PERSPECTIVES on Science and Christian Faith

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"The fear of the Lord
is the beginning of Wisdom."
Psalm 111:10

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Perspectives on Science and Christian Faith

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The American Scientific Affiliation Has a Stated Position

James C. Peterson

Each day of the annual meeting of the American Scientific Affiliation (ASA) began with worship: heartfelt and transforming worship. With all the diversity of academic field, hometown, language, citizenship, age, height and width and style, there was, as the Apostle Paul says, clearly one Lord, one faith, one baptism (Eph. 4:5). Brothers and sisters together worshipped the Creator revealed in Jesus Christ.

The annual meeting program states that "The ASA encourages thoughtful and provocative scientific presentations and discussions. Presenters and discussants are expected to maintain a humble and loving attitude toward individuals who have a different opinion." The presentations then are not given as official position statements of the ASA. Sometimes several papers in a row will lean one way or another, not to represent all of ASA, but as the compelling and thoughtful perspective of those who happened to present during that particular session.

In all its variety then, the meeting as a whole, like the journal, is richly plural with perspectives, but not an infinite number of approaches. Both the annual meeting and the journal are focused by two deep commitments that bring us together. As a group we are always refining and seeking to develop our best understanding of the available science, in conversation with our best understanding of Christian theology. What does our faith, so well articulated in the Apostles' and Nicene Creeds, have to say with science about the great issues of our day, life, and thought?

The ASA website puts it this way:

1. We accept the divine inspiration, trustworthiness and authority of the Bible in matters of faith and conduct.
2. We confess the Triune God affirmed in the Nicene and Apostles' Creeds, which we accept as brief, faithful statements of Christian doctrine based upon Scripture.
3. We believe that in creating and preserving the universe God has endowed it with contingent order and intelligibility, the basis of scientific investigation.
4. We recognize our responsibility, as stewards of God's creation, to use science and technology for the good of humanity and the whole world.[1]

The ASA website continues, "The above four statements of faith spell out the distinctive character of the ASA, and we uphold them in every activity and publication of the Affiliation."

Publishing in the journal does not require membership in the ASA, or even affirmation of the above, but material is selected as of interest because it in some way makes informed, new, clear, and important contributions to the above purpose.

We do not think that the interaction of science and faith will be exhausted in our lifetimes, but we can make genuine progress, and we do enjoy each other, as we work together.

In sum then, the ASA does have a stated position. It is that the above commitments—to develop in dialogue our best understanding of science and Christian theology—are worth our attention and pursuit. Indeed, they make for lively and life-giving conversations in this journal, in Diving Deeper discussions with *PSCF* authors, at our annual international meeting, within local chapters, at the Winter Symposium … Carry on! ▼

Note

[1]American Scientific Affiliation, "Our Platform of Faith Has Four Important Planks," accessed August 4, 2022, https://network.asa3.org/page/ASAbeliefs.

James C. Peterson
Editor-in-Chief

Tony Jelsma

Article

An Attempt to Understand the Biology of Gender and Gender Dysphoria: A Christian Approach

Tony Jelsma

The recent rise in the number of transgender individuals has perplexed many. A study of possible biological origins of gender dysphoria presents a complex picture. In some cases, prenatal hormonal imbalance may cause early-onset and persistent gender dysphoria. In contrast, late-onset cases are associated with a high incidence of comorbidities such as trauma, depression, and autism. In such cases, social isolation and an impaired body image may make individuals susceptible to social media suggestions of gender dysphoria. Moreover, affirmative counseling without addressing underlying comorbidities can strengthen this misperception, further moving these individuals along a trajectory toward transition. Care must be taken when considering early transition, given the fact that childhood gender dysphoria frequently desists. One must balance sparing a child from the distressing sexual changes of puberty with beginning transition in someone who might otherwise have desisted. Recent studies of perception suggest that it is a top-down predictive, "best guess" process. Although these "guesses" are continuously modified by sensory experience, they can persist; they might also apply to some cases of gender dysphoria. While some people have managed to detransition back to their natal gender, we should not assume that this is possible with everyone. As Christians, we need to examine each case individually, removing the stigma and supporting them through this distressing condition.

Keywords: gender dysphoria, gender incongruence, Waddington's landscape, puberty blockers, desistance, comorbidities, body perception, aromatase, integrity, disability, diversity

The recent dramatic increase in both the number of cases and the prominence of transgender individuals in our culture raises many questions. Responses from churches have been mixed, from outright condemnation to enthusiastic acceptance. How do we as Christians navigate this issue? One of the blessings of the American Scientific Affiliation that founded this journal is that it is an organization that values both science and scripture. It also recognizes that there may be differences of opinion within its members, so I expect that not everyone will agree with my conclusions, and I am open to correction as new evidence emerges. Since this is a rapidly evolving field, there often are not clear answers, and there can be vigorous disagreement. New findings may change perspectives. Unfortunately, the complexity of this topic and space limitations force me to oversimplify on occasion. Sadly, this issue is highly polarized, even in the scientific literature. Often the language itself is value-laden, which is well meaning but can be unhelpful for clarity. Moreover, every case is different, so generalizing can lead to mischaracterizations.

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The Biology of Sex and Gender

As we begin, we first need to distinguish sex and gender. *Sex* refers to one's biological sex, which is genetically determined and usually causes both body and brain to be male or female. *Gender* refers to one's internal perception that one is male or female. This can conflict with sex in gender incongruence or vary in people who identify as gender-fluid. Determining sex of the body is relatively straightforward in most cases (with exceptions, discussed below), but when we look at brain development, our conclusions are by necessity more tentative. Gender is more difficult to study because it is based on self-reporting.

The usual pattern of development is as follows. Males have a Y chromosome, which contains the *sry* gene. Around six weeks into embryonic development, this gene is activated, which causes an embryonic structure called the genital ridge to develop into testes. These testes then produce testosterone, which stimulates the development of the male internal and external reproductive organs. Females lack the *sry* gene, so ovaries develop instead, along with the female internal and external reproductive organs before birth and secondary sexual characteristics at puberty.

What about the brain? The classical model for explaining sexual behaviors is that there is a two-stage process. The *organization* stage occurs before birth, while *activation* occurs at puberty. In the organization stage, neural pathways in boys and girls develop differently under hormonal influence. These different neural pathways result not only in different behaviors during childhood, but also in different sexual behaviors in adolescence.[1] Our understanding is that the brain is masculinized by testosterone and possibly other hormones, including estrogen, while development of a female brain is the default pathway.[2]

In contrast, Brown University Professor Emerita and sex researcher Anne Fausto-Sterling has proposed a dynamic systems framework for gender/sex[3] development that is entirely based on conditioning.[4] Fausto-Sterling describes three phases of a child's gender/sexual identity. In the first phase (<15 months), the child is exposed to different stimuli, depending on their sex, which has an impact on brain development. From 15 to 18 months, there is this fluid period in which one's sense of gender/sex is developing but not yet apparent. After 18 months, the child has developed their sense of gender/sex and begins to act accordingly. While I agree that there are environmental contributions to brain development, including sexual functions, they are not the only factors. It is striking that Fausto-Sterling never mentions prenatal hormonal influences, dismissing those who argue for biological underpinnings of gender. Yet, these environmental influences that Fausto-Sterling describes are set in a context of previous brain development *in utero*, under the influence of different sex hormones. Surely, they also have an influence on gender! I will address these hormonal effects later in this article.

