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ORIGINAL RESEARCH/SCHOLARSHIP

Scientists' Views on the Ethics, Promises and Practices of Synthetic Biology: A Qualitative Study of Australian Scientific Practice

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Abstract

Synthetic biology is a broad term covering multiple scientific methodologies, technologies, and practices. Pairing biology with engineering, synbio seeks to design and build biological systems, either through improving living cells by adding in new functions, or creating new structures by combining natural and synthetic components. As with all new technologies, synthetic biology raises a number of ethical considerations. In order to understand what these issues might be, and how they relate to those covered in ethics literature on synbio, we conducted an interview study with practicing synthetic biologists affiliated with a synthetic biology centre in Australia. Scientists identified a range of ethical challenges germane to the field, including precarious employment, pressures from industry, gender inequity, and the negative effects of the hyping of synbio. These challenges differed markedly from those identified in the ethics literature, whose treatment of the harms and benefits of synbio remains largely speculative and abstract. In our discussion of the pragmatic, every day ethical issues synthetic biologists face, we illustrate how issues of waste or research integrity play pivotal roles in everything from lived experiences in the laboratory, to long-term research trajectories guiding the field. In a confirmation of the ethical relevance of our participant's views on the field, we argue that the subjects they raise must be included in any ethical analysis of synbio as a field.

Keywords Synthetic biology · Ethics · Scientific cultures · Ethics of emerging technologies · Qualitative research · Empirical bioethics

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Introduction

Synthetic biology (synbio) refers to the design and creation of novel living systems, ranging from altering existing organisms by adding new functions through to the as yet aspirational goal of creating new living organisms from inanimate components (Davies, 2018). Synbio is multidisciplinary, using the tools of molecular biology, DNA engineering, microbiology, computer sciences, biochemistry and more. The field is optimistic about its capacity to respond to some of humanity's most pressing challenges, including climate change and food insecurity (Hessel, 2014). Like many new technologies, the potential benefits are significant but entail unpredictable risks of harms (Gutmann, 2011). Many of the ambitions and promises of synbio have yet to materialise, resulting in largely hypothetical analyses in the existing ethics literature (Heavey, 2013; Holm, 2013). In addition, there are few detailed case studies on or empirical investigations of the practical ethical challenges raised by synbio (Calvert & Frow, 2015; Carter et al., 2021; Ginsberg et al., 2017; Hobman et al., 2022a, 2022b). Consequently, most ethical analyses tend to forecast what forms synbio might take in the future and anticipate the potential benefits and harms of 'the imagined futures of synthetic biology' (Rogers, 2015).[1]

The range of potential benefits canvassed in the ethics literature includes scientific knowledge production and the development of novel scientific methods alongside practical applications addressing material human needs and environmental challenges (Cho et al., 1999; Parens et al., 2009). Synthetic biologists are experimenting to increase the nutritional benefits of foods, create synthetic analogues to animal products and manufacture improved plant and animal feedstocks (Presidential Commission for the Study of Bioethical Issues, 2010). Microbial engineering is being used to produce industrial chemicals, break down environmental contaminants (Cho et al., 1999) and increase the climate-adaptive capacities of particular species (Sandler, 2019). From water toxicity detection to drug development to biofuel production, the 'enormous potential' of synbio 'excites its practitioners and proponents' (Anderson et al., 2012; Taylor & Woods, 2020). While these benefits appear positive, synbio is currently 'among a number of promissory sciences' (Taylor & Woods, 2020) seeking to provide solutions for pressing global challenges. Although the field 'is thought to be transformational', the technology is nonetheless still emerging; therefore, 'the final products and the impact they might have on society are as yet unknown' (Dalziell & Rogers, 2022).

The harms of synbio are typically cleaved into (potential) physical and non-physical harms. Non-physical harms refer to the ways in which synbio might reshape the relationship between humans and nature, such as by standardising life and reducing biological complexity through engineering organisms to suit human desires or challenging classical distinctions between the 'natural' and the 'artificial' (Kaebnick et al., 2014). There is uncertainty regarding the moral status of novel synthetic organisms, fear of unfair allocation of the benefits of synbio and power questions

[1] Responsible Innovation and Responsible Research and Innovation (RI/RRI) literature on synbio, although clearly engaging with ethical issues (see e.g., Delpy, 2011; Kahl, 2015; Marris & Calvert, 2020), exists somewhat in parallel with the bioethics literature. We return to this point in the discussion.

concerning 'what form of regulation may be needed and who should determine this' in the governance of synbio (Newson, 2011).

