SENIOR THESIS

Name

BENJAMIN FOSTER

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An Examination of the Intrinsic Ethical Concerns Associated with Synthetic Biology

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Tina Catalone, Ph.D. (Natural Sciences)

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Synthetic biology is an emerging science that applies the principles of engineering to biological systems. One group of experts states, “Synthetic biology is the engineering of biology: the synthesis of complex, biologically based (or inspired) systems which display functions that do not exist in nature. This engineering perspective may be applied at all levels of biological structures – from individual molecules to whole cells, tissues and organisms.” This definition highlights the ethically controversial elements of the science, particularly its focus on the de novo synthesis of new organisms. Indeed, this goal appears to be the driving force of synthetic biology, distinguishing the science from other fields such as molecular biology or genetic engineering. Because synthetic biology is based on engineering principles, it relies upon the existence of standard biological components or parts that “can be put together using bioinformatic and simulation tools to build circuits that will introduce or modify biological functions.” DNA and proteins are the most prominent standard biological components used in the practice of synthetic biology. The Massachusetts Institute of Technology has already created a registry that catalogues existing standardized genetic or proteomic parts, known as BioBricks. These various BioBricks can be used to synthesize highly regulated, novel biological systems. The predictability of these

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3 T. Douglas and J. Savulescu, 687.
4 L. Serrano, 1.
6 A. Balmer and P. Martin, 9.
7 A. Balmer and P. Martin, 9.
systems allows synthetic biologists to construct biological circuits that can be used to generate various products for the betterment of society.\(^8\) Drew Endy explains:

> The success of the building process [of synthetic biology] depends on (1) The existence of a limited set of predefined, refined materials that can be delivered on demand and that behave as expected [i.e. BioBricks], (2) generally useful rules (that is, simple models) that describe how materials can be used in combination (or not), and (3) skilled individuals [i.e. synthetic biologists] with a working knowledge and means to apply these rules. Biology itself is a natural resource that can be further adapted to help satisfy human needs.\(^9\)

Essentially, synthetic biology is a relatively new field that aims to use the scientific community’s ever-expanding knowledge of genetics and proteomics to construct predictable, beneficial biological systems.

The actual process of synthetic biology relies upon three main engineering principles.\(^10\) Standardization is the first of these principles.\(^11\) Ubiquitous examples of standardization include screw threads, units of measure and internet addresses.\(^12\) Existing biological examples include enzyme nomenclature, restriction endonuclease activity (restriction endonucleases cleave molecules of DNA at specific nucleotide sequences) and protein crystallographic data.\(^13\) While each of these current examples of biological standardization has catalyzed important advancements in their respective fields, synthetic biology proposes even greater

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\(^9\) D. Endy, 450.
\(^10\) D. Endy, 450.
\(^11\) D. Endy, 450.
\(^12\) D. Endy, 450.
\(^13\) D. Endy, 450.
standardization.\textsuperscript{14} As previously mentioned, synthetic biologists aim to generate an expansive catalogue of standard biological components (such as DNA sequences or proteins) with precisely defined functions that can be relied upon to interact with other biological molecules in entirely predictable ways.\textsuperscript{15} In addition, synthetic biologists employ the principle of decoupling in their efforts to construct life.\textsuperscript{16} Drew Endy writes, “Decoupling is the idea that it is useful to separate a complicated problem into many simpler problems that can be worked on independently, such that the resulting work can eventually be combined to produce a functioning whole.”\textsuperscript{17} Builders use decoupling principles when they separate the task of building a home into individual steps such as architecture, engineering, construction and inspection.\textsuperscript{18} In an analogous way, synthetic biologists have decoupled the synthesis of large DNA molecules into two main steps: design and fabrication.\textsuperscript{19} By creating this further specialization, the synthesis of novel sequences of DNA, which is required for the advancement of synthetic biology, will become more rapid and reliable.\textsuperscript{20} Finally, synthetic biologists also rely upon the engineering principle of abstraction.\textsuperscript{21} Drew Endy proposes:

Two forms of abstraction now seem worth exploring in biological engineering. First the information describing biological functions might be organized across levels of complexity [e.g. DNA, parts, devices and systems] using abstraction hierarchies. To be useful, biological

\textsuperscript{14} D. Endy, 450.
\textsuperscript{15} D. Endy, 450.
\textsuperscript{16} D. Endy, 451.
\textsuperscript{17} D. Endy, 451.
\textsuperscript{18} D. Endy, 451.
\textsuperscript{19} D. Endy, 451.
\textsuperscript{20} D. Endy, 451.
\textsuperscript{21} D. Endy, 451.
engineering abstraction hierarchies must (1) allow individuals to work at any one level of complexity without regard for the details that define other levels, yet (2) allow for the principled exchange of limited information across levels. Second, the parts and devices that comprise engineered biological systems should probably be redesigned and built anew so that they are simpler to model and easier to use in combination.\textsuperscript{22}

Endy’s first suggestion reveals that synthetic biologists must separate complex biological systems into various hierarchies including DNA, parts, devices and systems.\textsuperscript{23} Each level of this hierarchy can briefly interact with other levels; however, to ensure predictability within the biological system, these events must be highly regulated.\textsuperscript{24} In addition, Endy realizes that existing biological parts (including transcription promoters and open reading frames) are not entirely predictable and must be reengineered to produce useable novel biological systems.\textsuperscript{25} Therefore, specific biological components must be abstracted from their original context and simplified in order to advance the practice of synthetic biology. Overall, these engineering principles (standardization, decoupling and abstraction) allow further specialization within the various scientific fields that contribute to the practice of synthetic biology and promote humanity’s ability to manipulate biological systems.

To date, synthetic biologists have taken two approaches in their attempts to engineer new forms of life. The first is the more traditional “top-down” approach which “starts with some pre-existing natural living system and then re-engineers it

\textsuperscript{22} D. Endy, 451-452.
\textsuperscript{23} D. Endy, 451.
\textsuperscript{24} D. Endy, 451.
\textsuperscript{25} D. Endy, 452.
for some desired purpose, perhaps by synthesizing or transplanting entire genomes.”26 Craig Venter’s laboratory has employed a top down approach to delineate the 386 genes that encode the information required to carry out the essential biological functions of the bacterium *Mycoplasma genitalium.*27 This constitutes a so-called “minimal genome” that “can have other synthetic pathways added [to it], thereby enabling various products to be made from the same basic organism.”28 In terms of the engineering principles previously described, this sort of research represents an attempt to create a standardized biological genome. Another group of synthetic biologists use a “bottom up” approach which “attempts to make new simple kinds of minimal chemical cellular life, using as raw ingredients only materials that were never alive.”29 Steen Rasmussen is a prominent researcher in this area of synthetic biology.30 He has recently received a five million dollar grant to facilitate his attempts to construct so-called “protocells.”31 These protocells, which will be constructed using a synthetic Peptide Nucleic Acid, differ drastically from both naturally occurring cells and the minimal genome created by Craig Venter.32 This sort of synthetic biology is somewhat more radical than the “top down” approach and has received less attention from the public and bioethicists.33 However, the creation of the first “bottom up” synthetic cell “will

27 A. Balmer and P. Martin, 8.
28 A. Balmer and P. Martin, 8.
29 M. Bedau, E. Parke, U. Tangen and B. Hantsche-Tangen, 65.
30 A. Balmer and P Martin, 10.
31 A. Balmer and P. Martin, 10.
32 A. Balmer and P. Martin, 10.
33 M. Bedau, E. Parke, U. Tangen and B. Hantsche-Tangen, 66.
mark the first time humans have synthesized life from wholly nonliving materials.”

Therefore, this field has the potential to radically alter society’s understanding of both the definition of life and humanity’s proper function within the established natural order. For this reason, synthetic biology raises many interesting ethical questions for society.