Glossary

- **Gender incongruence**: incongruence between one's biological sex and one's gender. May be present with or without dysphoria
- **Gender dysphoria**: the sense of distress resulting from gender incongruence
- **FtM**: Female-to-Male transgender person or transition
- **MtF**: Male-to-Female transgender person or transition
- **Binary**: understanding sex and gender to be either male or female
- **Nonbinary**: allowing for a spectrum of sex and/or gender to be intermediate between male and female
- **Passing**: the ability of someone to be in public without others knowing that they are transgender
- **Puberty blockers**: GnRHa (gonadotropin-releasing hormone agonists), used to suppress sex hormone production and prevent the child from entering puberty. Originally developed to treat precocious puberty, these are used to suppress puberty in the Dutch protocol or to stop endogenous testosterone production in MtF individuals
- **WPATH**: World Professional Association for Transgender Health
- **USPATH**: United States Professional Association for Transgender Health
- **APA**: American Psychological Association

Nevertheless, Fausto-Sterling's emphasis on the dynamic nature of sex and gender development is helpful, as it avoids a rigid essentialist understanding of gender. She also applies Waddington's epigenetic landscape model to gender/sex development. Waddington's landscape is a helpful way to understand the dynamic and stepwise nature of embryonic development.[5] As an organism develops, cells progressively adopt cell fates by making developmental decisions. Waddington's model is that of balls rolling down an uneven slope, choosing different paths to descend, and thus ending in different places (fig. 1).

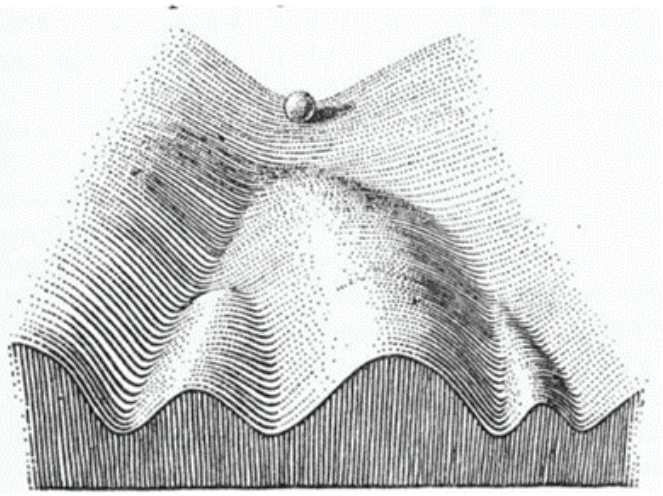

Figure 1. Illustration of Waddington's landscape. The ball rolls down the "developmental" hill, making successive pathway decisions along the way. Depending on which path is chosen, the cell/organ/individual will adopt a different fate.

There is a usual pattern but there is also an element of chance and variability, as the pathways that are chosen can be affected by the environment. Moreover, there is also increasing stability as the pathway is chosen. In brain development, these developmental changes primarily involve the formation and refinement of synaptic connections and epigenetic regulation of gene expression, which presumably result in sex-typical behaviors. It is not difficult to imagine variability in the behaviors that are expressed, and to what degree, depending on which pathways were chosen. Note that this is an oversimplified explanation of a very complex process involving many interacting neural pathways and many types of behaviors. There may be differences between the sexes, due to hormones and other influences, but there is also much overlap in behaviors and preferences.

Before proceeding further, we need to be clear that gender is not how one *acts*, as male or female; it is how one senses oneself *to be*. I frequently see references to gender as a social construct,[6] which seems to me to be a confusion of gender roles versus gender perception. To be sure, one's gender would affect how one acts—for example, mannerisms, clothing, choice of friends—but they *follow from* one's gender and are not equivalent to them. Gender *roles* are largely socially constructed but gender *identity* is not. As an example of this confusion, Meredith Meyer and Susan Gelman argue against gender essentialism on the basis that it forces children to stereotypical behaviors depending on their gender, which can lead to power inequality.[7] To be sure, rigid stereotypes of sex-specific behaviors are neither necessary nor helpful, but they do not change one's gender. We also need to distinguish gender from sexual orientation. The former is inwardly focused, the latter outwardly focused. Moreover, gender incongruence does not need to entail a particular sexual orientation. Although these are distinct, it is possible that the two may be conflated by someone wondering whether they have gender incongruence (see below).

Development of Gender

What do we know about the biological basis for gender? The organization/activation model used to describe sexual behaviors was originally developed and studied in rodents, but gender obviously cannot be measured in animals, as gender is one's *internal* sense of whether one is male or female. Moreover, since it cannot be objectively measured, gender is difficult to study. Still, there are indications of a role of biology in gender development.[8]

It is becoming more apparent that, despite our increasing knowledge of the anatomy and circuitry of the brain, we do not have a good understanding of the higher-order processing in processes like gender perception. As described by Matthew Cobb, there are numerous models describing how the brain works, including anatomy, circuitry, brain waves, and neurotransmitters, but none of them accurately describes how we think, let alone how we perceive gender.[9] The tools available to study human brain activity are far too crude to analyze complex neural pathways and synaptic rearrangements, which are key to understanding brain function.[10] Thus, we are limited to looking for correlations. In this section, I will look at different ways to study the brain and

look for correlations with gender incongruence to help us detect possible biological causes. An important caveat is that as we search for possible causes of gender incongruence, there are likely to be multiple causes, so we must avoid generalizations.

Biology of Gender—Anatomy

Is one's gender apparent in one's brain anatomy and altered in gender incongruence? There are regions of the brain that are sexually dimorphic, that is, they differ in size between males and females. Could studies in transgender brains help us understand their role in gender? Indeed, numerous studies suggest that some of these regions in transgender individuals were intermediate or closer to their gender identity than their natal sex.[11] However, these findings must be interpreted with caution. While these regions are sexually dimorphic, there is considerable overlap and mosaicism between males and females, that is, there is not a clear relationship between the sex of the individual and the anatomy of these regions.[12] Since these are postmortem studies, the number of samples is low, and there is variability between individual subjects.[13] Moreover, due to the plasticity of the brain, it is also possible that individuals who lived according to their identified gender may have had corresponding changes in brain anatomy as a result. Finally, we do not know *how* these structures may function in gender identity.