Potential physical harms encompass issues such as the patenting and intellectual property (IP) of synthetic products, the downstream consequences of synbio and issues of biosecurity and dual use research of concern (DURC) (Hunter, 2013; Taylor & Woods, 2020). Whether due to deliberate release, a failure in biocontainment strategies or malicious release as a form of bioterrorism, the effects of synthetic organisms on ecosystems and human health remain unknown but have potentially catastrophic consequences (Newson, 2011). Finally, there are evident tensions in the relationship between synbio and different publics. On the one hand, there are calls for public consultation and dialogue as the field grows and a perceived need to build public trust in the science and its applications (Taylor & Woods, 2020). On the other hand, some publics are imagined as potential threats to synbio, given the increasing uptake of synbio science and its techniques among citizen scientists, the threat of biohackers and the difficulty of regulating synbio beyond traditional research environments (Arnason, 2017).

Our aim is to supplement the largely theoretical existing bioethical analyses with empirical research into how practising synthetic biologists conceptualise the potential benefits and harms of synbio, identify the ethics of their lab practices or situate their research in relation to the public good (Jin et al., 2021).

Methods

This interview study with practising synthetic biologists in Australia was approved by the Macquarie University Faculty of Arts Human Research Ethics Committee (Approval No.: 52021980027992). Using a purposive sampling strategy, we recruited a representative sample of members of the Australian Research Council Centre of Excellence in Synthetic Biology (CoESB) and its affiliates resident in Australia. Our recruitment strategy aimed to include CoESB members of differing seniority and with differing roles from different disciplinary backgrounds and at different institutions. Participants were recruited using bulk email, advertising, investigator networks and snowballing. They received no payment or other benefits.

Individual in-depth interviews followed a semi-structured format (Bloom & Crabtree, 2006). Questions were informed by concepts in the existing synbio ethics literature and designed to elicit information about participants' motives, aims and goals in conducting synbio research and the ethical issues they encountered. Due to COVID-19 limitations, all interviews were conducted using Zoom and lasted 60–120 min. Field notes were made during and after interviews by the interviewer [Author 1]. Data collection ran from July 2021 to February 2022, ceasing when we reached data saturation (i.e., no further new information was gathered in subsequent interviews). With participant consent, interviews were digitally recorded and professionally transcribed. De-identified transcripts were checked by [Author 1] and stored securely. Both investigators read all transcripts and made memos.

Our analysis had multiple steps. Using inductive and deductive thematic analysis (Pope et al., 2000), a detailed coding scheme was developed with *NVivo* software. We began by inductively coding interview transcripts and completing memos on each interview to identify ethical issues emerging from the data. Based on the first round of coding, we developed a second coding scheme, where we searched for higher-level organising principles based on the inductive coding and conceptual material from the synbio ethics literature. [Author 1] performed primary thematic coding, but coding schemes were revised by both investigators, who liaised with each other regarding the definition of codes, performed cross-checking and confirmed a shared interpretation of the data coded. Rigour was guaranteed via multiple rounds of coding and cross-checking. The final analysis comprised three main categories that included both inductive and deductive codes.

Results

[Author 1] performed 34 interviews with 31 members of the CoESB; 3 participants were interviewed twice. Our interviewees were 9 PhD students, 15 postdoctoral fellows, 10 professors, 1 professional staff member, and 3 mid-career researchers. The gender breakdown comprised 11 women, 22 men, and 1 non-binary participant. The disciplines of scientists in the study included molecular biology, chemical and biological engineering, biotechnology, genetic engineering, systems biology and evolutionary biology. Participants came from nine different institutions across the CoESB and reflected the membership of the CoESB regarding the proportions of women and senior and junior researchers. Our results are grouped under the three main analytic categories of ‘Products’, ‘Practices’ and ‘Context’. The relevant participant quotations to illustrate each category are in Tables 1, 2, and 3.

Ethical Issues Raised by the Products of Synthetic Biology

Participants held diverse views about the potential benefits and harms of synbio research products. As most participants were bench scientists, the harms and benefits they canvassed are speculative rather than existing and predominantly overlapped with those identified in the ethics literature (see Table 1).

Beneficial Products

Participants identified various potentially beneficial synbio products, both material products generated by the science and larger societal benefits, such as addressing climate change. In healthcare, potential benefits included medical products and interventions such as novel therapeutics, more accurate and accessible diagnostic tools, and gene editing tools to eliminate disease. Possible synbio contributions to food security included the production of nutritional ingredients that would otherwise be sourced from animals (i.e., *Impossible Burger*®) or the creation of synthetic flavours and fragrances to replace expensive or rare naturally occurring equivalents.

