Bioethics
A Coursebook

Compost Collective

https://www.openbookpublishers.com

All external links were active at the time of publication unless otherwise stated and have been archived via the Internet Archive Wayback Machine at https://archive.org/web

Digital material and resources associated with this volume are available at https://doi.org/10.11647/OBP.0449#resources

Information about any revised edition of this work will be provided at https://doi.org/10.11647/OBP.0449

ISBN Paperback: 978-1-80511-510-6
ISBN Hardback: 978-1-80511-511-3
ISBN PDF: 978-1-80511-512-0
ISBN HTML: 978-1-80511-514-4
ISBN EPUB: 978-1-80511-513-7

DOI: 10.11647/OBP.0449

Cover image by Bartaku Vandeput.
Cover design by Jeevanjot Kaur Nagpal

7. Synthetic Biology

What is synthetic biology?

Synthetic Biology (SynBio) is a scientific field that has gained much prominence in popular media and scientific literature. In 1980, Barbara Hoom coined the term 'synthetic biology' to describe a specific class of genetically engineered bacteria using recombinant DNA technology. In 2000, Eric Kool and other speakers at the American Chemical Society annual meeting in San Francisco reintroduced the term to describe the synthesis of unnatural organic molecules that function in living systems.

SynBio refers to the building, modelling, designing, and fabricating of novel biological systems using customized gene components that result in artificially created genetic circuitry. This umbrella term covers a variety of research areas that can mainly be classified into two broad subfields. One *uses* unnatural molecules to produce a desired product from natural biology. The other seeks interchangeable parts from natural biology to assemble into systems that act unnaturally. The common goal for both subfields is to use interchangeable parts that can function independently to develop new systems that meet specific desired requirements. Identifying and creating such interchangeable parts or toolkits in the molecular world is the aim of SynBio.

SynBio has many applications. Drug discovery, reducing or improving our carbon footprint, and improving agriculture are three of its central goals. For example, in biomedicine, Synbio applications can accelerate molecular production, facilitate diagnosis through different health-monitoring systems using biochips or sensors to detect physiological changes, and revolutionize treatment procedures using new advances such as therapeutic nucleic acids, gene editing, and cell therapy, thereby enabling more accurate, targeted therapies. SynBio has also been suggested to have transformative potential for the agricultural and food industry. By programming plant activities and production, SynBio can help to improve the agricultural environment and enhance yield. Some examples of SynBio applications in agriculture are improving nitrogen fixation, reducing the use of synthetic fertilizers, improving the nutritional value of plants, aiding in soil remediation, and changing the production mode of chemical pesticides to biopesticides. As we will see later, however, while these developments can offer helpful solutions for longstanding agricultural problems, we should also recognize the associated risks of replacing traditional knowledge systems

https://doi.org/10.11647/OBP.0449.07

with scientific applications. Finding this balance is critical to ensure SynBio works as a boon in the agricultural domain, and for society at large.

SynBio research is also being used in biofuel production. SynBio uses different technologies to reprogram or create new microbes to aid in efficient biofuel production. SynBio not only could help improve the quality and efficiency of biofuel produced from traditional sources such as plants, but it could also enable the production of biofuels from non-traditional sources such as waste materials and novel microorganisms—by creating 'cell factories' capable of generating energy from the traditional and nontraditional feedstock. Creating new strains of novel microbes for biofuel production using natural or waste feedstocks, can enable the production of renewable and less toxic novel biofuels, thereby reducing the carbon footprint.

Conceptual issues in SynBio

When thinking about the ethics of SynBio, it is important that we first delve a bit deeper into some conceptual issues. First, the term SynBio covers much ground, which makes it difficult to create an 'ethics of Synbio'. For example, SynBio can refer to minimal genomes. The minimal genome is a concept that can be defined as the minimum set of genes sufficient for life to exist and propagate under nutrient-rich and stress-free conditions. It can also be defined as the gene set supporting life on a single cell culture in nutrient-rich media. It is thought that what makes up the minimal genome will depend on the environmental conditions that the organism inhabits. This minimal genome concept assumes that genomes can be reduced to a bare minimum, given that they contain many non-essential genes of limited or situational importance to the organism. Therefore, if a collection of all the essential genes were put together, a minimum genome could be created artificially in a stable environment. By adding more genes, the creation of an organism with desired properties is possible. The concept of a minimal genome arose from the observation that many genes are unnecessary for survival. To create a new organism, a scientist must determine the minimal genes required for metabolism and replication. This can be achieved by experimental and computational analysis of the biochemical pathways needed to carry out primary metabolic and reproductive functions. Some uses of the minimal genome are identifying genes essential for survival, thereby reducing the genetic complexity of synthetic strains to engineer—e.g. microbes designed to produce a desired product, or plants that survive in harsher conditions. These are just some examples of the many possibilities.