The social and ethical considerations associated with synthetic biology fall into two broad categories: extrinsic concerns and intrinsic concerns. Mark Bedau explains, “Extrinsic arguments are driven by the technology’s consequences.” These types of considerations usually involve evaluations of a technology’s implementation and safety. On the other hand, intrinsic arguments “are driven by the nature of the technology itself, yielding conclusions pertinent to any implementation of it.” (Italics added for emphasis). Examples of commonly encountered intrinsic considerations include various permutations of the “playing God” argument, concerns about “violating nature’s sanctity” and fears about promoting theories of biological reductionism.

Various extrinsic concerns are associated with the practice of synthetic biology. Because synthetic biology is still a fledgling science, its research initiatives must be evaluated by weighing hypothetical risks against hypothetical benefits.

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34 M. Bedau, E. Parke, U. Tangen and B. Hantsche-Tangen, 67.
36 M. Bedau and M. Triant, 32.
37 M. Bedau and M. Triant, 32.
38 M. Bedau and M. Triant, 32.
39 M. Bedau and M. Triant, 32 – 34.
40 M. Bedau and M. Triant, 37.
In this way, a “utilitarian calculus” can be used to assess the potential outcomes of synthetic biological research.\textsuperscript{41} Bioterrorism is possibly the most serious potential risk associated with the practice of synthetic biology.\textsuperscript{42} Through synthetic biology, technology will be developed that will catalyze the efficient production of novel organisms.\textsuperscript{43} This new technology will simultaneously ease the production of existing pathogens that can be used to promulgate bioterrorism.\textsuperscript{44} Therefore, some regulators fear that the construction of artificial cells will concomitantly promote the “the production of known, modified or new microorganisms designed to be hostile to humans either directly or indirectly.”\textsuperscript{45} These hypothetical concerns are already becoming partially realized. For example, two research groups have recently synthesized the Polio virus and the Spanish flu virus of 1918; both viruses could be used for nefarious purposes.\textsuperscript{46} However, synthetic biologists have noted that the most prominent bioterrorism concerns still involve “state-level biological warfare programs,” and many “technological obstacles” render synthetic biology’s safety “no more concerning than previous debates about genetic engineering.”\textsuperscript{47} In addition, bioterrorism remains a distant concern, considering that synthetic biologists have yet to produce a functioning artificial cell.\textsuperscript{48}

In addition to bioterrorism, many groups fear that the novel organisms produced through synthetic biology will be either accidentally or intentionally

\begin{thebibliography}{9}
\bibitem{41} M. Bedau and M. Triant, 37.
\bibitem{42} A. Balmer and P. Martin, 18.
\bibitem{43} A. Balmer and P. Martin, 19.
\bibitem{44} A. Balmer and P. Martin, 19.
\bibitem{45} A. Palmer and P. Martin, 19.
\bibitem{46} A. Palmer and P. Martin, 19.
\bibitem{47} A. Palmer and P. Martin, 20.
\bibitem{48} M. Bedau, E. Parke, U. Tangen, and B. Hantsche-Tangen, 68.
\end{thebibliography}
released into the environment. In particular, critics have asserted that “biological machines [i.e. synthetically produced organisms] are evolutionary machines; they are subject to natural selection and potentially gene flow. This means that mutations in the genome of the synthetic organisms could produce unexpected interactions with the environment and other living, natural organisms.” The novel genetic combinations used to construct synthetically produced microorganisms could give these species an evolutionary advantage over existing species. If this were to occur, synthetic organisms could potentially disrupt the natural order, bringing about unforeseeable consequences. However, proponents of synthetic biology have assuaged these fears by pointing out that synthetically produced organisms will be too weak to survive outside of a strictly regulated laboratory environment.

Fears about bioterrorism or the uncontrolled release of synthetic organisms represent prominent extrinsic ethical concerns associated with the safety and implementation of synthetic biology. However, these extrinsic concerns are dependent upon “highly uncertain consequences.” While in worst-case scenarios synthetic biology may lead to an increase in bioterrorism, the science also promises to enable the rapid production of energy resources, smart drugs, molecular devices

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49 A. Palmer and P. Martin, 16.
53 A. Palmer and P. Martin, 16.
required for tissue repair and personalized medicines.\textsuperscript{55} Clearly this new technology has numerous potential benefits and risks; however, speculating about the possible outcomes of synthetic biological research does not address intrinsic ethical concerns that question whether or not the entire field of synthetic biology is ethically permissible. Mark Bedau and Emily Parke write:

\begin{quote}
The creation of protocells [i.e. synthetically produced cells] promises to alter our world forever. Protocells could bring many impressive benefits for human health, the environment, and defense, and dramatically accelerate basic science. But they could also create new risks to human health and the environment, and enable new forms of bioterrorism. So, there potential upside and downside are both quite large.

In addition, creating life from scratch will fundamentally shake public perceptions about life and its mechanistic foundations, undermining certain entrenched cultural institutions and belief systems. Society should weigh all of these significant consequences when deciding what to do about protocells.\textsuperscript{56}
\end{quote}

While the modern emphasis on utilitarianism may skew ethical discussions concerning synthetic biology towards extrinsic concerns, Bedau and Parke note that this science may change humanity’s perception of life. Furthermore, many individuals believe that synthetic biology represents man’s attempts to “play God.”\textsuperscript{57} Both of these ethical considerations represent prominent intrinsic concerns associated with synthetic biology. The ethical discussion surrounding synthetic biology.

\textsuperscript{55} A. Palmer and P. Martin, 13.
biological research must evaluate these intrinsic concerns to elucidate whether or not the goals of synthetic biology coincide with existing religious beliefs and cultural understandings.

The “playing God” argument embodies the first of the intrinsic ethical concerns pertinent to synthetic biology. For Joachim Schummer, the “playing God” debate is rooted in cultural tensions that arose during the early nineteenth century.58 Before this time period, the concept of humans creating life from inanimate material seemed uncontroversial and even commonplace.59 For example, the medieval doctrine of spontaneous generation proposed that, under the right conditions, creatures could emerge from a variety of household objects.60 In addition, many philosophers throughout history, including Thomas Aquinas and Francis Bacon, reasoned that humans could craft new life from inert materials.61 Several ancient traditions also taught that humans could create artificial “humanoids.”62 Greek and Egyptian cultures strived to produce machines known as automata that could realistically mimic human behavior.63 In the Kabalistic tradition, human-like golems could be created from dust when Rabbis uttered the proper combination of Hebrew words.64 These two ancient cultural descriptions of artificial human life were relatively uncontroversial because they did not represent

59 J. Schummer, 126.
60 J. Schummer, 126.
61 J. Schummer, 127.
62 J. Schummer, 128.
63 J. Schummer, 128.
64 J. Schummer, 128.
human attempts to usurp God by generating creatures with “rational souls.”\textsuperscript{65} However, a third tradition outlined in ancient Arab texts, which described the creation of “alchemical homunculi” from male semen and a mixture of animal organs, did spark criticism from medieval society.\textsuperscript{66} In particular, the creation of “alchemical homunculi” was viewed as a threat to God’s power because it aimed to produce beings with rational faculties greater than humans.\textsuperscript{67} As a result, many denounced the practice of alchemy as a theologically perilous symbol of human hubris.\textsuperscript{68} Nonetheless, alchemy served as the ancient foundation for modern science.\textsuperscript{69} The historic divide between theology and alchemy is partially responsible for the “playing God” controversy that surrounds synthetic biology today.