Table 1 Ethical issues raised by the products of synthetic biology

Theme	Illustrative data (quotations)
Tangible benefits	'There's a lot of health-related benefits.' (12) 'In the area of alternative proteins, meeting that increasing gap in demand between high quality protein, high quality lipids, and what's currently available.' (21) 'We can reduce the need for herbicides and pesticides. We can reduce the amount of run-off that will increase the health of the marine environments around earth.' (15)
Knowledge production	'The other thing that excites me about synbio also is giving us the tools to start to answer questions that we as biologists have only been able to speculate about, and not actually answer, so being able to potentially address fundamental questions in, say, ecology and evolution.' (25)
Optimism	'Synthetic biology is one of the technologies for the future. I think it can make a huge impact.' (13) 'Synthetic biology offers opportunities to improve global wellbeing, to address sustainable development goals.' (31) 'Synthetic biology offers efficient ways, and tuneable ways, of cycling both energy and matter.' (18)
Inequities	'There's a lot of questions about the economics of it, and things like who's getting paid, which industries are you then disrupting … there's a lot of compounds that you would want to produce more stably, but that are currently produced, say, maybe in second or third world countries, and that's actually quite a large proportion of their income.' (4)
Direct harms	'There's the potential that synthetic biology could be used to make some type of pollution that we don't know how to deal with, like synthetic chemists have made all sorts of nasty stuff that's cluttering the earth currently, and just because cells are natural systems, it doesn't mean that they can't make other types of new pollution.' (28)
Dual use research of concern	'We used to say that there were, for example, dual use concerns, so using the technology for a nefarious purpose, or in a way that it wasn't designed (for). I'm not sure that's a real issue. I just haven't seen any evidence of that. I think it might be a fear that some people have.' (34) 'There's going to be the potential that it's used for bad. For bad purposes. For arms. I think about bioterrorism as well.' (5)
Unnaturalness	'There's the concept that you're playing with nature, right? That you are controlling something which is natural, and that can raise some ethical issues as to whether we should be doing that. Whether we should be manipulating what exists naturally … we shouldn't be trying to control the evolution of nature with synthetic biology, probably.' (20) 'We've been modifying ourselves and our environment for 30,000. We just became excessively good at it.' (14)
Managing risks and uncertainties	'What we don't really understand is what happens when we, for example, make a one hundred percent synthetic new genome.' (2) 'Having rules around it from a governmental level would definitely help, but it is really hard to try and settle on set rules when there are so many differing opinions about synbio, and its impact on the world.' (11)

Table 2 Ethical issues raised by the practice of synthetic biology

Theme	Illustrative data (quotations)
Precarious academic employment and fast science	'I'm thinking about the postdocs who supervised me and who are part of my, kind of, group, I saw how difficult it was for them to climb the ladder, because they moved to these institutes to have to set up equipment and students and all sorts of stuff, and only by the end of their 3-year contract were they able to start actually producing, but by that point they were seen as not productive and pushed out.' (30) 'That funding situation affects the researchers themselves, and the impact that's having on people's lives through that. The uncertainty in their careers, and that affects all of us, and it's always on the minds of the researchers. So that's got to impact their lives, and also the way that they're doing research.' (6)
Research integrity	'Everyone's pushing to publish or perish.' (15) 'We have to do more than what we have time to do, which means that sometimes we make—like, the science we are doing is not good science.' (22)
Equity and diversity	'You basically had to be three times better as a female to get the same funding that a male could get.' (33) 'You can do training all you want, but if the people aren't actually responding to it, it's not going to work. It's not going to help … There's an attitude across the lab, but particularly with the male students, that training is a waste of time. We just need to do the science.' (29)
Barriers to synbio success	'So, right now the barrier is time. As we move along and things become easier, there are going to be a lot of ethical boundaries, especially because it is manipulation of proteins, it's manipulation of DNA. There is a lot of resistance to that.' (11) 'I do think we might get stuck at looking at the product or the output of synbio rather than the problem that we were trying to solve, and that is a big thing for me, for example.' (34)
Waste	'People who will use synthetic biology as a novel production method for a compound that's already quite sustainably produced, or easy to produce in its natural way, but straight away if you're producing it using synthetic biology, that's a novel method of production, then they can patent that and then monetise that as a normal product, and it's completely for commercial gain as well as for, I guess, for status and how good it looks for you with all these patents you have, but it's pointless in what it achieves.' (7) 'I mean, maybe it will be resolved easily, but plastic waste in labs. We generate so much plastic waste.' (5)

Many participants spoke of synbio's potential to address planetary challenges, including climate change, ecological collapse and harmful agricultural practices. The notion of a circular green bioeconomy was central to many of these views, referring to a vision of synbio technologies that decrease or eliminate reliance on fossil fuels. Participants claimed that synbio might ameliorate current environmental threats by creating synthetic organisms for bioremediation or engineering temperature-sensitive organisms (e.g., coral) to make them more heat tolerant.

In agriculture, potential benefits included improved productivity and reduced requirements for chemicals. Further potential benefits included changes to the means and types of production, with the creation of 'value adding' jobs near to resource-rich centres, with associated beneficial impacts for local communities.