There is also the creation of *orthogonal biosystems*. The genetic information that all living systems require to function is stored, in coded form, in the sequence of the four types of sub-units that make up the long chains of DNA molecules. Researchers have been experimenting with various ways of modifying the system to carry the instructions for making types of protein unknown in nature. Even more radical is the synthesis and use of alternatives to DNA to create a new genetic material. Any alternative molecule would need properties comparable to DNA's—information storage, the ability to self-replicate, etc.—and should be able to function similarly. Living systems relying on an alternative of this kind might be unable to interact with conventional (DNA-based) life forms due to fundamental biochemical incompatibilities. Since the genetic circuits are designed using a distinct set of DNA bases and an alternative coding scheme, they can only be interpreted by organisms equipped with the corresponding molecular machinery As a result, these synthetic organisms would be unable to exchange genetic information with natural life forms. This process can potentially constitute a form of biological containment by preventing a created organism from surviving or interacting outside of its intended niche, which could have potential safety benefits (EASAC, 2011).

SynBio is also used to refer to *metabolic engineering*. This is the creation of new biosynthetic pathways to produce valuable materials that living organisms do not naturally create. It means engineering microbial or cell factories to produce the precursor to an end product or produce the product itself. Examples include the production of the anti-cancer drug taxol in the yeast *Saccharomyces cerevisiae* (*Zhou, 2023*), the creation of a precursor of spider silk using the bacterium *Salmonella typhimurium* (*Widmaier, 2009*), the manufacturing of second-generation biofuels in yeast (Basso, 2011), and the synthesis of hydrocortisone from glucose, again in yeast (Szczebara, 2003).

Regulatory circuits are another example of what is considered a SynBio application. The natural activity of cells is controlled by circuits of genes analogous to electronic circuits. So, new cell functions can be introduced by creating novel internal circuitry to alter their pattern of activity. Using well-understood genetic components that act as molecular switches, it should be possible to devise artificial gene networks. Linked together and implanted into natural systems, such networks could aid in control of what those systems do, when, and how frequently. Integrated into suitable cells, an artificial network might be used to sense and correct metabolic disturbances found in diabetes.

Science has, for a long time, drawn upon a variety of metaphors, including several from engineering. In *Metaphors We Live By* (1980), Lakoff and Johnson explain that language and metaphors shape how we understand the world. Scientific knowledge is structured at the primary level by certain concepts that shape our understanding of science. Metaphors are fundamental tools used to represent these concepts that structure scientific knowledge. Sometimes, those metaphors are not even evident because we use them unconsciously. For example, we say that the cell wall acts as a barrier. In this case, 'barrier' is a metaphor indicating that the cell wall is a separation or a protective layer. In other cases, the usage of metaphors is quite evident, e.g. we say DNA is the 'software of life', or we call genes 'codes' and bacteria 'chassis'. This also indicates the influence of computational or machine metaphors in biology. As the view of DNA as the 'software of life' became popular, scientists were driven by the idea that they might be able to direct cells like people program computers, but were confronted with the uncertainties and constraints of engineering in the cellular context.

All these different definitions and applications require different ethical considerations. Moreover, besides the question of what we are referring to when we talk about SynBio, the metaphors we use in science also influence our ethical reflection.

While viewing biology through the eyes of engineering, scientists are essentially trying to isolate each component of the living organism, understand its function, and rearrange them according to the desired final product. This is what engineers have been doing all along, but trying to apply the same principles in biology could create a sort of 'ethical puzzlement' for some. This is because fixing different blocks or units is how *machines* are created and understood, not life. Life has always been viewed as something created by nature, not by engineers. Thus, some have argued that this blurs the line between living organisms and machines. Organisms have a purpose: to self-generate, self-maintain, and perform their function. These are seen as intrinsic purposes. However, machines do not possess this; they possess extrinsic purposes determined by external agents. So, would it be right to view synthetic entities that can self-replicate, self-maintain, and evolve further as machines? The metaphor of 'living machines' in technologies like SynBio can create confusion among people who might have trouble with the idea of the sanctity of life now under human control. This could give rise to a slippery slope of problems, such as unattainable expectations of a utopian society, fear of playing God or overestimating human power, fear of unleashing a fierce creature, fear of eugenics, etc.

Metaphors are vital and inextricable in shaping our understanding; hence, they must be used responsibly. In the context of SynBio, metaphors play an even more critical role in shaping the emerging meaning of life and responsibility. They must be used responsibly because they are fundamental tools for thinking about and acting on the world. Metaphors matter, and they have direct and indirect ethical, legal, and social consequences, as well as political and economic ones. Metaphors can significantly impact science, policy, and public response in the context of synthetic biology.

Ethics of SynBio

Ethics in technology, simply put, refers to moral principles that govern how technologies should be utilized. SynBio is a powerful technology that allows us to design and create organisms/products to help us solve many current global problems, such as environmental damage or the lack of medicines. However, the ethical dilemma here is that we do not have complete control over our creation, and the outcome of our creation is highly unpredictable. In SynBio, our ability to create 'synthetic organisms with great power' and our inability to 'ultimately control' the actors involved raises ethical and social concerns. The actors here are not only the synthetic organisms we create but all the stakeholders involved in their creation—from the scientists in the lab to the funding agency and the governmental regulatory authorities.