Biology of Gender—Brain Function

If not anatomically, might gender incongruence be apparent in brain activity instead? One of the models for brain function that Cobb describes is a circuitry model. In this model, brain functions are not localized to a specific region, but using a wiring metaphor, brain functions result from different regions communicating with each other in a circuit. Such a circuit could differ between the sexes. Consistent with this model, there are differences in the cortex and gray matter between males and females, and individuals suffering from gender dysphoria display an intermediate pattern.[14]

Gender incongruence is often accompanied by comorbidities. One study found a high incidence of trauma, including anxiety, depression, family conflict, parental mental illness, separation, and bullying.[15] Autism rates are high in transgender people, but it is not clear if there is a common cause or a cause-and-effect relationship.[16] Gender incongruence may hinder psychological development of people with autism, thus amplifying the disorder. Alternatively, autism and accompanying social deficits might make it difficult for children to develop a sense of gender (reminiscent of Fausto-Sterling's dyad model of gender/sex development, described above). In addition to autism, gender dysphoria symptoms are also seen in schizophrenia[17] and an increased incidence of gender variance was also seen in children of both sexes with ADHD.[18]

Biology of Gender—Hormones

The strongest case for a biological cause of gender is that of hormonal regulation. As mentioned above, exposure to testosterone in the fetal brain masculinizes it, while absence of testosterone results in a female brain. There are multiple indications of an important role for sex hormones in gender development and alterations in this hormonal milieu could result in gender incongruence.[19]

- In a study of female patients with congenital adrenal hyperplasia (CAH), where high levels of androgens ("male-acting" hormones) are produced, a large proportion declared a male identity despite being raised as females.[20]
- In a study examining androgen insensitivity, where males have testes and testosterone but have defective receptors and physically develop as females, all (11/11) patients with complete androgen insensitivity identified as females, whereas most (11/14) patients with partial androgen insensitivity identified as males, despite having a female phenotype.[21] This strongly suggests that even a small response to testosterone can affect one's perception of gender.
- Polycystic ovary syndrome (PCOS) is accompanied by high levels of androgens in the blood. A study on female-to-male (FtM) transgender individuals found a high proportion (39%) of PCOS in these patients.[22]
- High levels of fetal testosterone may also contribute to gender dysphoria in girls but not in boys, which is consistent with the extreme male brain theory of autism.[23]
- Prenatal exposure to diethylstilbestrol (DES, a nonsteroidal synthetic estrogen prescribed to prevent miscarriage) causes sexual abnormalities, and there are links to gender incongruence in females as well.[24]

- Genetic studies have identified particular variants of the testosterone and androgen receptors that correlate with an increased incidence of gender dysphoria.[25]
- Exposure to endocrine disruptors such as bisphenols A and F might also have an effect.[26]

Greg Eilers's situation is another clue to the role of sex hormones in gender.[27] Eilers suffered lifelong gender dysphoria, which resulted in his resigning his position as a pastor, to transition to a woman. As a result of taking estrogen for his transition, his dysphoria resolved, and he sensed himself as a man again. His identifying as a man is dependent on continuing to take estrogen.[28] While it may seem surprising that taking a "female" hormone such as estrogen would resolve his dysphoria, it should be noted that estrogen is not strictly a "female" hormone, as it is present in male brains, being converted from testosterone by the enzyme aromatase.[29] Aromatase is expressed in many tissues, including nonreproductive organs, and plays a variety of roles, not just in reproduction.[30] Estrogen in the brain is involved in many functions, including cognition.[31] One might speculate that blocking testosterone and increasing estrogen normalized Eilers's estrogen levels, which were possibly perturbed by prenatal exposure to DES.

Kayo Takahashi et al. found that levels of aromatase in different brain regions correlate with personality traits.[32] Although gender was not specifically addressed in this study, it should be noted that levels of aromatase are decreased in autism, a common comorbidity in gender incongruence.[33] Though we do not understand *how* hormones regulate gender, it seems clear that hormonally regulated gene expression plays a role in at least some cases of gender incongruence.

To summarize, there are many biological factors that may play a role in contributing to gender incongruence but none of these is well understood. The above examples either increase the possibility of gender incongruence or play a more definitive role in a subset of cases.

Are Sex and Gender Binary, or a Spectrum?

The above discussion implies that both sex and gender are binary. One is either one or the other. Yet there are arguments that both sex and gender are nonbinary, and even a spectrum.[34]

The development of one's sex that is described above occurs in most cases. However, sometimes the usual developmental pathway is not followed. Such cases are collectively called disorders of sexual development (DSDs) and occur in roughly 1 in 100 live births.[35] This is a broad category, and the incidence of genital anomalies is much lower, at 1 in 4,500 births.[36] Other DSDs include androgen-insensitivity syndrome (described above), or gene mutations in the developmental pathways, which result in intermediate phenotypes. Still other DSDs result from a chromosomal abnormality, such as Turner (XO) or Klinefelter (XXY) syndromes, where the sex is apparent, but normal sexual development does not occur.

The existence of DSDs seems to be the exception that proves the rule of sex being binary. These conditions are a result of a developmental *disorder*, not normal variance. As Christians, we must acknowledge that people with these conditions exist, and we must love and support them. However, that does not mean that biological sex exists on a spectrum.

The binary nature of gender is more difficult to assert because the issues are more complex. First, gender is difficult to define because it is entirely self-reported. While one's experience of gender may be very real for those suffering from gender dysphoria, there are no objective criteria for assessing gender, and studies that are done to assess gender need further development to improve reliability.[37] It seems that most cases of gender dysphoria involve a gender binary, but assuming a developmental process of gender formation, one can certainly imagine exceptions to this pattern.[38] Note that, as mentioned earlier, we must still distinguish between variations in sex-typical behaviors and one's gender. Just because someone has preferences that do not conform to most others of that person's sex, does not mean they are nonbinary, let alone transgender.

Recent Increases in Gender Dysphoria

It is difficult to determine the frequency of gender dysphoria. The number of reported cases is rising, but reliable diagnosis of the condition is difficult. Estimates range from 0.5 to 1.3%,[39] although one recent study had roughly 10% of high school respondents claim to be gender-diverse.[40] More recently, however, the number of adolescents, particularly girls, with gender dysphoria presenting to clinics has increased considerably, with a lesser increase in boys

and in adults of both sexes.[41] There are several possible explanations for these changes.

One possibility is better diagnosis. With the increased prominence and social acceptance of LGBT individuals in our culture,[42] more people are aware of gender incongruence, may see themselves also having this condition, and present to gender clinics. The increased use of the internet, and particularly social media, makes information on gender dysphoria readily available. Mark Yarhouse and Julia Sadusky, citing Hacking, describe a "looping effect," where the naming of a condition (like gender dysphoria) results in an increase in the number of people identifying with that condition, which in turn increases the number of institutions and experts who deal with it.[43] This is not meant to invalidate gender dysphoria, but it does provide a possible explanation for its relatively sudden increased prominence.

The increased study of gender dysphoria has presumably also resulted in better evaluation criteria for diagnosis. One study carefully examined this possibility for the Swedish population from 2005 to 2015 but found similar results to those reported recently: a slight increase in diagnoses in both sexes aged 18–30; and a several-fold increase in females aged 10–17, but no corresponding increase in males of that age.[44] It is not clear why the incidence of gender dysphoria is higher in adolescent girls. One possible explanation is that the social consequences of transitioning are higher for boys than girls, thus suppressing the number of cases in boys.[45] However, if the dysphoria persists, then one would expect a later increase in boys, which is not seen.