Table 3 Ethical issues raised by the social context of synthetic biology

Theme	Illustrative data (quotations)
Priorities and setting the research agenda	'Should we focus on food more, or do we do chemical pharmaceutical production. And part of that, yeah, I guess, would be the ethics or the regulatory aspect. Some of it might be, "where do we have industry interest?"' (1) 'Who has the power to decide what sort of changes we're making, and what sort of projects get funded?' (24)
Hype	'The overhyping probably also has more of a meta-negative impact in that, after we inevitably fail to deliver what we hyped up, then it probably hurts, like, government funding for research, and public acceptance of science, and things like that.' (28) 'From the bench scientist point of view, it's not that much different, because the thing about synbio is that it's just hyped up, over-branded biochemistry.' (8)
Industry relations	'Industry is a double-edged sword with science, because on one hand it's so valuable in terms of funding, it's so valuable in terms of making sure that your work is actually translatable, that it will go towards something that all this time you've spent researching a particular topic, will actually go into a product and it will be worthwhile, but I think on the other hand, that push can sometimes reduce the quality of the research itself, because people are just trying to push it out to meet those goals rather than really taking the time to investigate something as thoroughly as it could have been done.' (7) 'The intersection between industry and university is probably swinging too far towards industry at the present time.' (3)
Synbio startups	'We start them up; they just don't go anywhere, because they don't have that supporting ecosystem. So, yeah. We don't have a scale-up capability in Australia. We start them up, but somebody else buys them out and scales them up elsewhere.' (16) 'The goals of you as a researcher about publishing early, collaborating with researchers, go completely against the start-up world of "keep it secret, you want to incubate stealthily until you're ready to dominate the market in a specific thing".' (4)

Knowledge Production

Knowledge and tools are the second main beneficial synbio products identified by participants. Many participants' research projects were remote from commercial products, but they noted that the knowledge created will be essential in the realisation of those products, echoing the 'build to know' ethos of synbio (Calvert, 2010). Tools such as CRISPR and cheap sequencing are already changing the way that science is done—synbio was described as a means to begin practically investigating questions that have until now been the stuff of speculation. Platform technologies (i.e., genetically modified microbes as tools with new cellular functions) were seen as critical infrastructure for realising the more applied potential benefits of synbio.

Optimism

Most participants expressed optimism about the potential benefits of synbio on industry and the economy by improving on naturally occurring processes. The notion of 'better' was understood as speeding up the rate at which scientists could perform biological manipulations, improving their sophistication and efficiency, or making them cheaper. This optimism was coupled with views about the moral obligation of scientists to ensure that the products of synbio benefit society. However, there were some cautionary reflections; for example, the use of synbio-mediated enhancements (e.g., changing skin colour) or the elimination of aging were viewed as ethically problematic given the risk of exacerbating social inequities.

Like the benefits, participants identified various potential but speculative harms of synbio, generally marked by a lack of social benefit and a tendency to focus on the possible (what synbio products can be made) rather than the essential or socially beneficial (what should be made).

Potential Inequities Raised by Synbio Products

A number of potential harms to humans and societies were identified, with the most extreme being ecological, societal or financial destruction. One major concern arose regarding the potentially unfair distribution of costs and benefits, both within and between societies. There were fears that industry interests will capitalise on publicly funded research, with subsequent profit shifting and loss of societal benefit. Some participants claimed that Australia was poorly placed to realise the benefits of synbio production due to the lack of national industrial capacity, with benefits accruing instead to multinational companies. Given the potentially wide-ranging and disruptive nature of synbio, participants noted that some people will inevitably be made worse off if synbio products displace existing ones from markets or increase costs. Participants were aware that successful synbio may shift production from disadvantaged to rich nations with subsequent impacts on livelihoods and worsening of inequities, such as in the synthetic production of compounds whose current production provides vital income to local communities.

Direct Harms

Some participants mentioned direct physical or health harms to humans, such as contamination with either lab-based or escaped or released genetically engineered organisms. The main harm to the environment envisaged by participants was the risk of synbio organisms adversely impacting the planetary ecosystem through accidental release, containment failure or as unanticipated consequences of deliberate releases. Types of impact ranged from novel problems, such as the possibility that synbio could create new types of pollution, through to the loss of biodiversity.

Dual Use Research of Concern

DURC—using synbio for bioterrorism, nefarious use or 'do it yourself' biohacking—was identified as a potential harm. However, there was little consensus about the significance or scale of any threats. Some participants were dismissive of DURC, while others noted potential dangers, claiming that it would be relatively easy for a biohacker or garage scientist to make dangerous products. Responses to potential DURC ranged from the view that this was unavoidable (e.g., if funded by state militaries), or could be managed, through to the need for scientists to weigh up potentially malevolent uses against potential benefits and the responsibility of scientists to possess the knowledge to undo any potential damage. One participant noted the danger of creating and sharing knowledge, while others claimed that because it is impossible to stop the dissemination of knowledge, access to materials should be tightly controlled.