SynBio is an example of a technology that could lead to *dual-use dilemmas*. Such dilemmas arise when scientific knowledge could be used in good and harmful ways, and the risk of harmful use is sufficiently high that it is no longer clear whether that knowledge should be pursued or disseminated. Besides the regular biosafety and biosecurity issues seen with genetic engineering, SynBio raises new concerns over the unpredictability and uncontrollability of creating new and novel entities. These 'human/lab-made' entities also raise various philosophical concerns challenging the current views and perceptions of life. Advocates of the technology state that it has great potential because its applications are so diverse—for example, it can be used to produce various bio drugs (or biologicals) and create tailor-made metabolic pathways for them, potentially transforming human life. At the same time, SynBio comes with its own set of ethical, legal, and social issues. SynBio has attracted the attention of philosophers, ethicists, anthropologists, and religious scholars, who warn about challenges surrounding the creation of de novo parts of biological processes and the potential unpredictability and uncontrollability of these components.

Ethicists have wondered about *the ethics of creating life* in synthetic biology. SynBio's ability to help create new entities from scratch in vivo has garnered attention and raised the eyebrows of many ethicists and philosophers. While the creation of life has always been seen as a power of nature or the divine, scientists can do the same in vivo, creating a slippery slope of concerns. The first is: are we humans taking up the role of the divine or are humans 'playing God?'. This is followed by fears of losing respect for the value of life. If life is eventually seen as something that can be manufactured in labs, would it lead to a loss of respect and humility toward the value of life? Synthetic biology could reduce life to just another product of industry, akin to other products. Are we, as humans, overstepping our boundaries in trying to protect nature?

When the creation of life shifts from 'nature' to 'labs', would life be seen as a technological production process? Once scientists create a new form of life or entity within these labs, what kind of 'moral status and moral values' can be attributed to it? Should they be considered alive because they fulfil the basic requirements such as metabolism, reproduction, etc., or should they be considered machines because they have been engineered in the lab? Do they possess intrinsic purposiveness (self-organizing, self-maintaining, and self-regenerating), or do they only possess extrinsic purposiveness (organized, assembled, and maintained by external agents), making them akin to machines? These questions arise because if we attribute 'moral status and moral values' to these entities, then—per some deontology theories—it would be wrong to use them for human benefit.

Besides uncertainties regarding the moral status of creating life and of the resulting life created, there are also social concerns when it comes to SynBio. These concerns can be broadly classified into three categories: knowledge-related, method-related, and application/distribution-related. Knowledge-related concerns are those related to knowledge creation and dissemination. The fear of misusing knowledge is a major concern in SynBio. The creation and dissemination of knowledge used to create new synthetic entities could also be misused. This concern raises questions about open sources and the sharing of knowledge. How do we draw boundaries around which forms of knowledge can be shared, to what extent, and with whom? There is the conflict of beneficence vs non-maleficence; while open science sources are essential to ensure the benefits of science reach all, if it ends up in the hands of biohackers, it could create trouble for society. If we try restricting knowledge creation, we will end up curtailing scientific autonomy and freedom.

The troubles associated with intellectual property rights and dangers associated with monopolies in the scientific field are yet another worry. Especially since SynBio deals with creating new entities and products, there is scope for multiple levels of patenting claims—the knowledge, the process, and the end product itself. The fear that the convergence of current IP laws with SynBio will engender cartels and monopolies, thereby increasing the commercialization of SynBio and leading to unjust scenarios, is widely discussed in this field. While some argue that patents are needed to encourage innovation and credit new inventions and discoveries, patenting underlying biological processes might be detrimental to society over time. Patents can hinder the work of more efficient competitors and inhibit or shut down research in neighbouring fieds, thereby holding back science. A good risk-benefit analysis and rethinking of the current patent system to fit a new technology like SynBio is required.

Method-related concerns such as *biosafety and biosecurity issues* arise in SynBio as well. The unpredictability and uncertainty associated with research in SynBio gives rise to many biosafety issues. The newly created synthetic entities are the first of their kind, and there is a lot of uncertainty around how they would behave and interact with the world if they escaped the specific niche designed for them. As mentioned in "Addressing biological uncertainties", "In SynBio, a circuit component well characterized in one species or strain can behave unpredictably when introduced into another due to unintended interactions with native parts" (Zhang, Tsoi, and You, 2016). In this article, the authors mention that the expression of an algal nucleotide transporter for the uptake of unnatural nucleotides caused growth inhibition in *E. coli*, which the authors attributed to the toxic effects of expressing heterologous membrane proteins. Another example would be that if newly synthesized entities were introduced into the environment, they could compete with native species, and either this interaction or the pathogenicity or toxicity of the engineered species might harm the environment.

Distribution/application-related issues are those associated with ensuring a justice-based approach in the downstream applications of research. Distributive justice focuses on the fair allocation of resources and benefits resulting from research, while procedural justice ensures that the process of distributing these resources and opportunities is fair, transparent, and inclusive. Who will have control of and access to the products of SynBio research? Would it be a monopoly yet again? How do we ensure no exploitation of human life or nature occurs during different research development stages? Once the research is completed, steps must be taken to ensure equal and efficient distribution of the benefits to all stakeholders, including the environment. The research should not widen the gap between developing countries. Extreme caution must be taken to ensure no 'helicopter research' or 'ethics dumping' occurs during the different research stages. Helicopter research occurs when researchers from high-income settings or other privileged backgrounds conduct studies in lower-income settings or on historically marginalized groups, with little or no involvement from those communities or local researchers in the research's conceptualization, design, conduct, or publication. 'Ethics dumping' occurs when similarly privileged researchers export unethical or unpalatable experiments and studies to lower-income or less-privileged settings with different ethical standards or less oversight.

