventing the wheel".
As the world 'life' has powerful connotations and no universal definition, it leads to ambiguous claims and emotional responses.	• Avoiding the word 'life' if a more accurate description can be used, or defining what one means by "life" in a given context.	• When encountering the world 'life', identifying what the author is actually referring to.
Synthetic biologists lack training and incentives to communicate with a public which is not made of their peers.	• Self-teaching how to communicate with the public, and taking the time to do so. • Creating incentives and training opportunities for public communication.	• Insisting on getting understandable information from synthetic biologists, even when it implies numerous, simple questions.
Synthetic biologists often fail to see beyond the bench, while non-biologists tend to lack technical understanding.	• Increasing opportunities for interdisciplinary communication and collaborative work.	• Increasing opportunities for interdisciplinary communication and collaborative work.