Unnaturalness

Participants' views about the 'unnaturalness' of synbio varied. Some were dismissive, contending that synbio did not constitute 'playing God' (Link, 2013), whereas others were more circumspect. Concerns about the unnaturalness of synbio clustered around the potential wrongness of manipulating nature, the unknown consequences of forcing evolution, and alienation and hubris. Many participants mentioned potential public concerns about unnaturalness, noting that these could be a barrier to the uptake of synbio products.

Managing Risks and Uncertainties

Most participants recognised the uncertainties (economic, financial, social, biological) in doing synbio regarding what products might be created and their consequences. The existence of 'unknown unknowns' was taken for granted by some, who believed that unintended consequences were likely. Various strategies for mitigating or controlling risk were proposed, ranging from using organisms that could not survive beyond the laboratory to following standard biosafety and containment regulations. Some participants were ambivalent about regulatory frameworks, which were seen both as a mechanism to mitigate risk while facilitating research and as bureaucratic red tape. Others mentioned the responsibilities of scientists to mitigate risk, together with concerns about this approach, questioning the existence of processes to manage negative consequences and whether scientists adequately considered possible outcomes before conducting their research.

Ethical Issues Raised by the Practice of Synthetic Biology

Participants identified a range of ethical concerns arising from the practice of synbio, which posed barriers to realising the potential benefits. Issues included employment conditions, research funding and power relations (see Table 2). While most data pertained to participants' current positions, some comments reflected historic experiences.

Precarious Academic Employment and 'Fast Science'

Precarious academic employment was an issue for postgraduate and early career researchers. They described a shortage of postdoctoral opportunities, a lack of secure junior positions and reliance on senior researchers to secure funding for salaries. These factors contributed to what was described as pressure to conduct 'fast' science. For example, participants claimed that short-term contract positions led researchers to avoid projects that might not yield significant results within a 2–3 year fellowship as the corresponding lack of publications would risk the researcher being classed unproductive and therefore uncompetitive for further academic positions. This 'publish or perish' orientation favoured research questions that would most quickly generate publishable academic outputs over projects with greater value or long-term advantage, thereby reducing possibilities for critical exploration and discovery.

The perceived pressure to choose short-term projects was linked to difficulty in securing funding for speculative (or 'blue sky') projects, based on the view that funding sources were 'risk averse'. Participants claimed that funding bodies favoured applied research with industry application over blue sky projects, thereby risking loss of innovation. Some junior participants claimed that the funding environment and associated employment precarity created a brain drain, pressuring scientists to move into industry, overseas or into synbio startups.

Research Integrity

Relatedly, participants expressed concern about the impact of their employment conditions on research integrity. One participant described how high-pressure work environments could result in short cuts, thereby compromising scientific integrity and rigour. Junior participants described instances of plagiarism, project theft and authorship order disparities. Dishonesty in reporting results, such as the 'massaging' of data to fit a preconceived theory, was linked to the pressures of industry partnerships. For example, scientists felt obliged to 'talk up' the promise of their projects to industry partners to secure funding. Yet if the research could not produce the promised results in time, scientists felt caught between dishonest handling of data and overt failure (with attendant career risks). Several participants described not having time to consider the ethical implications of their research.

Equity and Diversity

Precarious labour conditions disproportionately affected scientists of minority backgrounds, creating inequities. Some female participants reported unfairly gendered labour patterns (being given feminised, administrative, secretarial and emotional labour) while their male counterparts were allocated what was understood as differently valued, intellectual labour. Female participants variously reported sexual harassment, having to work harder than their male colleagues or being dismissed or intellectually undermined at work, with associated feelings of imposter syndrome and poor mental health. Having children created further barriers, with claims that funding and university policies failed to take full account of the impact of parenthood on scientific careers.

Female participants reported that male scientists in positions of power were sometimes resistant to equity initiatives, training and the genuine inclusion of women within the field or were simply unwilling to catalyse change in their laboratories. One participant expressed gratitude for the support and mentorship of a male supervisor while simultaneously noting his reluctance to address gender inequities in his laboratory; another reflected on the difficulties of explaining gendered discrimination to male colleagues who had not experienced it.

Several participants expressed concern that despite some attention to gender equity in the field, there was little consideration of broader equity issues. For instance, participants identified issues of racism and lack of engagement with Indigenous Australian scientific perspectives as well as the inequitable effects of class, given the considerable material and emotional resources needed to successfully complete a PhD and enter academia. Demographic monocultures among senior staff were described as enabling and perpetuating sexism and racism.

Barriers to Synbio Success

The preceding issues were seen as barriers to doing good science. One recurring concern was the tendency of synbio approaches to focus narrowly on products rather than a more expansive understanding of the problem those products aim to address. Participants identified the need for interdisciplinary approaches to address 'wicked problems' but spoke openly about not knowing how to collaborate with non-scientists and lacking the time and incentive within their workplaces to do so.