The case of artemisinin is an example of a justice concern in synthetic biology. Artemisinin is a key ingredient in first-line malaria treatments recommended by the World Health Organization (WHO). It is extracted from the traditional Chinese medical herb *Artemisia annua*. According to the WHO (WHO 2018), artemisinin-based combination therapies (ACTs) provide the most effective treatment against malaria. Until 2013, natural artemisinin was sourced entirely from an estimated 100,000 small farmers in Asia and Africa, as well as wild harvesters of the crop in China. The pharmaceutical industry sources natural artemisinin from thousands of small farmers who grow *Artemisia annua*, primarily in China, Vietnam, Kenya, Tanzania, Uganda, Madagascar, and India. The average crop area per farmer in China and Africa is around 0.2 hectares. Current market demand for artemisinin is about 150–180 metric tonnes (MT). The major buyers are a handful of approved pharmaceutical companies making ACT drugs. These demands were met solely by farm-grown *Artemisia Annua* plants until the market started wavering due to climate conditions and their downstream consequences. That is when the Gates Foundation decided to step in and, supported by their funds, synthetic biologists at California-based Amyris, Inc. engineered yeast to produce artemisinic acid, a precursor to artemisinin. Pharmaceutical giant Sanofi Aventis has now scaled up commercial production to 35–60 MT of what is marketed as Semi Synthetic Artemisinin (SSA). Amyris founder Jay Keasling expressed an interest in having SSA take over full global production. In 2013, Sanofi produced 35 MT of SSA, with production rising to 50–60 MT in the coming years.

Although advocates claim synthetic biology will make anti-malarial drugs cheaper, the current production run of SSA is in fact priced at between \$370–\$400 per kg, significantly above the price of naturally-derived artemisinin, which sells for around \$250–\$270 per kg. Natural artemisinin producers further claim that it is impossible to know the true cost structure of SSA since it has received extensive philanthropic subsidies. The introduction of SSA coincided with a dramatic fall in artemisinin prices in 2013. Subsequently, in 2014, plantings of Artemesia were at only a third of previous production levels, and commercial operations were at a standstill.

Due to the production of SSA and its introduction into the market, the farmers could face a wide range of issues. It is not just the Artemisia producers who will lose a big source of their income, but also the locals who work with the downstream processes like packaging and transporting the plant. ACT's entire production and manufacturing would shift to pharma companies in the West, where malaria is less prevalent than in other parts of the world. A 2006 report from the Netherlands-based Royal Tropical Institute predicted that the SSA production could further destabilize a very young market for natural Artemisia, undermining the security of farmers just beginning to plant it for the first time. Natural producers fear the competition is unfair if SSA is marketed at a 'not-for-profit price based on large subsidies and philanthropic support from the Gates Foundation.

Apart from the impact on livelihood, another less discussed impact is the environmental impact. The lab production of most products—like semi-synthetic artemisinin or synthetic vanillin—depends on sugar, which means extensive sugarcane cultivation is required, leading to many environmental problems. For example, the increase in demand for sugar leads to an increase in the cultivation of sugarcane, which requires a lot of land and water. The surge in demand also leads to the replacement of food crops by sugarcane crops. This replacement leads to a regular monoculture of sugarcane that not only affects the biomass of the soil but also depletes nutrients in the soil, thereby affecting the ecological balance. Extensive sugarcane cultivation also contributes to rainforest deforestation and slave labour conditions.

Finally, the cultivation and agriculture of traditional plants is part of Indigenous culture and tradition which ought to be preserved, not lost in our quest for scientific discoveries and development.

Microbial cell factory

What is a microbial cell factory?

Microbial cell factories (MCFs) are gaining scientific attention for their ability to sustainably synthesize biofuels, pharmaceuticals, chemicals, and enzymes, reducing industries' environmental footprints. As a cornerstone of synthetic biology, MCFs replace resource-intensive methods with eco-friendly alternatives. In the food industry, microbial fermentation produces high-nutritional proteins and amino acids from non-edible biomass, offering sustainable solutions for animal feed, fertilizers, and alternative meat production, contributing to global food system sustainability.

What are the ethical issues?

The ethical challenges associated with microbial cell factories are multifaceted and require evaluation across the domains of biosafety and security, justice and societal impact, and philosophical considerations.