While alchemy was denounced early in its history, both the doctrine of spontaneous generation and ancient attempts to construct artificial life forms without rational capabilities remained acceptable during the medieval period. From the medieval perspective, synthetic biology’s modern attempts to create living cells would be acceptable because a single cell is not considered a rational being. However, Schummer proposes that developments in both theology and science changed society’s willingness to accept spontaneous generation.\textsuperscript{70} The first step in this historical movement began in the seventeenth century when Newton and Boyle’s forays into the laws of physics spurred a revival of the theological concept of

\textsuperscript{65} J. Schummer, 130.  
\textsuperscript{66} J. Schummer, 129.  
\textsuperscript{67} J. Schummer, 129.  
\textsuperscript{68} J. Schummer, 130.  
\textsuperscript{69} J. Schummer, 130.  
\textsuperscript{70} J. Schummer, 131-132.
causal determinism.\textsuperscript{71} Schummer writes, “In this natural theology, which became very popular in the eighteenth-century philosophy and the dominant motive in natural history, anything, including any current living being, could be indirectly linked to divine creation and providence.”\textsuperscript{72} This revelation, coupled with both a greater understanding of reproduction and the publishing of Darwin’s \textit{Origin of Species}, allowed theologians and scientists to question the concept of spontaneous generation.\textsuperscript{73} For some, Darwin’s theory of evolution seemed to suggest that the creation of any living organism could ultimately lead to the development of a rational being.\textsuperscript{74} In the light of evolution, spontaneous generation’s apparent ability to haphazardly introduce new beings into God’s created natural order became a challenge to “the core of divine creation, the making of Adam, and thereby the core of Christian salvation and moral theology, the immortal soul imbued with original sin. One answer to that challenge was nineteenth-century creationism, according to which any living being owes its existence [solely] to the primordial divine creation...”\textsuperscript{75} Overall, Darwin’s theory of evolution actually provided the foundational reasoning required to articulate Christian creationism.\textsuperscript{76} In turn, creationism eventually refuted and replaced the reasoning that protected and validated both the medieval doctrine of spontaneous generation and the cultural acceptance of myths regarding artificially created forms of life.

\textsuperscript{71} J. Schummer, 131.
\textsuperscript{72} J. Schummer, 131.
\textsuperscript{73} J. Schummer 131-132.
\textsuperscript{74} J. Schummer, 133.
\textsuperscript{75} J. Schummer, 133.
\textsuperscript{76} J. Schummer, 133.
Schummer concludes his historical reflection by suggesting that modern synthetic biologists try to create life in the laboratory in order to illustrate the “creative power of man.” Rather than trying to improve God’s creation, early twentieth century synthetic chemists tried to produce the “living nature” that could not be recreated by early alchemists. As synthetic organic chemistry produced more and more organic compounds, synthetic chemists began to understand that they not only had to “learn from nature” but could also “master and design nature.” With this goal in mind, synthetic biology appears to be nothing more than an outgrowth of synthetic organic chemistry. As such, synthetic biologists see redesigning “living nature” as a desirable pursuit. While synthetic biologists try to carry out the ancient aspirations of alchemists, creationists now view any means of creating life, no matter how simple, as a possible challenge to God. Therefore, when some proponents of creationism disdainfully state that synthetic biology is equivalent to “playing God,” synthetic biologists reinterpret such allegations as an indication that they are successfully manipulating the “living nature” that eluded science for decades. This difference in the interpretation of the phrase “playing God” has created a rift between science and religion. Therefore, discussions about “playing God” in the context of creating life are often tinged with misunderstandings between scientists and theologians, and an ethical or theological

77 J. Schummer, 137.
78 J. Schummer, 134-135
79 J. Schummer, 135.
80 J. Schummer, 139.
discussion of the topic cannot overlook the historical basis for these fundamental tensions.

Whereas Schummer reveals that the “playing God” debate has been fomented by the historical confusion the phrase creates between scientists and creationists, Willem Drees explains the reasoning behind one of the modern theological interpretations of the argument. In particular, he demonstrates that individuals who believe in a “God of the gaps” use the “playing God” argument to halt the development of technological advancements (like the creation of a synthetic cell). 

Throughout his argument, Drees uses the expression “God of the gaps” to refer to “the tendency to focus on holes in our knowledge, on limitations in our current understanding, and to assume that such gaps are where God is at work.” Those who mistakenly believe in a God of the gaps relegate the work of God to gaps in human understanding; therefore, science and technology’s persistent attempts to expand human knowledge are seen as incrementally diminishing God’s participation in the world. Essentially, when humans “play God” by creating new technologies, they simultaneously marginalize God. For individuals who subscribe to a God of the gaps, the advances of synthetic biology threaten their image of God. However, Drees points out that the God of the gaps theory is inherently flawed and cannot be used to prevent scientific progress. He writes

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82 W. Drees, 644.
83 W. Drees, 644.
84 W. Drees, 644.
85 P. Dabrock, 48.
86 W. Drees, 645-653.
that those who believe in a God of the gaps mistakenly view engineers and scientists as threats. Instead, Christians should appreciate technological skills as “gifts of God” that can be used to better serve humanity. Furthermore, individuals cannot simply appreciate scientific advancements; they must create them. In the God of the gaps theory, humans can only accept and appreciate the established natural order; human creations that interfere with the natural world are unacceptable. Therefore, Drees proposes that a God of the gaps theory must be dismantled by emphasizing humanity’s ability to beneficially transform God’s creation. He explains, “But human activity is not only a threat to God’s good creation. It has also been seen as taking up what God entrusted to us: to work for the good, under the guidance of the Holy Spirit.” Science does not have to be a source of unease; rather, its “transformative power” can be seen as a way to bring good into the world. From this perspective, synthetic biologist may be “playing God,” but they do so ethically because they attempt to advance human understanding and provide solutions to the problems facing the global community.

Willem Drees’ argument suggests that determining whether or not humanity should transform God’s creation has been a source of confusion for some Christians. Schummer has already pointed out that this topic was debated in medieval

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87 W. Drees, 645.
88 W. Drees, 645.
89 W. Drees, 648.
90 W. Drees, 650.
91 W. Drees, 649-650.
92 W. Drees, 649.
93 W. Drees, 650.
society. Ultimately, medieval authorities allowed individuals to bring artificial life into God’s creation as long as the act of human creation did not result in a rational being. Synthetic biology’s attempts to create living cells from chemicals and biological molecules have once again sparked a theological debate about humanity’s proper relationship with the divinely created natural order. Those who oppose synthetic biology now raise the “playing God” argument to indicate that scientists are approaching a boundary they should not cross. This group of Christians believes that God’s intended role for mankind is being perverted by modern science. Peter Dabrock writes that synthetic biology “might question the boundaries between the animate and inanimate. Religious cultural traditions, however, define this as a divine privilege and...the guiding function of the religious motive for guarding this fundamental boundary is still widely appreciated.” Essentially, synthetic biologists “play God” when they attempt to create life from the inanimate. This type of science is viewed as unacceptable because it involves performing an activity that must only be performed by God. In this light, the “playing God” argument is used to indicate that synthetic biologists are sinfully overstepping the intended function of mankind.