Public acceptance and perception, the circulation of misinformation and a general lack of scientific literacy were identified as barriers to the success and uptake of synbio. Fear over public backlash was particularly salient concerning public reactions to the potential release of synthetic or genetically modified organisms (GMOs). Participants noted the need for robust public engagement.

Regulations were seen by some as limiting the possibilities of synbio research. For example, there were concerns that regulations like the Australian Gene Technology Act (2000) obstructed research, hindering the development of beneficial new products. Some participants expressed fears that synbio products would automatically be labelled as GMO, thereby attracting potentially hostile scrutiny and onerous regulation. Others expressed uncertainty regarding how to manage commercial investment and IP without knowing what research disclosures would compromise patents.

Waste

Waste was a final theme identified by participants. One source was scientific 'waste', or science that held negligible societal benefit, such as producing synthetic versions of natural compounds that were already sustainably produced solely for commercial gain, patents or professional prestige. This phenomenon was linked to perceived wasted opportunities caused by the lack of consensus regarding what goals should be driving the field. Another source of waste arose from the scientific cultural norm of not valuing or publishing research with results that were negative or perceived as 'dull', such as characterising proteins. Finally, participants raised material issues pertaining to plastic use and waste within laboratories as running counter to the environmental aspirations of synbio.

Ethical Issues Raised by the Social Context of Synthetic Biology

Participants identified ethical issues raised by the broader social context in which synthetic biology takes place, including priority and research agenda setting, the role of hype, and industry-related conflicts of interest (see Table 3).

Priorities and Setting the Research Agenda

Regarding agenda setting or priorities for synbio research, participants articulated several overlapping concerns, including the power of industry to dictate the science, the defunding of fundamental research, the financing of synbio and the focus of the field. Some participants openly questioned what direction their individual research projects should take or how to determine the ultimate goals of the technology. Adjacent concerns included who held relevant decision-making power and difficulty in trying to monitor or manage the direction of progress of synbio. Key normative aspirations for synbio included equitable access to data, increased inclusion of the Global South and alignment with the Convention on Biological Diversity and the Nagoya Protocol. Some participants also articulated the need for robust ethical and sociological reflection, given the disruptive potential of synbio.

Participants raised questions about the financing of synbio and its impact on setting research agendas: where money was being spent, whether its use was effective, and whose decisions were guiding this spending. There were conflicting views over the appropriate relationship between synbio and its funders and the role of industry funding in determining research priorities. For example, opportunities related to Australia's large agricultural industry were seen to push scientists towards research into agricultural wastes and feedstocks. There were some criticisms of the emphasis on application and industry outcomes. These included views that the overlap between university research and industry involvement was too heavily weighted in the direction of industry and that industry influence threatened the integrity and objectivity of the science.

A second concern about the impact of funding on the research agenda involved a tension between blue sky research and outcome-based research, with the potential loss of unanticipated discoveries, such as that of CRISPR, which emerged from open scientific enquiry. Participants talked about the difficulties of supporting fundamental research given their endless need for securing funding, which usually required the promise of a commercial application. Strategies for managing this dilemma included matching the promises of the science to external factors, such as prevailing government priorities. Finally, in considering vision, participants identified the need for greater contextualisation of the products of synbio within a complex economic and sociological setting.

Hype

Hype was raised as an ethical issue, given the potential negative effects of over-promising on the credibility of synbio. Some participants viewed synbio as exemplifying scientific hype, claiming the field was largely promissory rather than reflecting disciplinary integrity or specificity and that scientists would knowingly capitalise on the associated hype to further their careers. Yet, importantly, synbio hype exists due to its capacity to attract competitive funding. Participants described a self-perpetuating cycle in which scientists mobilised hype to secure funding, thereby creating pressure for others to match the hype. This hype-driven cycle was deemed a risk for synbio as it could soon be eclipsed by a newer technology. Negative effects of engaging in hype included promoting a product or project that under-delivers, thereby jeopardising future funding or public acceptance; causing discomfort due to the disjunct between the hyped promises of synbio and its actual potential; and foreclosing other solutions for tackling challenges. For instance, one participant noted that wealthy individuals might see investing in synbio startups as altruistic, but philanthropic money could be better spent on initiatives with more direct benefits. There was also a sense that while well-intentioned, scientists' habit of believing that their technology would solve global problems was risky.

Industry Relations

Participants noted the powerful but double-edged sword of industry in synbio. Reflecting limited government funding, industry partnerships were essential for research but created power imbalances and perverse incentives, including over-promising industry-relevant research results to secure funding. Participants perceived pressures to manipulate scientific outcomes to be more industry-relevant than they really were. Simultaneously, there was unease over feeling pressured into producing industry outcomes at the expense of science with potentially greater societal benefit. This tension was articulated as an impasse between relying upon industry for key aspects of the science (e.g., scale-up, translation and funding) and industry influence reducing the quality of the science due to its emphasis on applications, products and commercial priorities. At times, participants felt conflicted about whether they should patent and commercialise a product, thereby enabling its translation towards public access, knowing that commercialisation could give a single corporation exclusivity over the product and any associated profits. Industry partners were sometimes framed as lacking ethical awareness, creating concerns for participants that their research would be sold to third parties with agendas and values that conflicted with the original intentions of the science.