1. **Biosafety risks:** The escape of engineered microbes into the environment is a significant biosecurity concern in most microbial technologies. The potential disruption of the ecosystem, interaction with the native species, creation of new unknown species, and outcompeting of native species by engineered species are some biosafety concerns.
2. **Biosecurity concerns:** Biosecurity concerns focus on the risk of dual-use dilemmas. These arise when tools or knowledge developed for beneficial purposes are repurposed for harm, including bioterrorism or the development of antibiotic-resistant pathogens.
3. **Social concerns:** These concerns include regulatory challenges such as intellectual property claims, the creation of policies and laws regarding the use of newly designed products, and more. Patents on newly designed microbial strains or technologies can hinder further advancement and innovation and possibly hinder accessibility to the technology.
4. **Justice concerns:** Justice issues concentrate on the need to ensure equal distribution of technology's benefits and minimal to no harm to the environment, including human life. An important aspect is ensuring that the benefits of microbial cell factories are not concentrated in wealthy nations or large corporations, leaving marginalized communities at risk of exclusion from technological advances. Economic displacement of traditional industries is also a worry associated with developing new technologies.
5. **Philosophical concerns:** Concerns about 'playing God' by altering or creating new forms of life present a potential ethical hurdle for the progress of microbial cell factories. The moral status of engineered microbial strains may also face scrutiny from those who argue that using microbes solely for human benefit conflicts with ethical perspectives that recognize the intrinsic value of all life forms.

Semi-synthetic artemisinin

What is semi-synthetic artemisinin?

Artemisinin, a key malaria treatment, is traditionally extracted from the sweet wormwood plant (*Artemisia annua*). However, this method is labour-intensive and yield-dependent. Semi-synthetic artemisinin, developed using genetically engineered yeast, offers a stable supply of antimalarial drugs for high-burden regions. However, despite its medical promise, its production raises significant ethical concerns.

What are the ethical issues in semi-synthetic artemisinin production?

The ethical challenges associated with semi-synthetic artemisinin production require evaluation across the domains of biosafety and security, justice and societal impact, and philosophical concerns:

1. **Impact on farmers and local economies:** The shift to semi-synthetic artemisinin threatens the livelihoods of thousands of farmers in Asia and Africa who depend on cultivating *Artemisia annua*, often as their sole income source. This change also impacts workers in processing, packaging, and distribution, weakening local economies and raising concerns about fairness and the socioeconomic effects of technological advancements.
2. **Equity and accessibility:** Malaria remains a significant issue in the Global South, yet semi-synthetic artemisinin production is concentrated in Western nations, where malaria is less prevalent. This raises concerns about equitable benefit distribution, as high production and distribution costs could make the drug inaccessible to low-income, malaria-endemic regions.
3. **Patenting and monopoly:** Factory-based production risks centralizing control to a few corporations through patents and monopolies. This dependency could weaken the resilience of the global artemisinin supply chain, particularly during economic or political instability.
4. **Environmental justice:** Although it reduces agricultural reliance, semi-synthetic production requires significant energy and sugar inputs, raising sustainability concerns. Excessive sugarcane cultivation leads to monocropping, depletes water resources, disrupts ecosystems, and increases the carbon footprint.
5. **Loss of traditional knowledge systems:** The complete transition to lab-based production risks eroding traditional farming practices and the ecological knowledge embedded in them. Balancing technological innovation with preserving traditional systems is essential for ecosystem protection and cultural heritage.

Genetic modification

What is genetic modification?

Genetic modification involves altering an organism's genetic make-up using techniques such as CRISPR-Cas9 for precise gene editing, gene insertion to enhance desirable traits, or synthetic biology to create new genetic functions (see also the Health Care Ethics chapter). It can serve various purposes, including curing diseases, preventing the inheritance of specific genes, or enhancing physical, cognitive, and behavioural traits. In humans, genetic modification might improve intelligence, strength, or longevity; while in agriculture, it could boost crop yields or pest resistance. Despite its potential benefits, genetic modification raises significant ethical concerns.

What are the ethical issues related to genetic modification?

1. **Global access and inequity:** Genetic enhancement could widen existing social inequalities between those who can afford modifications and those who cannot. This could lead to the emergence of 'genetic elites' with advantages in education, employment, and social status, deepening global divides and raising concerns about fairness and fear of stratification in the society.
2. **Risk of eugenics:** Genetic enhancement might revive eugenic ideologies, promoting the idea of designing 'better' humans. The practice may revive eugenic ideologies by stigmatizing undesirable traits, reinforcing discrimination, and leading to the marginalization of individuals with disabilities or differences.
3. **Threat to individual autonomy:** The normalization of genetic modification could pressure individuals to participate in it for social or professional benefits, undermining their personal choices and autonomy.
4. **Germline genetic enhancement and unintended consequences:** Heritable genetic modifications raise concerns about consent, unforeseen health risks, and disruptions to biological systems, affecting future generations. Modifications could also have unforeseen impacts on human health, including increased susceptibility to diseases or disruptions to complex biological systems.