Dabrock argues that the practice of synthetic biology can be classified as sinful only if the discreet activity of synthesizing a living cell can be considered

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94 J. Schummer, 127-130.
95 J. Schummer, 127-130.
96 P. Dabrock, 48.
97 P. Dabrock, 48.
98 P. Dabrock, 48.
99 P. Dabrock, 48.
“qualitatively similar to God’s creative doing and may therefore affect or replace it.”100 In other words, synthetic biologists perform a sin if their work reflects an attempt to become co-creatores Dei (creators equal to God) and to undermine God’s established creation.101 Dabrock reveals that humans cannot create in the same sense that God creates because God’s creations become finite and are opposite to His nature.102 However, humans can never produce something infinite out of their own finite nature. Therefore, humans can never become co-creatores Dei, and the practice of synthetic biology is not sinful.103 If some religious groups believe that synthetic biologists can create in the same way that God creates, they fail to recognize the essential distinction that must be made between creature (mankind) and creator (God).104 Therefore, the idea that any human act could rival the creation of God truly represents both a “misconception of God,” and a failure to realize that “man can principally not act like God.”105 This notion is enhanced by the concept of creatio ex nihilo which represents an act of creation that can be performed only by God.106 Henk van den Belt explains that, “If the construction of artificial life forms only deserves to be called creation of life when it is created literally out of noting (creatio ex nihilo), then we can be pretty sure that this elusive aim will never be achieved.”107

100 P. Dabrock, 50.
101 P. Dabrock 50-51.
102 P. Dabrock, 50.
103 P. Dabrock, 51.
104 P. Dabrock, 50.
105 P. Dabrock, 51.
106 P. Dabrock, 50.
While Dabrock convincingly argues that humankind cannot rival God’s creative capabilities, he also postulates that synthetic biologists’ prideful attempts to “play God” and become co-creatores Dei could be viewed as sinful. To expand upon this theory, he uses the term imago Dei. He clarifies that imago Dei:

…does not label man as the chosen creature that possesses divine qualities. Unlike animals, human beings are equipped with the skills of reflection, of forming concepts and with a potential for self-distance, traditionally referred to as reason. Nevertheless, according to Protestant theology, these qualities are not the core of the noble category ‘imago Dei’ (Dabrock et al. 2004). Rather, it stresses the ennoblement of man through the direct address by God. This status of being addressed by God is granted to man – neither can he actively acquire it, nor is he principally entitled to receive it. This circumstance is inextricably linked to obligations: From the perspective of Christian tradition, God charges man with the responsibility for his fellow humans and all other creatures...

The concept of Imago Dei grants man the ability, “to exercise stewardship over creation.” Through this activity, individuals can use their divinely granted intellect to not just preserve the natural order, but also advance what is beneficial for man and animal alike. In this respect, synthetic biologists must perform their actions while “paying tribute to the loyalty of God as creator...” Thus, if synthetic biology does not represent a human attempt to pay homage to God, the science may be deemed sinful. However, several prominent synthetic biologists have already

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108 P. Dabrock, 51.
109 P. Dabrock, 51.
110 P. Dabrock, 52.
111 P. Dabrock, 49.
112 P. Dabrock, 52.
expressed that their work is not meant to compete with God. For example, Drew Endy, a leader in the field, humbly asserts:

I do not view [my research] projects as creating life, but rather [as] construction projects. For me as an engineer, there is a big difference between the words creation and construction. Creation implies I have unlimited power, perfect understanding of the universe, and the ability to manipulate matter at a godlike level. That’s not what I have. I have an imperfect understanding, a budget, limited resources, and I can only manipulate things quite crudely. In that context, with those constraints, I’m a more humble constructor.113

By making a clear distinction between construction and creation, synthetic biologists do not envision themselves as omnipotent creators of life. Their self-described function is that of a “constructor,” indicating that they do not even aspire to become co-creatores Dei. If this is the case, then synthetic biologists are not suffering from sinful hubris; rather, they are acting as stewards trying to incorporate something beneficial into God’s creation.

To briefly summarize, the theological versions of the “playing God” argument have been largely refuted by thinkers like Willem Drees and Peter Dabrock. Drees persuasively argues that using a “God of the gaps” theory to pit God against technology (including synthetic biology) not only limits the scope of God’s presence in the world, but also prohibits humanity from beneficially transforming God’s creation.114 Drees proposes that the skills of engineers and scientists should be viewed as God-given tools that can be used to mold creation to more accurately

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reflect its divine origin.\textsuperscript{115} Dabrock further explains that the work of synthetic biology cannot remotely compare to the creative acts of God.\textsuperscript{116} He also writes that synthetic biologists do not suffer from hubris; rather they act responsibly in \textit{imago Dei} to bring about something that may benefit humanity.\textsuperscript{117} Therefore, from a Christian theological perspective, synthetic biology appears permissible. However, the “playing God” argument is not used exclusively by Christians. In fact, some theologians suggest that it is actually rooted in secular thinking.\textsuperscript{118} Biomedical ethicists like Arthur Caplan explain that, when individuals use the phrase “playing God,” the emphasis is frequently on “playing,” not God.\textsuperscript{119} Therefore, secular opponents of synthetic biology raise the “playing God” argument to indicate that synthetic biologists are carelessly manipulating nature in a way that could harm humanity’s position in and relationship with the natural world.

Philosopher Ronald Dworkin suggests that the secular undertones of the “playing God” debate reflect a general unease over mankind’s changing concept of reality.\textsuperscript{120} Essentially, synthetic biology forces society to accept a blurring of the previously well-established distinction between the animate and the inanimate.\textsuperscript{121} The resulting insecurity that accompanies such a paradigm shift is manifested in

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\textsuperscript{115} W. Drees, 650. \\
\textsuperscript{116} P. Dabrock, 50 – 51. \\
\textsuperscript{117} P. Dabrock, 51-52. \\
\textsuperscript{118} H. van den Belt, 263. \\
\textsuperscript{120} W. Drees, 651. \\
\textsuperscript{121} H. van den Belt, 257. 
\end{flushleft}
the “playing God” controversy that surrounds the practice of synthetic biology.\textsuperscript{122} Drees adds that, “We accuse others of playing God when they have moved what was beyond our powers to our side of the boundary. The fear of playing God is not the fear of doing what is wrong, which is an issue on our side of the boundary, but rather the fear of losing grip on reality through the dissolution of the boundary.”\textsuperscript{123} In the end, the types of quasi-religious concerns outlined by both Dworkin and Drees fail to recognize humanity’s innate tendency to manipulate nature.\textsuperscript{124} Essentially, humans are “designed’ by nature to be good designers;” thus, synthetic biologists’ recent experiments are simply an outgrowth of an innate human desire to engineer.\textsuperscript{125} This line of reasoning seems to be the secular companion to Drees’ assertion that mankind has been granted intellect by God in order to transform creation.\textsuperscript{126}

In addition to reflecting mankind’s insecurities, the secular aspects of the “playing God” debate seem to represent an effort to protect the “sacredness of nature that the modern life sciences [like synthetic biology] threaten to profane.”\textsuperscript{127} Thus, the phrase “playing God” does not always refer to the “God of the bible;” rather, God is secularly reinterpreted as a “deified nature.”\textsuperscript{128} Anne Chapman has articulated the ideas behind this so-called “unnatural argument.”\textsuperscript{129} She writes that

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\textsuperscript{122} W. Drees, 651.
\textsuperscript{123} W. Drees, 651.
\textsuperscript{124} P. Dabrock, 47.
\textsuperscript{125} H. van den Belt, 263.
\textsuperscript{126} W. Drees, 650.
\textsuperscript{127} H. van den Belt, 265.
\textsuperscript{128} H. van den Belt, 265.
\end{flushright}
modern society views nature as a “social construct.” As such, nature is seen as being a mere extension of human activity and is no longer thought of as something beyond the realm of human control. Those who use the “unnatural argument” believe that “natural processes and living organisms have their own autonomy, an ‘otherness’ that is always, to some extent opaque to human understanding: nature ‘lives and grows by itself.’” Furthermore, nature is seen as an “autonomous partner” who deserves humanity’s respect and admiration. She explains:

In such constitutive relationships [e.g. humanity’s relationship with nature] what one has a relationship with (the other), because it is different from and independent of the self, offers resistance to and puts limits on the activities of the self. Not to respect those limits, but instead to seek simply to control and dominate the other, is to attempt to make the other into merely an extension of the self: something that exists simply to meet the ends defined by the self. This denies the possibility of a relationship with the other, a relationship that could have enriched the self. The self is thus diminished if it denies otherness by not respecting limits that the independence of others places on it (Plumwood 1993). Recognition of and respect for the otherness of natural processes is thus essential if we are to have a relationship with nature that can become part of who we are.