Synbio Startups

Negotiating ethics within the synbio startup space was another challenging subject. One participant who was a startup founder described a pull between the academic environment, in which scientists are encouraged to publish and collaborate widely, and the startup sector, which is characterised by secrecy and market domination. Although startups offered opportunities for scientists to conduct research beyond the precarity of academia, they created tension between producing company profit and manufacturing synbio products with broader benefits. However, the creation of startups was one major avenue through which scientists could deliver on the promises of synbio.

Discussion

Our results provide a detailed account of the views of practising synthetic biologists on the ethical issues raised by their work. Before discussing salient points, we acknowledge two caveats. First, our research is geo-temporally specific to members of an Australian Research Council-funded research centre in the second of its 7 years of funding. Australia lost up to 35,000 jobs from the tertiary sector during the 2020–2021 COVID-19 pandemic, with early career staff being among the most affected (Norton, 2022). This, together with government policy prioritising funding of applied and industry-partnered research, may have influenced participants' views regarding employment precarity and industry relations. Second, many of the issues raised by participants, such as gender and race equity and pressures to publish, are prevalent throughout science (Ross et al., 2022).

Although neither of these problems is unique to synbio, it is nevertheless important to highlight them as indicators of the ubiquity and significance of structural factors affecting science. Material conditions, including employment precarity, funding sources and equity and diversity issues, influence what research is done and how and should therefore be included in any analysis of the ethics of synbio. These issues have particular salience for synbio given the increasing reliance on technologies such as synbio to address existential problems of climate change (Fulvi & Wodak, 2023). However, scientists represent only one set of stakeholders, and other views (like those of policymakers and publics) are also relevant to this discussion (Carter et al., 2021; Hobman et al., 2022a, 2022b).

The results on ethical issues raised by products of synbio mirror most closely the theoretical literature on this topic. Despite two or more decades of research, the benefits remain largely speculative. We found consensus that synbio research should address 'grand challenges' such as climate change, but few participants identified pathways from their research to specific outcomes related to these challenges.

Participant views echoed related study findings (Jin et al., 2021), which demonstrate a disproportionate emphasis on benefits above risks and an optimism and faith in the ability of synbio to solve such challenges. As in the literature,[2] the aspiration to do research for the public good remains poorly specified in terms of what products synbio should be aiming to produce. The harms identified likewise mirrored those in the literature, largely focusing on the potentially adverse consequences of the release of engineered organisms and DURC (Oye et al., 2014). However, there was little consensus on the likelihood or threat of the latter and, unlike the findings of Carter and DiEuliis (2019), no discussion of biosecurity concerns regarding the production and selling of synthetic DNA. Participants also had a range of views on non-physical harms such as unnaturalness or playing God (Baertschi, 2013). Similar to the findings of Fernau et al. (2020), participants held complex and contradictory views regarding the differentiation of synthetic from non-synthetic life and the place of synbio within digital, biological and artificial worlds.

This diversity of views is potentially problematic for developing the unity in vision and agenda necessary to realise the goals that synbio has set for itself. This point is all the more salient given that many of these goals are climate-related and, as such, accompanied by diminishing timescales. Disciplinary diversity may, in part, explain the heterogeneity in perspectives we encountered; however, due to small sample size and the risk of anonymity breaches, we were unable to explore this issue further.

Although our participants identified benefits and harms consistent with the literature, they were less concerned with some ethical questions, such as the creation of life, that figure prominently in the literature (Belt, 2009). Instead, what was ethically relevant for our participants were more concrete or pragmatic issues, like secure employment, funding sources or industry involvement affecting the rigour of research. Here, our findings overlap with issues canvassed in the RI/RRI literature (Delpy, 2011; Kahl, 2015; Marris & Calvert, 2020), although this was not terminology used by any of our participants as RI/RRI is relatively unfamiliar in Australia (Ashworth et al., 2019).