5. **Slippery slope to non-essential enhancements:** Approving genetic modifications in order to improve health could slowly blur the line between necessary and optional modifications. This could eventually lead to a slippery slope of non-essential enhancements, like improving skin texture, changing eye colour, and increasing physical strength or mental capability.
6. **Environmental and ecological implications:** Genetic modifications in agriculture to improve the physical traits of livestock crops can have a detrimental effect on the ecosystem, because they might lead to unforeseen ecological imbalances which eradicate natural populations in the wild

SynBio and non-dualism

All concerns in SynBio challenge distinctions such as life vs machine, natural vs unnatural, and life vs non-life and question the role of humans in creation, the boundaries in terms of trying to protect nature, and the moral status of the newly created entities. In current ethical literature on synthetic biology, the distinctions between life and non-life, biology and technology, and natural and unnatural carry normative weight. The fact that synthetic biology challenges these distinctions is considered ethically relevant. At the same time, the common factor among many ethical concerns surrounding SynBio is that they begin from a dualistic assumption. For example, they assume that the moral status of these created entities hinges on the answer to the question of whether they pertain to the domains of 'life' or 'non-life'. The fact that humans—or, more specifically, synthetic biologists—are now at the threshold of constructing living beings or parts of living beings from scratch raises questions about their authority to create life from scratch. One of the biggest worries in ethical literature is the scientists' role in creating entities that have never existed before. Concerns start with the risk of scientists 'playing God' by creating life, the moral status of these newly created entities, and the essence of human relationships with nature.

Let us try considering these concerns through a non-dualistic approach or framework to find a possible way to address them. This section will use ancient Indian philosophy to situate and address these philosophical concerns through the Indian philosophical framework. Ancient Indian Hindu philosophy is an example of biocentrism in which, though a human being is thought to be endowed with a consciousness that exceeds the consciousness of other species, they are not considered superior to other species. Hinduism takes a holistic approach to life and nature which considers each human being an integral part of an organic whole, and the natural forces are considered sacred. In the spiritual, metaphysical view of Hinduism, human life—like every other life on earth—forms part of the web of existence. Together with material elements, human and non-human species are indissolubly linked to an organic whole, thereby remaining non-dualistic in their approach.

To better understand any philosophical system or theory, including Hinduism, it is essential to understand its origin. India was originally referred to as 'Bharath' in Sanskrit, where *Bha* refers to light, knowledge, and effulgence, and *Rath* means 'in search of'. Bharath essentially meant 'in search of light'. This was a geographical identity used to denote the land with a conglomeration of different kingdoms, big and small, all bound by a common culture—the culture of experiencing divinity in all aspects of life. The people of this land lived a particular way of life in sync with nature called the 'Sanatana Dharma', which we now know as 'Hinduism'. The roots of the phrase 'Sanatana Dharma' can be traced back to ancient Sanskrit literature as a kind of cosmic order in which *Sanatana* denotes 'that which is without beginning or end' or 'everlasting', and *Dharma*—coming from *dhri*—means 'to hold together or sustain'. *Dharma* is often interpreted as meaning 'natural law'. 'Sanatana Dharma' can thus be understood as 'eternal duties' or natural way to live'.

In Sanatana Dharma, Atman,and Brahman are two metaphysical concepts, where Atman is the individual self and Brahman is the ultimate reality, the supreme being. While Brahman is the divine essence of the universe, Atman is the essence that lives in all: humans, non-humans, and nature. According to the philosophy of Sanatana Dharma, the ultimate reality of everything in the universe is the Brahman which is attribute-less (nirgun), formless (nirakar), infinite (anant), and omnipresent (sarvabyapi). 'Sarvam khalvidam brahma' (everything that has existence is Brahman; Chhandogyopanishad) (Awasthi, 2021). The concept of Brahman in Santana Dharma is very similar to the concept of Tao in Taoism, both conveying something that rational thoughts or words cannot convey (Brahman, the Tao, and the Ground of Being, 2016).

Sanatana Dharma sees only one reality or being, Brahman, which all different living and non-living forms are born from and assimilate back into after death. This is similar to the thought that "everything that exists is nature" (Ducarme and Couvet, 2020). In other words, in this culture, 'God' is not a supreme being among lesser, subordinate beings; instead, all beings are a manifestation of the one reality or being called Brahman. In this culture, God (Brahman) is omnipresent and resides in everyone and everything, including all living and non-living things, thereby blurring the difference between living and non-living.

Humans and nature or non-human forms are seen as separate entities in dualistic frameworks. Sanatana Dharma, one of the non-dualistic frameworks, views nature as inclusive of all forms in this universe—which are seen as contiguous components of a hierarchical order of beings, related to each other through a network of functional and natural relationships based on their location in this order. The order is maintained by a universal natural law, sometimes called *Rta* (pronounced rita). Meera Baindur, in her work *Nature as Non-Terrestrial*, explains the diversity of beings and their relationships to each other and details how the inner being or consciousness is viewed as one in all forms in this universe (Baindur, 2009).

While thinking about the role of human beings in this world, as per Sanatana Dharma—there is no inherent superiority of any species—humans are neither co-creators with 'God' nor stewards of nature; superiority, if any, is only in living, and upholding Dharma. It is proposed that while humans have the advantage of equipment and methods such as Jnana, karma, bhakti, and raja yoga compared to other forms of life, it is the quality of 'atma-vichara' (self-contemplation) that might be unique to human beings.