Thus, synthetic biology’s attempts to reduce nature to a set of genes and proteins undermine mankind’s potentially enriching relationship with nature. By attempting to replicate biological processes, nature, as an independent entity, is

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130 A. Chapman, 85.
131 A. Chapman, 85.
132 A. Chapman, 86.
133 A. Chapman, 86.
134 A. Chapman, 86.
135 A. Chapman, 86.
marginalized and forgotten.\textsuperscript{136} Those who oppose synthetic biology believe such actions are deleterious to society. Such secular views closely mirror the “God of the gaps” thinking explained by Drees. Just as those who believe in a “God of the gaps” accuse technology of diminishing God’s presence in the world, those who use the “unnatural argument” blame the ‘unnatural’ work of synthetic biologists for incrementally dismantling nature’s autonomy.

However, this secular version of the “playing God” argument does not seem to make much logical sense. Chapman notes that there is an inherent difficulty in discerning which actions are ‘natural’ and which are ‘unnatural.’\textsuperscript{137} Theoretically, one could argue that because humans are part of the natural world, all of our activities must also be natural.\textsuperscript{138} This line of thinking is used when synthetic biologists defend their work by arguing that humans are “designed’ by nature to be good designers.”\textsuperscript{139} In this light, synthetic biology does not challenge nature; instead, this branch of science flows from humanity’s natural inclination to manipulate the natural order. Obviously those opposed to synthetic biology do not accept this interpretation of ‘natural.’ Alternatively, ‘natural’ can mean, “everything which is of itself, without voluntary human intervention.”\textsuperscript{140} However, this statement indicates that all volitional human actions are ‘unnatural’ and consequently immoral, yet this is incompatible with the concept of free will.\textsuperscript{141}

\textsuperscript{136} A. Chapman, 86.
\textsuperscript{137} A. Chapman, 81.
\textsuperscript{138} M. Bedau and M. Triant, 33.
\textsuperscript{139} H. van den Belt, 263.
\textsuperscript{140} A. Chapman, 81.
\textsuperscript{141} M. Bedau and M. Triant, 33.
Therefore, the “unnatural argument” can exist, “only if ‘natural’ is interpreted in such a way that we can engage in both natural and unnatural acts and the unnatural acts are intuitively wrong.”\textsuperscript{142} In an attempt to further define natural and unnatural acts, Chapman asserts, “While natural methods involve humans understanding natural processes and then adapting their behavior or channeling the natural processes to meet human ends, unnatural methods aim to give human behavior a freer rein: nature is to be altered to suit human behavior, institutions and practices, so the latter are freed from the constraints imposed by nature.”\textsuperscript{143} From this perspective, activities are classified as unnatural if they attempt to supplant natural processes with artificial syntheses.\textsuperscript{144} By this definition, synthetic biology would be unnatural. However, the “unnatural argument” does not necessarily equate the unnatural with the immoral. Indeed, the unnatural process used to chemically engineer more effective pharmaceutical drugs is not immoral. Therefore, synthetic biology may be unnatural, but the “unnatural argument” fails to prove that this science is intrinsically immoral.

Overall, both the theological “playing God” argument and its secular counterpart, the “unnatural argument,” fail to sufficiently prove that the actions of synthetic biologists violate existing religious or cultural beliefs. If the theological “playing God” argument is presented from the God of the gaps perspective, it does not carry much weight because those who believe in a God of the gaps fail to realize that humans are granted reason to improve the human condition and bring the

\textsuperscript{142} M. Bedau and M. Triant, 33.
\textsuperscript{143} A. Chapman, 83.
\textsuperscript{144} A. Chapman, 82.
natural world closer to the divine. Furthermore, technology should not be seen as a challenge to God; rather, scientific advancements should be interpreted as a beneficial consequence of the reason that God has granted to humanity. Others who state that the work of synthetic biology represents a challenge to the creative capacities of God fail to realize that humans can never create in the same sense that God creates. Indeed, synthetic biology is much more similar to construction than it is to divine creation. As demonstrated, the “playing God” argument can also be used to vocalize secular concerns about the marginalization of an autonomous, deified conception of nature. However, these concerns are not convincing because they fail to articulate a clear distinction between actions that stem from nature and actions that are inherently unnatural. Furthermore, the “unnatural argument” ultimately fails because it cannot prove that unnatural acts are inherently immoral. In the end, all modern theological or secular conceptions of the “playing God” argument either lack a theological basis or are hopelessly illogical. Therefore, these considerations are not legitimate intrinsic ethical concerns; rather they are weak attempts to halt potentially beneficial scientific progress.

In addition to inciting “playing God” criticisms, the practice of synthetic biology appears to be changing the way humanity defines life, and this constitutes another important intrinsic ethical concern associated with the science. Synthetic biology puts forth the idea that life arises from nothing more than a small genetic code that is capable of producing the proteins that are required to carry out the purely mechanistic processes of life. Henk van den Belt states that this constitutes
“the informational view of life that has dominated molecular biology since Watson and Crick unraveled the structure of DNA ...”\textsuperscript{145} This description of life stands in stark contrast to vitalism, which argues that there is a “vital force” that is an “ineffable current distinguishing the living from the inorganic.”\textsuperscript{146} By proposing that life can be synthesized using purely chemical processes, synthetic biology refutes the fundamental principle of vitalism.\textsuperscript{147} However, the relatively new field of synthetic biology is not unique in its anti-vitalistic attitudes. Synthetic biology is rooted in a “philosophical mechanism” which was initially adopted to separate the emerging “new biology” from the study of natural history and to legitimize the science by rooting its foundations in physical and chemical laws.\textsuperscript{148}

Garland Allen describes the ways in which the description of life began to shift within the sphere of biology during the early twentieth century. First, he describes philosophical mechanism as “the view that likens organic (or other complex) entities to the interaction of material components in a machine.”\textsuperscript{149} He adds:

\begin{quote}
In the Mechanistic view the world appears as a mosaic of separate, independent parts. A detailed description of each of these parts and their interactions would produce a complete description of the system (a machine or an organism). From the Mechanistic point of view, the proper way to study any system is to take it apart (the analytical method) and determine the characteristics of
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\textsuperscript{145} H. van den Belt, 258
\textsuperscript{147} A. Caplan, 3.
\textsuperscript{149} G. Allen, 263.
the individual, isolated parts under as controlled a set of conditions as possible.\textsuperscript{150}

In order to achieve a “controlled set of conditions,” early twentieth century biologists began reducing the scope of their work to systems that could be readily analyzed.\textsuperscript{151} This process constituted a “reductionist strategy” which involved creating levels of organization.\textsuperscript{152} Studies involving the molecular or cellular levels of organization were seen as the most controllable, and the data gleaned from these experiments were thought to provide the most fundamental descriptions of life.\textsuperscript{153} By applying a mechanistic approach to the study of life, biologists could rely more heavily upon experimentation, which involved formulating hypotheses that could be subjected to experimental tests.\textsuperscript{154} Because vitalism was not amenable to physical testing, biology’s increased reliance upon experimentation further discredited this description of life.\textsuperscript{155} Therefore, the alternatives to mechanism, namely holism and vitalism, were subjected to increasing suspicion and criticism.\textsuperscript{156}

As philosophical mechanism became biology’s driving force, holistic biologists of the period argued that biology’s reliance upon this philosophy oversimplified living systems.\textsuperscript{157} However, even holistic biologists sought “to account for living processes as functioning wholes within the framework of known physical laws.”\textsuperscript{158}

While they accepted that biologists must describe life in material terms, they

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\item \textsuperscript{150} G. Allen, 265.
\item \textsuperscript{151} G. Allen, 265.
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\item \textsuperscript{154} G. Allen, 266.
\item \textsuperscript{155} G. Allen, 266.
\item \textsuperscript{156} G. Allen, 263.
\item \textsuperscript{157} G. Allen, 266.
\item \textsuperscript{158} G. Allen, 266.
\end{itemize}
differed from purely philosophical mechanists by asserting that studying isolated levels of organization provided an inaccurate understanding of various life processes. They believed that a biological system must eventually be evaluated as a functioning whole. Allen writes, “For holistic biologists, complex systems (even very simple ones) show emergent properties that are the product of the individual parts plus their interactions (what we today call synergistic effects are an example of emergent properties).” From this perspective, examining individual levels of organization causes biologists to forget that life is greater than the sum of its parts. Biologists who subscribed to philosophical mechanism were not persuaded by this argument, and they quickly tossed holism aside as a form of mysticism that had no place in science.