A controversial explanation of social contagion was first proposed by Lisa Littman, who described transitioning in clusters of friends, often encouraged by YouTube videos and other social media.[46] This phenomenon of rapid onset gender dysphoria (ROGD) was picked up by others, including the popular press, in both the US and the UK.[47] The Littman paper was critiqued on methodological grounds,[48] but the phenomenon exists,[49] and an explanation for the higher rates in this segment of the population remains elusive. A similar phenomenon involved an increase in Tourette's-like tics, which was linked to the viewing of TikTok videos of Tourette's syndrome by teenage girls and young women during the COVID-19 pandemic.[50]

What might be the role of environmental factors such as social media on gender? The possible perturbance of Waddington's epigenetic landscape was described earlier in the context of gender development in the fetus (the organization stage). Can it also function in adolescence, to provide an explanation for late-onset gender dysphoria? Fausto-Sterling discussed brain plasticity in the context of child development, but the dramatic changes in the brain that occur during puberty,[51] with the rise in the levels of sex hormones, may also occasion further changes in brain organization and behavior. Intrinsic stressors, such as depression or eating disorders, or extrinsic stressors, such as family trauma or social isolation, may contribute to instability in the epigenetic landscape and contribute to gender dysphoria.[52]

The Process of Transitioning

Transitioning is a big step to take and must not be taken lightly. Transitioning can (but does not necessarily) involve multiple steps in the progression: psychotherapy, hormone treatments, nongenital surgery, and genital surgery. The later stages are also costly and largely irreversible (but see below). Even with the extensive surgeries and lifelong hormone treatments, it can be difficult to "pass" as a member of the opposite sex. Despite these concerns, many deem the process to be essential, to relieve them of the dysphoria they experience. Which treatments that are done, and in what order, can depend on the individual. Many transition socially and hormonally but do not go further. Social transitioning can involve changes in hair and clothing, name change, and coaching to modify mannerisms and speech to the desired gender.

The World Professional Association for Transgender Health (WPATH) has laid out guidelines to determine if a patient is ready for surgery:

- Patient's gender dysphoria is persistent and well documented.
- Patient has the capacity to make a fully informed decision and consent for treatment.
- Patient is the legal age of majority in a given country.
- Patient's medical or mental health comorbidities, including any psychiatric disorders, are "reasonably well controlled" (for chest surgery) or "well controlled" for genital surgery. Obviously,

surgery should not be performed on actively psychotic patients.[53]

The initial steps include confirmation that the patient meets the criteria for gender dysphoria, assessment by mental health professionals, psychotherapy, and social transition for at least three months before hormone therapy is initiated.[54] Although these guidelines are clear, these are just guidelines, and they may not always be followed.[55] A culture of gender "affirmation" may be encouraging transition instead of using it as a last resort when other options have been exhausted.

Hormone treatments are the next step in transitioning. Gonadotropin-releasing hormone analogs (GnRHa) act on the pituitary to suppress the release of luteinizing hormone and follicle-stimulating hormone, which in turn prevents the production of estrogen in females and testosterone in males. GnRHa drugs were originally developed to treat precocious puberty but are also used off-label in this context. Female-to-male (FtM) patients receive testosterone, administered in various ways, sometimes with GnRHa or the less cost-prohibitive progestin to suppress endogenous estrogen production. Male-to-female (MtF) patients require GnRHa and estrogen, which can be associated with more adverse events, including blood clots. In the US, the diuretic spironolactone is commonly used off-label instead of GnRHa because it also blocks the effect of testosterone and is much less expensive. However, it also blocks the activity of aldosterone (sodium/potassium balance) in the kidney for which it was originally developed, so patients need to be closely monitored for adverse effects.[56] WPATH guidelines call for the individual to be on hormone treatments for a year before surgery.[57]

Reviews of studies on the effects of hormone treatments on gender dysphoria, quality of life, and psychological functioning found mixed results.[58] One recent review found a lack of high-quality randomized clinical trials to assess the safety of hormone use in trans women.[59] Yet another study found that testosterone therapy in trans men resulted in an increased body mass index (BMI) and decreased high-density lipoprotein ("good" cholesterol),[60] while a different study found increased occurrence of acute cardiovascular events in trans people of both sexes.[61]

While hormone treatments do alter facial shape and body contours, nongenital surgery can also modify the outward appearance to help the individual "pass" as the opposite sex in public. In MtF cases, this includes hair removal, voice modification surgery, and facial feminization surgery. Other surgeries include body contouring by fat redistribution (the particulars depend on the desired sex) and mastectomy. Genital surgery in both MtF and FtM cases removes the testes or ovaries, which means the individual needs to take sex hormones for life and will be infertile.

While the goal of genital surgery in FtM patients is to produce a phallus that can become erect, allow standing urination, and have both tactile and erogenous sensation, none of the available surgeries can accomplish this goal.[62] There are two main options for FtM genital surgery. Metoidioplasty is the least complicated and involves enlargement of the clitoris through hormone therapy and using local skin and tissues to construct a penis and scrotum, which will have testicular prostheses. While metoidioplasty maintains sensation and allows standing urination, the neo-phallus is small and generally does not allow penetrative sex. The alternative is phalloplasty, in which tissue is grafted from elsewhere in the body (forearm, back, leg, or groin). This procedure is more technically challenging and complex. While phalloplasty results in an anatomically sized neo-phallus and allows for standing urination, erogenous sensation is poor or lacking. Penetrative sex is possible only if an inflatable prosthesis is included or if bone or cartilage are included in the graft. This latter option means the neo-phallus is permanently rigid, which can cause other complications. In all cases of phalloplasty, the donor site is considerably altered. Despite these challenges, genital surgery is reported to have a high level of satisfaction.[63] This is most likely because it resolves the dysphoria in gender incongruence.

Like the FtM situation, the goal of genital surgery in MtF patients in constructing a vagina that can achieve pleasurable penetrative sex has not been achieved. This surgery involves the removal of the penis and the construction of a vagina. There are two options for constructing a vagina, neither of which generates a surface that is designed for penetrative sex. The interior walls of the vagina contain an epithelium that can withstand abrasion (stratified squamous) but also provides lubrication for intercourse, due to the seeping of fluid through the epithelium in arousal (in addition to mucus produced by vestibular glands). A mucous vaginal

interior can be accomplished by grafting part of the small or large intestine. These tissues contain mucus-producing cells, but they are designed for nutrient absorption, not to withstand abrasion. Instead, in most cases, skin from the penis and perineum is used to construct the vagina. This surface is better able to withstand abrasion but does not produce any liquids or mucus for lubrication. Moreover, the amount of skin is limited, and dilation is needed, more so if the patient received puberty blockers before transitioning, which prevents the normal enlargement of the penis during puberty. Not surprisingly, pain in intercourse is common. The construction of a clitoris with erogenous sensitivity and labia majora are more straightforward but constructing labia minora is more challenging.[64] Complications of the surgery are common and wide-ranging, often requiring secondary procedures.[65] Urinary complications are also common. Detransitioning surgery in cases of regret is possible after MtF transitions, resulting in a phallus that provided improved esthetic and psychological status.[66] However, this surgery (phalloplasty) does not provide erogenous sensation.

More attention is now being paid to the needs of detransitioners.[67] Mental health usually improves after transition, particularly over time,[68] but some decide to detransition. While it is difficult to obtain accurate numbers, studies have suggested that the incidence of regret is low (approximately 1%[69] but may be higher[70]) and is due to a variety of reasons.[71] A reddit site exists to support detransitioners,[72] and as more studies are done, it is hoped that the frequency and causes of detransitioning will be better understood.