सर्वभूतस्थमात्मानं सर्वभूतानि चात्मनि ।
ईक्षते योगयुक्तात्मा सर्वत्र समदर्शन: || 29||

BG 6.29: The true yogis, uniting their consciousness with God, see with an equal eye all living beings in God and God in all living beings. (Mukundananda, 2014)

As per Sanatana Dharma, humans have a responsibility towards nature and all forms of life, not as co-creators but as people who are a part of the web of nature. This is often enacted through various forms of 'non-violence'—a general term attributed to India and Hinduism. However, it is essential to point out that while Indian Hindu philosophies stress the importance of non-violence toward all creatures, it does not only mean non-violence through action but also non-violence in thought, word, and deed. This is seen as the highest of all forms of righteousness or *dharma*.

Based on the principles of Sanatana Dharma, every entity—irrespective of its origin—possesses moral status and value since all forms and entities in this universe (living and non-living) are parts of nature and comprise of the same five elements known as *panchabhutas*, or *panchamahabhutas*, in Sanskrit. They form the basic building blocks of the universe; every person, animal, plant, and thing is composed of various combinations of the *panchabhutas*, thereby removing any difference between the living and non-living as we have been viewing them. This view also stems from a belief in the concept of reincarnation. Hindu teachings suggest that the human soul can reincarnate in any form, including the forms of lesser and simple living organisms, as well as more complex forms this gives rise to the *dharma* of treating everyone and everything with respect and reverence.

Science and culture or religion are part of the same system. As in most non-Western philosophies, the non-dualism of science and culture or traditions is another feature of Sanatana Dharma. In the book *Research is Ceremony*, author Shawn Wilson quotes the Mayan scholar Carlos Cordero (1995): "The difference within the Western knowledge system is that there is a separation of areas called science from those called art and religion. On the other hand, the [Indigenous] knowledge base integrates those areas of knowledge so that science is both religious and aesthetic" (p. 55). While in most parts of the West, knowledge is approached using intellect, most non-Western and Indigenous cultures approach knowledge through senses and intuition. Sanatana Dharma has a holistic understanding of everything in the universe, where the universe and every small entity are understood as a whole and not studied or viewed as separate parts.

As per Sanatana Dharma, the universe came into being by the wish of Lord Vishnu, and Lord Vishnu maintains the entire universe and its cosmic balance. While this might be a story or a superstition for many, the beautiful part is the intricate meaning behind the name 'Vishnu'. In Sanskrit, *Viṣṇu* includes the root *viś*, meaning 'to settle, to enter', or also (in the Rigveda) 'to pervade'. While the Sanskrit term cannot be translated completely faithfully into English, something close would be 'all-pervasive'. Someone who is everything and is found in everything. The name indicates the whole universe in one, irrespective of our forms. This is one of the reasons why Sanatana Dharma, like other Eastern and Indigenous concepts, emphasizes the importance of transcending the material world and finding one's true divine inner nature and one's place in the universe.

Hindu philosophy is one example of the many non-dualistic philosophies around the world. Being open to embracing viewpoints from these philosophies allows us to widen our perspectives and view ethical concerns in a different light. In synthetic biology, the philosophical and anthropological concerns that often dominate scholarly engagement are largely based on dualisms that separate human life from nature. If such dualisms and the questions they raise can be addressed through taking up a non-dualistic stance, we may be able to refocus our efforts on other social concerns that require our urgent attention.

Conclusion

Ethical considerations in synthetic biology (SynBio) extend beyond biosafety and biosecurity concerns to encompass issues of justice and politics, necessitating an approach that accounts for both theoretical frameworks and the practical realities of laboratory research. Given SynBio's interdisciplinary nature and dual-use potential, ensuring its overall positive impact requires a stage-wise and research area-specific ethical analysis, rather than treating it as a monolithic technology. Ethical assessments should be integrated at distinct phases of research—knowledge generation, methodological development, and application—while also prioritizing environmental and livelihood justice to address broader societal implications. Establishing ethical awareness early in researchers' careers can foster a long-term commitment to responsible research practices, influencing both individual projects and institutional policies. Although political and corporate interests often drive technological development, fostering public engagement and ethical discourse remains imperative. Furthermore, current ethical discussions on SynBio frequently rely on dualistic frameworks, such as nature versus machine or life versus nonlife, which can lead to conceptual deadlocks. Integrating non-dualistic perspectives, particularly from non-Western philosophies, can provide deeper insights and contribute to a more holistic and context-sensitive ethical approach to SynBio.

Bibliography

Aravind Paleri, Varsha, and Kristien Hens. 2023. "Beyond the Organism versus Machine Dichotomy: A Review of Ethical Concerns in Synthetic Biology". *ACS Synthetic Biology* 13 (1): 3–14. https://doi.org/10.1021/acssynbio.3c00456

Baindur, Meera. 2015. *Nature in Indian Philosophy and Cultural Traditions*. Vol. XII. Sophia Studies in Cross-Cultural Philosophy of Traditions and Cultures. New Delhi: Springer India. https://doi.org/10.1007/978-81-322-2358-0

Baindur, Meera. 2009. "Nature as Non-Terrestrial: Sacred Natural Landscapes and Place in Indian Vedic and Purāṇic Thought". *Environmental Philosophy* 6 (2): 43–58. https://doi.org/10.5840/envirophil20096213