At this same time, vitalism continued to offer a possible alternative to strict philosophical mechanism. As mentioned previously, vitalists believed that living systems could not be described in purely physical or chemical terms. They thought organisms possessed a “vital force” that could not be quantified or described materialistically. In this respect, vitalists differed from both philosophical mechanists and holistic biologists, and they represented the most radical anti-mechanistic philosophers of the early twentieth century. Hans Driesch, a German embryologist, helped to popularize vitalism. His experiments demonstrated that

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159 G. Allen, 268.
160 G. Allen, 268.
161 G. Allen, 268.
162 G. Allen, 268.
163 G. Allen, 267.
164 G. Allen, 267.
165 G. Allen, 271.
divided sea urchin embryos could develop into smaller separate but complete embryos.\textsuperscript{166} According to a mechanistic philosophy, he had postulated that his experiments would produce half-embryos.\textsuperscript{167} When this outcome was not observed, he shunned philosophical mechanism and began to understand life in vitalistic terms.\textsuperscript{168} He described embryonic development as being the product of “an organizing, directive force that consumed no energy, was immaterial, but was the factor that distinguished living from non-living matter.”\textsuperscript{169} These types of conclusions were obviously rejected by philosophical mechanists, and they viewed vitalism “as fuzzy-minded and subjective nonsense that offered no concrete research agendas, and provide[d] no real guidelines for practical investigation.”\textsuperscript{170} In some ways, vitalism helped to further galvanize the research efforts of philosophical mechanists. Eventually the mechanistic philosophy dominated the field of molecular biology, and this driving force eventually produced synthetic biology, a science in which life is thought of as something that can be created from wholly inorganic parts.

Even though the mechanistic philosophy essentially overtook the fields of molecular biology and synthetic biology, some prominent thinkers still rejected the notion that life was purely material.\textsuperscript{171} At the end of the twentieth century, C. S. Lewis argued that describing life, especially human life, in material terms would

\textsuperscript{166} G. Allen, 271.
\textsuperscript{167} G. Allen, 271.
\textsuperscript{168} G. Allen, 271.
\textsuperscript{169} G. Allen, 271.
\textsuperscript{170} G. Allen, 267.
cause society to forget that “humans possess an essential nature, and live within an essential natural order that cannot be altered without harm.”

In addition, C. S. Lewis’ comments revealed a “concern that the very acts of rational science – dissection, analysis, and quantification – are a violation of the sacred integrity that lies behind all nature.” These types of criticisms clearly reflect a vitalistic philosophy and also possess some aspects of the ‘unnatural argument’ which has been previously analyzed. However, C. S. Lewis did make some unique insights when he stated that “if man chooses to treat himself as raw material, raw material he will be, not raw material to be manipulated by himself as he fondly imagined, but by mere appetite.” Therefore, synthetic biologists may think that defining life in purely materialistic terms will free society from a constraining natural order; however, in doing so, humanity will ultimately reduce their own nature to a critical point where human life is no longer viewed as sacred and can be carelessly manipulated. However, synthetic biology is still in its infancy, and this field of research has yet to create a single functioning artificial cell. Currently, the issue of manipulating human life through synthetic biology is so remote that it is essentially meaningless. However, synthetic biology’s attempts to create life from inert materials may alter the way humanity approaches critical questions such as

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172 L. Zoloth, 153.
173 L. Zoloth, 153.
174 L. Zoloth, 153.
175 L. Zoloth, 153.
176 M. Bedau, E. Parke, U. Tangen, and B. Hantsche-Tangen, 68.
when life begins or what constitutes death. In this sense, synthetic biology’s antivitalistic attitudes may have real consequences for society.

Philosophers and scientists have tried to predict the ways in which the definition of life will change when the first artificial cell is synthesized. Some believe that the subsequent blurring between the animate and inanimate will catalyze a refreshing and overdue revelation for society. In a *Nature* editorial, one writer explains:

> There is a popular notion that life is something that appears when a clear threshold is crossed. One might have hoped that such perceptions of a need for a qualitative difference between inert and living matter – such as vitalism – would have been interred alongside the pre-darwinian belief that organisms are generated spontaneously from decaying matter. Scientists who regard themselves as well beyond such beliefs nevertheless bolster them when they attempt to draw up criteria for what constitutes ‘life’. It would be a service to more than synthetic biology if we might now be permitted to dismiss the idea that life is a precise scientific concept. (Italics added for emphasis).

By eliminating the seemingly artificial boundary between mere matter and life, synthetic biology may concomitantly cause humanity to view life in non-scientific terms. Whereas C. S. Lewis thought synthetic biologists’ efforts to close the gap between the living and nonliving threatened to destroy humanity’s “essential nature,” this fear may be unwarranted. Synthetic biology seems to demonstrate

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179 “Meanings of ‘Life’: Synthetic Biology Provides a Welcome Antidote to Chronic Vitalism,” 1032.
180 L. Zoloth, 153.
that the conditions that are conducive to life are dependent upon circumstance and external factors. For example, a synthetic cell cannot come into being as a sole entity; its ‘life’ is dependent upon both temperature and the surrounding chemical composition of the cell culture medium. Some speculate that synthetic biology’s reliance upon external forces to produce artificial cells will cause society “to confront the contextual contingency” of life. This realization will precipitate a further muddling of the criteria that can be used to define life. Ultimately, humanity may determine that no strict criteria can be used to separate the living from the nonliving. If this occurs, synthetic biology’s persistent reliance upon harsh material reductionism will paradoxically bring about a non-scientific reconceptualization of life. When life is understood as something beyond quantification, its “essential nature” can no longer be subjected to experimentation and cannot be challenged through science.

However, synthetic biology may not lead to a non-scientific redefinition of life as some have speculated. Indeed, it appears more likely that synthetic biology will cause a further solidification of the “informational view of life.” Indeed, “top down” synthetic biologists are trying to create a minimal genome which encodes only the genetic information strictly required for life. With this goal in mind, synthetic biology appears to promote a genetic definition of life. This definition states, “A being is alive if it is a ‘vehicle’ instructed (built) by its own genes in order

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181 “Meanings of ‘Life’: Synthetic Biology Provides a Welcome Antidote to Chronic Vitalism,” 1032.
182 “Meanings of ‘Life’: Synthetic Biology Provides a Welcome Antidote to Chronic Vitalism,” 1032.
183 H. van den Belt, 258.
to propagate the genes themselves.” Giovanni Boniolo and Pier Paolo Di Fiore explain that any definition of life must also provide a corresponding definition of death; thus, they take a dyadic approach that is used to define both life and death simultaneously. They argue that the genetic definition of life not only defines life but also provides a workable definition of death. Using the genetic definition of life given previously, they write that, “A living being is dead if it has ceased to be a ‘vehicle’ instructed (built) by its own genes in order to propagate the genes themselves.” In addition, the genetic definition of life can provide a definition of those things which were never living. They write that, “A being is not a living being if it is not a ‘vehicle’ instructed (built) by its own genes in order to propagate the genes themselves.” Therefore, the genetic definition of life can be used to define life, death and nonlife.