Desistance and Early Transition

Another controversy in this field is the question of desistance, that is, children whose childhood gender dysphoria resolved in puberty or adolescence. Littman and Shrier suggested that many of the adolescent girls did not have genuine gender dysphoria, based on reports that most childhood gender dysphoria desists when the individual reaches puberty, with some having same-sex attraction instead.[73] This raises further questions about diagnosis and treatment.

Is there a difference between those cases that desist and those that persist? Are they qualitatively or quantitatively different? Clearly, if we can distinguish them, we can spare the desisters from irreversible treatments and proceed with the others. The criteria generally used to determine which cases are likely to continue are that the dysphoria is persistent, consistent, and insistent. These criteria are not that clear cut, however, given different personalities of these children, and there is considerable debate and a dearth of high-quality studies to provide clarity.[74]

In one report, Steensma et al. studied 53 adolescents who had gender dysphoria, 24 of whom desisted, to see whether there were differences related to their psychosexual development.[75] Both groups were similar before puberty, being indifferent up to age 5 (which is inconsistent with other studies showing dysphoria at younger ages) but identifying with the other sex around age 6/7. The difference between persisters and desisters became apparent at puberty, starting around age 10. For persisters, the dysphoria intensified with the social and physical changes and the beginnings of sexual attraction that accompanied puberty, while the same changes resulted in dissipation of dysphoria in desisters. There was also a difference in the sense of gender of the two groups before they reached puberty. Those who persisted asserted that they *were* the opposite gender, whereas those who desisted *wanted to be* the opposite gender. A follow-up study by the same researchers also found that the intensity of the dysphoria was greater in the persisters than the desisters.[76] Despite this promising finding, others have not described a similar phenomenon; it remains unclear how reliably one can predict persistence or desistance.

Clearly, the question of desistance presents a dilemma for treatment.[77] Given that most children with gender dysphoria will desist, early transitioning will result in transitioning in someone who would not have otherwise persisted. The permanent nature of some aspects of transitioning, including hormone therapy, argues that unnecessary treatments should be avoided. Despite this concern, the WPATH and USPATH have issued a joint statement supporting treatment for children with gender dysphoria.[78]

Another concern with treating gender dysphoria in children is the question of consent. Our brains undergo considerable development in puberty and adolescence, which has a profound impact on behavior.[79] Can a prepubescent, or even an adolescent understand well enough who they are, what the process of transitioning will be like, and what the final

consequences will be (including loss of normal sexual function and fertility), to provide truly informed consent?

Moreover, what is the effect of counseling on a child's (or parent's) decision to transition? Concerns about "conversion therapy" are well founded; the consensus is that counseling cannot resolve genuine cases of gender dysphoria. However, given that gender *affirmation* is the prescribed approach to counseling,[80] how many children proceed along the pathway of transition when they do not have genuine gender incongruence?[81] As mentioned above, there are significant comorbidities with gender dysphoria; is the counselor addressing them? If so, how?

On the other hand, waiting until puberty, known as "watchful waiting," can make transitioning more difficult, as the development of secondary sex characteristics (for example, bone structure, breasts, body hair) is more difficult to undo and makes it more difficult for the person to "pass" after transitioning. Additionally, the individual would experience an extended time of distress and further social consequences before transitioning.

The "Dutch protocol" involves treatment at the beginning of puberty, using GnRHa puberty blockers to delay puberty temporarily.[82] As their name suggests, they can be used either at the beginning of puberty, or later in adolescence as part of the transitioning process. When administered at the beginning of puberty, the goal is to buy time for gender dysphoric children before the physical changes of puberty exacerbate their dysphoria. In addition, puberty blockers would eliminate the need for many surgical procedures to treat the irreversible secondary sex characteristics that develop in puberty. However, side effects include a reduction in height when accompanied by cross-sex hormones,[83] weight gain,[84] and reductions in bone density.[85] A further complication is that puberty blockers prevent the normal growth of the penis, providing insufficient skin for the construction of a neo-vagina from the penis should the person desire this surgery.[86]

The use of puberty blockers has proved to be controversial because they may also block desistance. In a study of 70 patients taking puberty blockers, none of them desisted (when a large proportion would be expected), although there were fewer emotional problems and depressive symptoms.[87] The reasons for the lack of desistance are unclear but may have been partly due to more-stringent selection criteria for inclusion in this study. Alternatively, if it is the changes in hormone levels *per se* that occur in puberty that are responsible for desistance, then it should not be surprising that puberty blockers would block desistance. It should be noted that the prefrontal cortex, which is responsible for cognition, does not mature until late in adolescence.[88] Jack Turban et al. claim that the use of puberty blockers in adolescents improves mental health and reduces suicidal ideation.[89] However, this conclusion has also been challenged, citing weak data and confounding factors such as comorbidities.[90] In a systematic review, Lieke Vrouenraets et al. report disagreement on the use of puberty blockers, citing numerous areas in which our understanding is incomplete.[91] A more recent (but small) study found little change in psychological function after use of puberty blockers.[92]

The treatment of gender-dysphoric children in the UK has been contentious, centering around the services provided by the Gender Identity Development Service (GIDS). It is claimed that these services are overwhelmed and that providers are unable to adequately judge the suitability of a patient to consent to puberty blockers.[93] Indeed, former GIDS employees and others have compiled a book to protest perceived inappropriate services provided by GIDS.[94] In response to a lawsuit filed by Keira Bell, who was prescribed GnRHa and transitioned to a male before detransitioning sometime later, the British High Court banned the prescription of puberty blockers to patients below the age of 16, citing their inability to provide truly informed consent.[95] This ruling is being appealed, and the National Health Service (NHS) has announced an independent review of the gender identity services for children and young people.[96] Sweden does not initiate treatment for children under 16, and requires a court order to initiate treatment in children from 16 to 18.[97] On the other hand, in the US, a recent survey of a listserv of providers of gender-affirming care found overwhelming support for medical interventions before age 18.[98]

Sensing One's Gender

In reading works by transgender authors, I am struck by the certainty with which they express their sense of gender, even though it is incongruent with their sex. This is not a matter of "determining" their gender; they just "know" what gender they

are. They usually do not want this incongruence but feel helpless to change it. Consequently, it is entirely understandable that trans people want acceptance in our society because it is simply who they are. Thus, I disagree with well-meaning people who claim that gender is simply a matter of choice, and that sheer willpower can overcome it.

However, the scientific evidence I have described has not yet given a straightforward biological cause for gender incongruence. Hormonal factors that alter developmental trajectories seem to play a role, but it is not clear how this occurs. Moreover, the desistance data for childhood gender dysphoria, the recent increases in cases of gender dysphoria, and the common occurrence of comorbidities all argue against a single biological cause for this condition. Most likely, there are multiple causes, at least some of which involve perturbations in the hormonal milieu *in utero*. But might other cases involve a different cause, which may be more psychological in nature? I must be careful here not to imply a false dichotomy between biology and psychology. Clearly, psychological changes involve biological changes as well, but at this point an understanding of the basis of gender is beyond the reach of biology. Since my formal training is not in psychology, I must also present these ideas somewhat tentatively, but I find them intriguing and suggestive.