Basso, L. C., Thiago Olitta Basso, and Saul Nitsche Rocha. 2011. "Ethanol production in Brazil: The industrial process and its impact on yeast fermentation". In Biofuel Production—Recent Developments and Prospects, edited by Marco Aurelio dos Santos Bernardes, pp. 85–100. Rijeka: IntechOpen. https://doi.org/10.5772/17047

Benner, Steven A., and A. Michael Sismour. 2005. "Synthetic Biology". *Nature Reviews Genetics* 6 (7): 533–43. https://doi.org/10.1038/nrg1637

"Case Study: Artemisinin and Synthetic Biology | ETC Group", 2 July 2014. https://www.etcgroup.org/content/case-study-artemisinin

Douglas, Thomas, and Julian Savulescu. 2010. "Synthetic Biology and the Ethics of Knowledge". *Journal of Medical Ethics* 36 (11): 687–93. https://doi.org/10.1136/jme.2010.038232

Ducarme, Frédéric, and Denis Couvet. 2020. "What Does 'Nature' Mean?". *Palgrave Communications* 6 (1): 1–8. https://doi.org/10.1057/s41599-020-0390-y

European Academies Science Advisory Council (EASAC). *Synthetic Biology: An Introduction*. January 2011. https://www.interacademies.org/sites/default/files/publication/synthetic_biology_an_introduction_feb_2011.pdf

Gibbs, W. Wayt. 2004. "Synthetic Life". *Scientific American* 290 (5): 74–81.

Hudson Robotics. n.d. "Introduction to Synthetic Biology: Exploring the Basics and Applications". Accessed 11 July 2024. https://hudsonrobotics.com/introduction-to-synthetic-biology-exploring-the-basics-and-applications/

Kitney, Richard, and Paul Freemont. 2012. "Synthetic Biology - the State of Play". *FEBS Letters* 586 (15): 2029–36. https://doi.org/10.1016/j.febslet.2012.06.002

Lakoff, George, and Mark Johnson. 2003. *Metaphors We Live By*. Chicago: University of Chicago Press. https://press.uchicago.edu/ucp/books/book/chicago/M/bo3637992.html

"Nature Addresses Helicopter Research and Ethics Dumping". *Nature*, 30 May 2022. https://doi.org/10.1038/d41586-022-01423-6

Okafor, Justus Onyebuchi, and Osim Stella. 2018. "Hinduism and Ecology: Its Relevance and Importance". *FAHSANU Journal* 1 (1). https://philarchive.org/rec/OKAHAE

Ouaray, Zahra, Steven A. Benner, Millie M. Georgiadis, and Nigel G. J. Richards. 2020. "Building Better Polymerases: Engineering the Replication of Expanded Genetic Alphabets". *The Journal of Biological Chemistry* 295 (50): 17046–59. https://doi.org/10.1074/jbc.REV120.013745

"Scientific Committee on Health and Environmental Risks (SCHER) - European Commission". Accessed 11 July 2024. https://health.ec.europa.eu/scientific-committees/former-scientific-committees/scientific-committee-health-and-environmental-risks-scher_en

Szczebara, F. M., Cathy Chandelier, Coralie Villeret, Amélie Masurel, Stéphane Bourot, Catherine Duport, Sophie Blanchard, Agnès Groisillier, Eric Testet, Patricia Costaglioli, Gilles Cauet, Eric Degryse, David Balbuena, Jacques Winter, Tilman Achstetter, Roberto Spagnoli, Denis Pompon, and Bruno Dumas. 2003. "Total biosynthesis of hydrocortisone from a simple carbon source in yeast". *Nature Biotechnology* 21 (2): 143–149. https://doi.org/10.1038/nbt775

"When Synthetic Biology Meets Medicine | Life Medicine | Oxford Academic". Accessed 11 July 2024. https://academic.oup.com/lifemedi/article/3/1/lnae010/7623268

Widmaier, D. M., Danielle Tullman-Ercek, Ethan A Mirsky, Rena Hill, Sridhar Govindarajan, Jeremy Minshull, and Christopher A. Voigt. 2009. "Engineering the Salmonella type III secretion system to export spider silk monomers". *Molecular Systems Biology* 5 (1): 309. https://doi.org/10.1038/msb.2009.62

Wilson, Shawn. 2008. *Research Is Ceremony: Indigenous Research Methods*. Nova Scotia: Fernwood Publishing.

World Health Organization (WHO). "Artemisinin resistance and artemisinin-based combination therapy efficacy: Status Report". December 2018. https://www.who.int/docs/default-source/documents/publications/gmp/who-cds-gmp-2018-26-eng.pdf

Zhang, Carolyn, Ryan Tsoi, and Lingchong You. 2016. "Addressing Biological Uncertainties in Engineering Gene Circuits". *Integrative Biology* 8 (4): 456–64. https://doi.org/10.1039/c5ib00275c

Zhou, Y., et al. 2023. "Improved production of Taxol® precursors in Saccharomyces cerevisiae using a genome-scale metabolic model-guided approach". *Microbial Cell Factories* 22 (1): 221. https://doi.org/10.1186/s12934-023-02251-7