While the genetic definition of life is useful in its simplicity, it does have several shortcomings that cause the definition to disagree with commonly held beliefs about life. First, Boniolo and Paolo Di Fiore point out that sterility complicates the genetic definition of life. They write that, “a human being who decides (for whatever reason) not to have offspring is still a ‘vehicle’ built by its own genes in order to propagate the genes themselves; after all a pianist remains a

184 G. Boniolo and P. Paolo Di Fiore, 618.
185 G. Boniolo and P. Paolo Di Fiore, 612.
187 G. Boniolo and P. Paolo Di Fiore, 618.
188 G. Boniolo and P. Paolo Di Fiore, 618.
190 G. Boniolo and P. Paolo Di Fiore, 620.
pianist even when not playing the piano.” However, they reach the startling revelation that aging women who “cease to be fertile” must be classified as dead. Specifically, postmenopausal women “cease to be a ‘vehicle’ instructed by their own genes in order to propagate the genes themselves.” This is the very definition of death that flows from the genetic definition of life. From this initial revelation, Boniolo and Paolo Di Fiore reveal many other instances where the genetic definition of life opposes society’s intuitive notions about life and death. They write:

Take an entity (human or belonging to any other species) that, for pathological reasons, becomes infertile and has ceased to be a “vehicle” for the genes. Such an entity is dead. Surprisingly, perhaps, a human being in an irreversible coma and with no cortical activity has not ceased to be a “vehicle” for his/her genes. Thus, he/she is alive. And what about embryos? Are they “vehicles” or “vehicles in the making”? Do we become alive only when we reach fertile age? One could argue that a “vehicle in the making” is alive. After all we are not instantaneously created (“we,” in this case, means humans and multicellular organisms). Unfortunately, this type of reasoning runs the risk of turning into a quagmire when dealing with potentiality...

While the genetic definition of life does provide working criteria for life and death, the definition is also impractical in many circumstances. This flaw does not mean that the definition is not a proper definition; rather, it creates a reality that differs sharply from humanity’s intrinsic understanding of both life and death. Boniolo and Paolo Di Fiore explain:

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192 G. Boniolo and P. Paolo Di Fiore, 620.
194 G. Boniolo and P. Paolo Di Fiore, 621.
195 G. Boniolo and P. Paolo Di Fiore, 621.
The reason for this is quite simple: the evolutionary ‘head count,’ so to speak, only tallies live heads and not dead ones. Thus, every definition of life and death, based on evolutionary principles (and the one proposed here implicitly is) is bound to get close to the mark when used as a criterion to define “being alive” but will be (more or less) widely off target when used to define “being dead.”

Ultimately, the genetic definition of life (which is supported by synthetic biology) fails because it does not provide a logical definition of death and cannot appropriately address entities which seem to be either on the verge of life or at the beginning of life.

Some scientists have already postulated that the genetic definition of life supported by synthetic biology will change the way society views the human embryo. One individual writes:

Synthetic biology’s view of life as a molecular process lacking moral thresholds at the level of the cell is a powerful one. And it can and perhaps should be invoked to challenge characterizations of life that are sometimes used to defend religious dogma about the embryo. If this view undermines the notion that a ‘divine spark’ abruptly gives value to a fertilized egg – recognizing as it does that the formation of a new being is gradual, contingent and precarious – then the role of the term ‘life’ in that debate might acquire the ambiguity it has always warranted.

This viewpoint corresponds with Boniolo and Paolo Di Fiore’s assertion that subscribing to a genetic definition of life may cause society to view the human embryo as a “vehicle in the making.” In doing so, the embryo is no longer viewed

196 G. Boniolo and P. Paolo Di Fiore, 621.
197 “Meanings of ‘Life’: Synthetic Biology Provides a Welcome Antidote to Chronic Vitalism,” 1032.
198 G. Boniolo and P. Paolo Di Fiore, 621.
as fully alive; rather, it is merely a “precarious” stepping stone to life.\textsuperscript{199} Therefore, synthetic biologists’ attempts to create life in the laboratory may promote a worldview that diminishes the moral status of the human embryo. Obviously such conclusions are morally perilous, and these types of societal consequences must be considered when evaluating the ethicality of synthetic biological research.

Because the genetic definition of life does not adequately coincide with society’s preconceived ideas about death and does not grant the human embryo its proper moral status, this particular scientific approach to defining life cannot be universally accepted.\textsuperscript{200} Boniolo and Paolo Di Fiore propose that in order to generate a description of life that corresponds with humanity’s existing ethical notions about life, society must look beyond the realm of science.\textsuperscript{201} They assert, “Nevertheless, to cross the ethical threshold, we must introduce a new concept that encompasses the extra-biological (in particular ethical) values that we wish to attribute to certain biological species or to a certain period of a given biological species’ life-span.”\textsuperscript{202} Boniolo and Paolo Di Fiore suggest that the term “existence” can be used to define life and grant living things their appropriate socially defined ethical value.\textsuperscript{203} Specifically, they write, “This new concept can be that of ‘existence,’ by which we mean life, considered from a genetic point of view, endowed with the values which we attribute to it on the basis of our beliefs.”\textsuperscript{204} They add:

\textsuperscript{199} “Meanings of ‘Life’: Synthetic Biology Provides a Welcome Antidote to Chronic Vitalism,” 1032.
\textsuperscript{200} G. Boniolo and P. Paolo Di Fiore, 625-626.
\textsuperscript{201} G. Boniolo and P. Paolo Di Fiore, 626.
\textsuperscript{202} G. Boniolo and P. Paolo Di Fiore, 626.
\textsuperscript{203} G. Boniolo and P. Paolo Di Fiore, 626.
\textsuperscript{204} G. Boniolo and P. Paolo Di Fiore, 626.
Life, therefore, relates only to the scientific description, in our case based on genetics. Speaking in terms of existence implies that there is someone (a single individual, a community, etc.) that, by resorting to philosophical, religious or ideological beliefs (which are historically and culturally determined) gives a particular value to that particular form of life or that particular period of its lifespan.\textsuperscript{205}

Therefore, the shortcomings of a purely genetic definition of life bring humanity to the realization that, while life can be rigidly defined, this definition cannot be useful because life is also a “culturally constructed and value-laden concept.”\textsuperscript{206} By generating the new concept of “existence,” which roots ethical beliefs about life in philosophy or religion, society now has a term that can be used to grant living things their appropriate moral status.\textsuperscript{207}

To briefly summarize, two theories have arisen to explain how synthetic biology will change society’s ideas about life. The first postulates that when synthetic biology successfully constructs an artificial cell from inert materials, humanity will have to accept a blurring of the distinction between animate beings and inanimate objects. By doing so, synthetic biology will also catalyze a realization that no harsh criteria can be used to separate life from nonlife. Rather, life must be understood as gradually and ambiguously evolving from nonlife. In this light, sharp distinctions between mere matter and life are not scientifically possible. Therefore, society must accept that a rigid scientific definition of life is not possible, and various cultures must use their existing beliefs to define life in non-scientific terms.

\textsuperscript{205} G. Boniolo and P. Paolo Di Fiore, 626.  
\textsuperscript{206} G. Boniolo and P. Paolo Di Fiore, 626.  
\textsuperscript{207} G. Boniolo and P. Paolo Di Fiore, 628.
On the other hand, some have predicted that synthetic biology will lead to a solidification of the “informational view of life.”\(^\text{208}\) Thus, the practice of synthetic biology will popularize a so-called genetic definition of life as defined by Boniolo and Paolo Di Fiore. However, such a stringent definition will undoubtedly conflict with society’s inherent ethical notions about life and death. So an initial turn towards a strict genetic definition of life will ultimately cause society to create the value laden term “existence” to assign moral categories to different forms of life. In the end, both of these emerging theories predict that synthetic biology will cause humanity to realize that life should not be rigidly characterized by science. Therefore, it seems plausible to predict that society will not blindly succumb to the purely scientific definition of life that flows from the harsh philosophical mechanism and material reductionism used by synthetic biologists.