The neuroscientist Anil Seth recently gave a TED talk,[99] further elaborating on his book *Being You*,[100] in which he explains the research done by his group and others to describe how we interpret what we experience. Intuitively, one would think that the process is one of an analysis of our surroundings to construct a sense of reality, in a bottom-up fashion. However, such an approach would make us continuously a step behind in our assessment of our environment. Instead, Seth argues that our brains *predict* or *generate* our reality in a top-down manner, using sensory clues, and these "controlled hallucinations" are modified by continuous sensory input. Optical illusions demonstrate this phenomenon; our brains construct a reality that does not really exist. In the same way, our sense of self is constructed by a "best guess" of who we are, based on what our internal senses tell us.[101] This internal sense is surprisingly malleable. The classic rubber hand illusion describes a procedure where tactile stimulation of a rubber hand in one's field of view coupled with simultaneous stimulation of one's real hand, which is hidden, leads to a sense of ownership of the rubber hand as part of the body.[102]

Seth goes on to explain how this predictive aspect of constructing reality also applies to our physiology. Our bodies' physiology often changes in anticipation of an action: for example, commencing digestion before we have started eating, or mobilizing energy reserves before a race. This phenomenon is called allostasis, in contrast to the better-known homeostasis. Homeostasis is inadequate because it is always a step behind, so it needs to be supplemented by the more-predictive allostasis.[103]

How pervasive is this predictive aspect of interpreting reality? While not discussing gender, the social psychologist Jonathan Haidt made a similar argument a decade ago in his book *The Righteous Mind*, in which he shows how intuition *precedes* rationality, and that "explanations" are often *post hoc* rationalizations.[104] This phenomenon is also reminiscent of the difficulty of people to give up mistaken beliefs and conspiracy theories despite contrary evidence.

Could gender dysphoria be an example of people making incorrect assessments of their gender? This would not preclude biological contributions, such as hormones, but incorrect generation of one's identity may also occur in gender dysphoria. I hasten to add that I am not implying that gender dysphoria is something that people just "make up," as if it were easy to dispel this incongruence. Nonetheless, Seth's research, and our own personal experiences, indicate that we can easily be mistaken about what we think is reality. One would think that a misconception like that of gender would be easily corrected, simply by looking at one's own body. However, Seth cites other body ownership conditions such as phantom limb syndrome, asomatognosia, and xenomelia (the sense that an extremity does not belong to one's body and should be amputated[105]) as persistent examples of disorders of our sense of self.[106] One could add anorexia and body dysmorphic disorder[107] to the list.

Several lines of evidence suggest that body misperception could lead to gender incongruence. It may seem surprising, but multiple studies indicate that our own sense of gender is not as fixed as we might expect.[108] Magnetic resonance imaging studies in both trans men and trans women found weaker structural and functional connections in regions of the brain that process their own body perception in

the context of self.[109] In a different study, researchers used a variation of the rubber hand illusion to alter the subject's sense of gender.[110] Subjects wore virtual reality goggles that presented a body of the opposite sex to theirs in place of where their body was. They then watched that body being stroked on the leg and abdomen, simultaneous to their own body being stroked in the same locations. After a few minutes of this activity, their sense of body ownership moved toward that of the opposite sex.

This malleability of self-perception extends to social media, which is a prominent means by which adolescents decide that they are trans.[111] Adolescents who feel isolated from their communities—recall that many cases of gender incongruence have significant comorbidities—can readily find a replacement community online, where social media influencers convince them that they are trans. Websites such as TrevorSpace are devoted to supporting LGBTQ adolescents.[112] While such information may be helpful for some, this information is not given by someone with a personal knowledge of them and their situation. Moreover, gender-affirming counseling, as opposed to watchful waiting, can likewise perpetuate and reify this misconception.

A common feature of early onset gender dysphoria is desistance upon reaching puberty. Could the development of secondary sexual characteristics provide enough of a corrective in some people to dissipate the gender dysphoria? What about those for whom it does not dissipate? A characteristic of gender dysphoria is the sense that one's sexual organs (for example, penis, breasts) do not belong to the body and greatly contribute to the dysphoria, which is reminiscent of xenomelia.[113] Along these lines, a study of FtM transgender individuals found differences in brain activation by stimulation of a sexed body part (breast) versus a nonsexed body part (hand) between transgender individuals and controls, suggesting differences in neural representation of the body in gender dysphoria.[114] Finally, a controversial proposal was made by Stephen Gliske, who suggested that gender dysphoria is a condition that involves the distress, social behavioral, and body-ownership networks (more on this below).[115]

Could it be that one's misperception of one's own gender is actually the *cause* of the dysphoria, leading one to see one's sexed body parts as not belonging to them? The rubber hand and the opposite-body illusions are fleeting and quickly resolved, but could a combination of hormonal and environmental conditions direct someone to a more robust gender dysphoria, one that cannot so easily be resolved? While this is beyond my area of expertise, I look forward to future studies, particularly collaborative work by Christians in biology and psychology, to provide clarity to this question.

Christian Perspectives

Having covered many potentially controversial aspects of the science of gender dysphoria and various treatments, we need to see how a Christian perspective can inform us on how to approach these controversies. Sadly, this topic has become highly polarized, and whatever position is taken by one will result in disappointment and possible hurt for others. Various denominations and individuals have expressed differing Christian perspectives on this topic.[116] Space does not permit me to go into depth here, and a trained theologian might provide further insight, but allow me to make a few observations.

Although the Bible does not directly address transgender issues, we can nevertheless use scriptural guidelines to help us. First, as Christians who are called to love God above all and our neighbor as ourselves, we need to act in a manner that is consistent with scripture and in the person's best interest. All human beings are created in the image of God and deserve our love and care, particularly those who are suffering. To this end, one can appreciate the desire to destigmatize gender dysphoria. Moreover, assigned gender roles, whether by our culture or (mis)perceived biblical standards, can exacerbate the stress in someone who does not fit their gender stereotype.

Second, the binary of sex and gender are rooted in creation. Although he does not directly address gender dysphoria, Christopher West, in his book on Pope John Paul II's *Theology of the Body*, describes how the creational structure woven throughout scripture is one of (binary) complementarity and relationship.[117] To list just a few examples, marriage and sexual union are depicted in the Garden of Eden (Gen. 2:23), the first sin marred that relationship (Gen. 3:12), an entire book of the Bible (Song of Songs) is about sex, Jesus's incarnation was a conception (Luke 1:35), his first miracle was at a wedding (John 2:11), and the church is the bride of Christ (Rev. 22:17). One

of the most grievous sins is adultery (for example, Genesis 6, Exodus 32, and Numbers 25, not to mention the many references in the epistles). Idolatry is depicted as adultery: for example, consider the book of Hosea and also the Ten Commandments, in which both idolatry and adultery are prohibited. Moreover, one's sex is integral to one's identity, even after death. For example, biblical characters in the intermediate state (Samuel, Elijah, and Moses) or after resurrection (Jesus) retained their sex, apart from the body.