Operating alongside and extending current conversations that link ethical issues to the context and practice of the science, our findings support the call for a 'post-ELSI [ethical, legal and social issues] space' (Balmer et al., 2015). The matter of setting the research agenda was central as many of the ethical issues can be traced back to who decides what research gets done. Other than general national research priority goals (Australian Research Council, 2019) relevant to obtaining government funding, such as 'Food', 'Resources' or 'Health', participants did not identify any formal processes for setting priorities for their projects. Instead, they described various factors that influenced which projects were undertaken, including the likelihood of generating fast and publishable results, the fundability of the project and the aims of any industry partners. This apparently strategic or reactive approach to research priority setting has the potential to fracture the effectiveness of research programs unless active steps are taken to build direction and cohesion. This approach also generates tensions. The need for fundamental basic science is played off against the

[2] See, for example, the code of practice for the Synthetic Yeast Genome Project in Sliva et al. (2015).

promise of applied projects, while the need to generate quick (and positive) results pulls against the integrity and soundness of more deliberative and collaborative science. Given the central role played by industry partners in determining research agendas, scientists have little power in fulfilling any commitment to do science for the public good. Synbio products that are commercially viable, such as synthetic botanicals (Zhu et al., 2021), rank low in terms of human needs and have potentially inequitable effects on primary producers but nevertheless attract funding.

Industry partnerships exerted effects beyond shaping the research agenda. Patenting and privatising IP (especially when generated by publicly funded research) can lead to a range of ethical issues—patent thickets, 'anti commons' and the slowing of the potential and progress of biotechnological advances—this study suggested that these were heightened by the pressure to partner with industry (Calvert, 2008; Rai & Boyle, 2007). For instance, the unfairness of cost shifting can be exacerbated by the incompatibility of a patenting system with the commitment to open-source and transparency that is one of the founding norms of synbio (Stirling et al., 2018).

A final observation pertains to the place of hype. As something deemed both necessary and detrimental, we should ask whether there are better ways to cultivate interest in an emerging discipline rather than problematic over-promising. For instance, if funding or support for synbio is mobilised through hype, the field risks faltering when the hype inevitably wanes. In addition, by making promises it cannot fulfil, hype risks setting synbio up for failure and harming funding opportunities or public trust.

Conclusion

These results are of value to multiple stakeholders invested in synbio, adding valuable empirical detail about ethical issues in practice to contrast with academic or theoretical concerns. These concrete ethical issues (e.g., conflicts of interest, priority setting, employment precarity and sexism in laboratory life), which impact the daily practice of the science and the potential trajectory of the field, were far more urgent to our participants than metaphysical concerns over the creation of life (Catts & Zurr, 2012). Issues such as the wielding of power within the field and associated justice issues and the consequences of the complex relationships between different actors within synbio receive scant attention in the ethics literature, calling into question the utility of that literature in supporting those navigating these 'real world' ethical difficulties. Centring ethical investigation in concerns that are genuinely salient to synbio scientists and that foreground scientists' material experiences in negotiating ethics at work can trigger relevant ethical oversights in key areas. For instance, we note the need for identifying and engaging with the 'very purposes and motivations' (Owen et al., 2012, p. 754) of innovative sciences such as synbio as an essential part of responsible practice. For ethicists, our findings illustrate the value of empirically anchored investigation. To ethically inform the field as it develops requires attentiveness to real-world practices, power dynamics, questions of justice, context-specificity and to relationality rather than abstract, high-level analysis. Our findings also illustrate the continuum between bioethical approaches to synbio and those of RI/RRI scholars who have turned to empirical methods and sociopolitical critiques (Brian, 2015; Cserer & Seiringer, 2009; Pansera et al., 2020; Raman, 2015).

The need for robust science policy is another implication of our study; here, too, the emphasis is on the social context of synbio. Themes such as the equitable distribution of benefits and gains from synbio, how to prevent the monopolisation of knowledge or its loss in patents, and roadmaps to forecast the effects on different stakeholders of synbio industry disruptions all require substantial policy guidance. Our findings support calls for global synbio research agenda setting (Dixon et al., 2022).

The implications for those funding synbio research are significant, given the ways our study reflects the powerful directional pull funding holds in determining the shape and future of the field. Our research draws attention to the value of funding blue sky research, longer-term rather than shorter-term projects and risky and ambitious projects; tackling grand challenges; and ensuring at least some research independent of output or industry-driven agendas. Given the power of funders, there is both an opportunity and a clear ethical obligation for funders to demand equity and diversity in the labs they fund. Addressing these concerns will support high standards of research integrity and rigour that may otherwise be threatened by factors including academic labour conditions. However, mechanisms for mandating the types of research and conditions that address these issues are limited given diverse funding sources and the emphasis on research impact.

Our findings illustrate the perceived effects of funding sources and employment conditions on the quality of synbio research. Likewise, creating an equitable and diverse workplace culture is essential for the production of the highest quality science and should not be dismissed from ethical or scientific consideration. Rather, these ostensibly sociological, cultural or political facets of the science are fundamental to its very practice, demonstrating the need for laboratory leaders, funders, policymakers and ethicists to have a sophisticated understanding of the relationship between science and the social and to foreground this relationship in setting the research agenda for the field. Such overt attention to agenda setting is essential to harness the public benefit of synbio, thereby reflecting the underlying motivation of synbio scientists to do research.

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Declarations

Conflict of interests The authors declare no competing interests.

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