In addition, some modern philosophers have now realized that the reductionism that has been adopted by many biologists may not realistically reflect the dynamic nature of life. Alwyn Scott postulates that, although biological levels of organization are useful for scientific inquiry, biology must also allow for “nonlinear phenomena.”\(^\text{209}\) He writes that nonlinear phenomena “are those for which the whole is greater than the sum of its parts.”\(^\text{210}\) For Scott, various nonlinear dynamics work within the framework of the biological levels of organization to bring about “emergent structures, and nonlinear interactions among these structures.

\(^\text{208}\) H. van den Belt, 258.
\(^\text{210}\) A. Scott, 51.
provide a basis for the dynamics at the next higher level.” For example, nonlinear dynamics between various molecules (nucleotides, amino acids, etc.) provide the complex nonlinear framework that is required to generate macromolecules such as DNA and proteins. With its reliance upon emergent structures, this critique of scientific reductionism is very similar to the holism which emerged during the early twentieth century. However, Scott’s philosophical argument ultimately goes beyond simply asserting that emergent structures exist. He also addresses the ways in which these emergent structures interact to inject diversity and spontaneity into the physical framework of life. He describes the phenomenon of “dynamical chaos,” which allows for small variations in initial circumstances to generate enormous differences in final outcomes. This line of thinking is sometimes referred to as the “butterfly effect,” and it is largely ignored in the rigidly linear thinking of philosophical mechanists. Because of dynamical chaos, Scott writes, “The number of possible entities that can emerge at each level is immense, implying that all possibilities cannot be physically realized in a finite universe. Thus only a small subset of the possible emergent and chaotically interacting entities actually occur.” For example, the number of proteins that can theoretically exist is $20^{200}$; this number is so large that most possible proteins will never exist in the context of a living system. The proteins that are found throughout nature were created out of “historical accidents” that are consistent with

211 A. Scott, 52.
212 A. Scott, 53.
213 A. Scott, 53.
214 A. Scott, 53.
215 A. Scott, 57.
the laws of physics and chemistry but not determined by them.”216 (Italics added for emphasis). If synthetic biology is truly attempting to explain life in solely physical and chemical terms, Scott’s philosophy (especially its reliance upon coincidence) obviously provides an argument against this viewpoint. However, Scott does not think his philosophy contradicts the current trends in biology. He writes, “Few biologists now doubt that the phenomena of life – including both its emergence from the chemical scum of the Hadean seas and its subsequent evolution – will eventually be understood as a complex process comprising many closed causal loops and networks of positive feedback that thread through several levels of nonlinear dynamics.”217 (Italics added for emphasis). Therefore, Scott proposes that most biologists (not including synthetic biologists) do not accept that life can be understood in strictly mechanistic terms.

While many scientists may accept that life is an exceedingly complex process that incorporates nonlinear elements and emergent structures, synthetic biologists still propose that life emerges from basic chemical reactions.218 Therefore, the practice of synthetic biology ultimately supports material reductionism.219 It is hard to determine whether synthetic biologists wish to promote reductionism in an epistemological or ontological sense. Garland Allen asserts that early twentieth century biologists initially used philosophical mechanism and reductionism epistemologically; therefore, it could be logically inferred that synthetic biology also

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216 A. Scott, 57.
217 A. Scott, 66.
218 M. Bedau and M. Triant, 34.
219 M. Bedau and M. Triant, 34.
employs these philosophies to investigate life, not define it. Even though synthetic biologists may not be trying to uncover the essential nature of life, some would still argue that they should not even try to create life from nonliving matter because such reductionism will undoubtedly reduce society’s respect for life. Mark Bedau and Mark Triant take issue with this argument and they write, “This objection [to the practice of synthetic biology] does not exactly require that biological reductionism be false, but merely that it be bad for us to view life reductionistically. Of course, it seems somewhat absurd to admit the truth of some form of biological reductionism while advocating an antireductionist worldview on moral grounds.” This quotation suggests that even if synthetic biology only promotes epistemological reductionism, some would still argue that such a philosophy is harmful to humanity’s understanding of life.

Synthetic biologists argue that their reliance on biological reductionism is morally acceptable. Bedau and Triant state:

If living things are really irreducible to purely physical systems (at least in some minimal sense), then creating life from nonliving chemicals would presumably be impossible, so the argument is moot. By the same token, if living things are reducible physical systems, it is hard to see why fostering reductionistic beliefs would be unethical. It is by no means obvious that life per se is the type of thing that demands the sense of awe and respect this objection is premised on, but even if we grant that life deserves our reverence, there is no reason to assume that this is incompatible with biological reductionism. Many who study the workings of life in a reductionistic

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220 G. Allen, 263.
221 M. Bedau and M. Triant, 34.
222 M. Bedau and M. Triant, 34.
223 M. Bedau and M. Triant, 34.
framework come away from the experience with a sense of wonder and an enhanced appreciation and respect for their object of study. Life is no less amazing by virtue of being an elaborate chemical process. In fact, only after we began studying life in naturalistic terms have we come to appreciate how staggeringly complex it really is.\textsuperscript{224}

Therefore, they believe that the validity of biological reductionism will be revealed through the work of synthetic biology.\textsuperscript{225} If a synthetic cell cannot be created from solely physical components, then life cannot be understood within the framework of biological reductionism. If inert materials can be used to form living cells, then synthetic biology will legitimize biological reductionism. Furthermore, Bedau and Triant postulate that describing life as a reducible chemical system does not have to strip life of its cultural value. Rather, if synthetic biology demonstrates that life is an extremely complex (but reproducible) chemical process, this complexity may imbue the concept of life with a new sort of awe.\textsuperscript{226} This viewpoint is logical; however, Boniolo and Paolo Di Fiore have already pointed out that even if synthetic biology can successfully synthesize an artificial cell, society cannot subscribe to a stringent reductionistic definition of life. Any definition of life must not rely solely upon science; it must also have cultural significance. Therefore, the definition of life necessarily falls outside the realm of synthetic biology; and, in this regard, synthetic biology cannot challenge societal understandings about life. In the end, the intrinsic ethical concern dealing with synthetic biology’s potential to detrimentally alter humanity’s understanding of life is not warranted.

\textsuperscript{224} M. Bedau and M. Triant, 34.
\textsuperscript{225} M. Bedau and M. Triant, 34.
\textsuperscript{226} M. Bedau and M. Triant, 34.
In conclusion, fears that synthetic biologists are playing God or destroying cultural understandings of life are not persuasive enough to deem the practice of synthetic biology unethical. These intrinsic ethical concerns primarily arise from the general unease that humanity feels as synthetic biologists blur the ancient distinction between life and nonlife. Rather than stating that the dissolution of this boundary is uncomfortable, opponents of synthetic biology put forth illegitimate intrinsic ethical concerns to preserve their particular perception of reality. However, these feeble arguments are largely unfounded. As previously illustrated, those who use the “playing God” argument either mistakenly believe in a “God of the gaps” or fail to realize that humans can never realistically challenge the creative capacities of God. Furthermore, individuals who wish to put forth the secular “unnatural argument” cannot conclusively show that ‘unnatural’ acts are inherently immoral. Finally, people who believe that synthetic biology will precipitate a harmful redefinition of life (such that the term ‘life’ becomes void of any moral associations) ultimately overlook science’s inability to prove or disprove cultural concepts that lie outside the realm of experimentation. Therefore, each of these intrinsic ethical concerns cannot be used to halt synthetic biological research.

Ultimately, synthetic biology aims to blend engineering and science in such a way that artificial cells can be created to supply society with beneficial products. Therefore, synthetic biologists do not attempt to “play God” or redefine life; rather, they attempt to use their knowledge to better society. Naturally, some individuals

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227 W. Drees, 651.
228 W. Drees, 651.
will feel uncomfortable when the first artificial cell is produced because this act will mark the first time that humans have been able to produce life from nonlife. However, general unease cannot serve as the basis for unwarranted ethical criticisms of synthetic biology.

Works Cited