Despite this pattern of complementarity, however, there clearly are exceptions. Not all humans live in a complementary relationship. Some, either by choice or by circumstance, never marry. Indeed, Paul describes the ability to remain single as a gift from God (1 Cor. 7:7). But these are exceptions. Does being transgender or nonbinary also fall into the category of a legitimate exception to the pattern?

Yarhouse and Sadusky describe three approaches that Christians take toward transgender questions: the *integrity*, the *disability*, and the *diversity* approaches.[118]

The *integrity* approach holds that God created a binary of sex and gender. Any deviation from that binary is sin and the goals of treatment must be conformity of gender to one's biological sex. If that is not possible, then the dysphoria must be a burden to carry because of the Fall.[119] The integrity position sometimes points to Deuteronomy 22:5, which is a prohibition of people wearing clothes of the opposite sex. However, it is argued that this verse is irrelevant to the transgender discussion because it refers to deception (avoiding or entering military service, or men gaining access to women's spaces) and does not apply to cross-dressing or gender dysphoria.[120] Cross-dressing by people with gender dysphoria is palliative, done to relieve distress, and not done for deception. While the attraction of the integrity position is that it takes scripture seriously and strives to live by what it says, those holding the integrity position are obliged to be careful to appreciate fully the possible biological causes of the condition and the inability of some people to relieve their dysphoria without transitioning. While there are some people who have detransitioned as part of their religious conversion,[121] one cannot extrapolate from a few examples to all who suffer from gender dysphoria.

The *disability* (or disorder) approach likewise holds to a binary of sex and gender as rooted in creation, but recognizes that we live in a fallen world, and sometimes we need to make allowances for that fact. Sometimes sex and gender are incongruent, and the dysphoria cannot simply be wished away or endured. As was mentioned earlier, suicide rates in gender-dysphoric individuals are frighteningly high before (and after) transitioning. Suggesting that people can always just tough it out is insensitive and futile.

The *diversity* approach holds that while the sex/gender binary in creation are *de*scriptive, they are not *pre*scriptive. A spectrum of sex and gender are welcome, not as a disability but as part of the diversity in creation.[122] This position is consistent with the WPATH and APA standards of care, which describe gender incongruence as an aspect of diversity, not pathology.[123] Austen Hartke has made the comparison with eunuchs, who are outside the male/female norm but are welcomed in the church (Acts 8:35ff).[124] The attraction of this position is the evident love and concern that it holds for those who suffer from gender dysphoria. However, depathologizing a condition like gender incongruence (which this approach and WPATH and APA do) may also be unhelpful, if the treatment for it is so radical that it involves loss of fertility, disfiguring surgery, and lifelong hormone treatments.

How do we deal with situations that do not conform to the usual pattern? The integrity and disability approaches argue that we should maintain a holistic view of ourselves, where possible, maintaining consistency between gender and sex. The body is not irrelevant. Many transgender people instinctively agree, and this explains why they undergo hormonal treatments and surgeries to relieve their dysphoria and align their gender and sex. The challenge is in knowing what should be changed when there is incongruence. Do we maintain a conservative approach, doing only as much as is needed to relieve the dysphoria (if that is possible), or is the goal a full transition?

Can we get guidance by comparing transitioning for gender dysphoria to other health conditions? It is not comparable to same-sex attraction. We do not encourage someone who is same-sex attracted to act on those impulses because the Bible forbids *any* sex outside of marriage. The fact that there is a biblical

prohibition indicates that it is possible to withstand these temptations (1 Cor. 10:13). Alternatively, a possible comparison may be someone with cancer. We generally support cancer treatments that may require the removal of a body part or the use of chemotherapeutic drugs that will affect one's quality of life because these treatments achieve the greater goal of saving the patient's life. A still closer (but rare) comparison may be xenomelia, described above, in which a body part is felt not to belong to the body and therefore must be amputated. In both cases, there is the prospect of body-altering surgery on an individual who is otherwise physically and psychologically healthy but has this particular psychological trauma. By making an analogy to gender dysphoria, a case has been made in favor of amputation for xenomelia.[125]

On the other hand, Monique Robles, publishing in a Catholic bioethical journal, argues that transition "violates the body-soul union, disregards the principle of totality and integrity, and debases the dignity of humanity."[126] While there may be some merit to the arguments, one must also consider that, in this broken world, transitioning may be making the best of a difficult situation.

Final Thoughts

How did we go from a time when people with gender dysphoria were shunned from society, to today when sex changes are celebrated? The pendulum has now shifted to the point that any questioning of the legitimacy of gender dysphoria is met with vehement opposition.

Gliske's article proposing a scientific basis for gender incongruence was withdrawn by the journal, in part because of claims that it was disrespectful and pathologized gender dysphoria.[127] When Ryan Anderson's book *When Harry Became Sally* critiqued this cultural shift,[128] it received considerable opposition from the LGBT community (it is still not available for purchase on Amazon).

Carl Trueman in *The Rise and Triumph of the Modern Self* traces the importance of one's personal identity, from Rousseau, through Nietzsche, Sartre, de Beauvoir, Freud, to the present day.[129] There isn't space in this article to outline his arguments, but clearly the tide has shifted when it comes to our understanding of sex and gender. Even the secular community is raising concerns. Blaire White and Buck Angel, both trans people, express their fears on YouTube about indiscriminate transitioning of children and adolescents,[130] and sex researcher Debra Soh also voices concerns in her book *The End of Gender*.[131]

For many, gender incongruence/dysphoria is a very real condition, which causes considerable distress in those who suffer from it. In many cases, the underlying causes are not well understood. Full understanding and accurate diagnosis remain a challenge, as does finding a standard path for treatment.

As Christians, we cannot ignore this condition, either in our churches or from our task in the society at large. As agents of restoration, we are called to do what we can to help those suffering from gender dysphoria. This is no small task, however; it requires collaborative efforts by people trained in different fields, including biology, psychology, social work, philosophy, and theology. In addition, we must look to both science and scripture to guide us in these investigations. While we recognize that in this life we may make only small beginnings in that task, we can look forward to the time when Christ will return to make all things new. ▼

Notes

[1]Arthur P. Arnold, "The Organizational-Activational Hypothesis as the Foundation for a Unified Theory of Sexual Differentiation of All Mammalian Tissues," *Hormones and Behavior* 55, no. 5 (May 2009): 570–78, https://doi.org/10.1016/j.yhbeh.2009.03.011; Jo-Anne Finegan, Betty Bartleman, and P. Y. Wong, "A Window for the Study of Prenatal Sex Hormone Influences on Postnatal Development," *The Journal of Genetic Psychology* 150, no. 1 (March 1989): 101–12, https://doi.org/10.1080/00221325.1989.9914580.

[2]Katherine A. O'Hanlan, Jennifer C. Gordon, and Mackenzie W. Sullivan, "Biological Origins of Sexual Orientation and Gender Identity: Impact on Health," *Gynecologic Oncology* 149, no. 1 (April 1, 2018): 33–42, https://doi.org/10.1016/j.ygyno.2017.11.014; Julie Bakker, "The Role of Steroid Hormones in the Sexual Differentiation of the Human Brain," *Journal of Neuroendocrinology* 34, no. 2 (2021): e13050, https://doi.org/10.1111/jne.13050; and Julie Bakker and Michael J. Baum, "Role for Estradiol in Female-Typical Brain and Behavioral Sexual Differentiation," *Frontiers in Neuroendocrinology* 29, no. 1 (January 2008): 1–16, https://doi.org/10.1016/j.yfrne.2007.06.001. The situation is more complicated in rodents, on whom most studies have been done, where testosterone in the brain is converted to estrogen by the enzyme aromatase. Although aromatase is also found in the human brains, the importance of estrogen in human brain sexualization is unclear.

[3]Fausto-Sterling uses the term gender/sex to indicate the interconnectedness of sex and gender, which I welcome.

[4]Anne Fausto-Sterling, "A Dynamic Systems Framework for Gender/Sex Development: From Sensory Input in Infancy to Subjective Certainty in Toddlerhood," *Frontiers in Human Neuroscience* 15 (2021): 150, https://doi.org/10.3389/fnhum.2021.613789.

[5]Adam R. Navis, "Epigenetic Landscape," Embryo Project Encyclopedia (2007-10-30), accessed September 9, 2021, https://embryo.asu.edu/pages/epigenetic-landscape.

[6]For example, Kumar Ravi Priya and Ajit Kumar Dalal, *Qualitative Research on Illness, Wellbeing and Self-Growth: Contemporary Indian Perspectives* (New Delhi, India: Routledge, 2015); World Health Organization | Western Pacific, "Gender in the Western Pacific," accessed September 29, 2021, https://www.who.int/westernpacific/health-topics/gender; Catherine Dohrn and Dan DeBonis, "How Digital Technology and Remote Assessment Strategies Can Aid Clinical Trial Research," Applied Clinical Trials, July 24, 2020, https://www.appliedclinicaltrialsonline.com/view/how-digital-technology-and-remote-assessment-strategies-can-aid-clinical-trial-research.

[7]Meredith Meyer and Susan A. Gelman, "Gender Essentialism in Children and Parents: Implications for the Development of Gender Stereotyping and Gender-Typed Preferences," *Sex Roles* 75, no. 9 (2016): 409–21, https://doi.org/10.1007/s11199-016-0646-6.

[8]Frederick L. Coolidge, Linda L. Thede, and Susan E. Young, "The Heritability of Gender Identity Disorder in a Child and Adolescent Twin Sample," *Behavior Genetics* 32, no. 4 (July 2002): 251–57, https://www.academia.edu/19196986/The_heritability_of_gender_identity_disorder_in_a_child_and_adolescent_twin_sample.

[9]Matthew Cobb, *The Idea of the Brain: The Past and Future of Neuroscience* (New York: Basic Books, 2020).

[10]Scott Marek et al., "Reproducible Brain-Wide Association Studies Require Thousands of Individuals," *Nature* 603 (2022): 654–60, https://doi.org/10.1038/s41586-022-04492-9.

[11]Antonio Guillamon, Carme Junque, and Esther Gómez-Gil, "A Review of the Status of Brain Structure Research in Transsexualism," *Archives of Sexual Behavior* 45, no. 7 (2016): 1615–48, https://doi.org/10.1007/s10508-016-0768-5.

[12]Daphna Joel et al., "Sex beyond the Genitalia: The Human Brain Mosaic," *Proceedings of the National Academy of Sciences* 112, no. 50 (2015): 15468–73, https://doi.org/10.1073/pnas.1509654112; and Lise Eliot et al., "Dump the 'Dimorphism': Comprehensive Synthesis of Human Brain Studies Reveals Few Male-Female Differences beyond Size," *Neuroscience & Biobehavioral Reviews* 125 (2021): 667–97, https://doi.org/10.1016/j.neubiorev.2021.02.026. This point needs some clarification. There were several responses to this paper, arguing that while male and female brains are indeed mosaics, i.e., some structures are more "female-sized" while others are more "male-sized," based on the overall anatomical differences, one could predict the sex from the anatomy (but not the other way around). Thus, there are differences but there is no diagnostic anatomical feature that reliably indicates the sex of the brain. See the reply from Daphna Joel et al., "Reply to Del Giudice et al., Chekroud et al., and Rosenblatt: Do Brains of Females and Males belong to Two Distinct Populations?," *Proceedings of the National Academy of Sciences* 113, no. 14 (2016): E1969–E1970, https://doi.org/10.1073/pnas.1600792113.

[13]Alberto Frigerio, Lucia Ballerini, and Maria Valdés Hernández, "Structural, Functional, and Metabolic Brain Differences as a Function of Gender Identity or Sexual Orientation: A Systematic Review of the Human Neuroimaging Literature," *Archives of Sexual Behavior* 50 (2021): 3329–52, https://doi.org/10.1007/s10508-021-02005-9.

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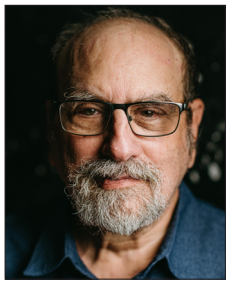

Sy Garte

Continuity, Simplification, and Paradigm Shifting in Biological Evolution

Sy Garte

The principle of continuity in evolution is often violated by discontinuous saltations leading to "punctuations" in evolutionary history. Highly accurate cellular replication fidelity is a requirement for biological evolution. In previous work, I have used a statistical theoretical model to demonstrate discontinuity in the evolution of high replication fidelity. Depending on the granularity of approach, both a continuous and a saltational view of evolutionary history are consistent with a scientific worldview of creation, and with the concept of simplification in biology as articulated by Emily Boring et al. The apparent contradiction between the complexity of biological systems with the idea of evolutionary simplification can be resolved by considering the globally simplifying selection of single systems and the local evolution of increasing system complexity. Explanations of thresholds and discontinuities during evolution might require the inclusion of paradigms such as teleology and agency in biological science, with theological implications.

Keywords: self-replication, discontinuity, convergence, teleology, teleonomy, agency, agonomy, origin of life

Continuity in Evolution

The role of continuity (sometimes referred to as gradualism) has been an important aspect of biological evolutionary theory since its inception. Charles Darwin famously wrote:

> If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down. But I can find out no such case.[1]

Eugene Koonin defined evolutionary continuity as the "general Darwinian principle … [that] evolution must proceed via consecutive, manageable steps, each one associated with a demonstrable increase in fitness."[2]

Continuity involves a process that progresses in steps, whereby each step produces a meaningful difference in an outcome compared to the previous step. Meaningful differences can be assessed statistically for measurable outcomes. Continuity can thus be determined by the smallest number of fixed-size steps that result in a statistically significant difference in outcome. If a large number of steps is required before a significant outcome difference is observed, then continuity is broken, and the best explanation is saltation. This approach was used in my previous work on discontinuity in replication accuracy.[3]

Evolution, including its detailed biochemical and molecular mechanisms, is a cogent, strictly biological theory that operates only in the biological world. If we examine the evolutionary history of

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life on this planet, we can see strong evidence for discontinuity at many points.[4]

The great paleontologist Stephen J. Gould proposed the concept of punctuated equilibrium based on fossil data. Gould and Niles Eldredge found many examples of long periods of slow or negligible evolution, interrupted (or punctuated) by dramatically rapid and unexpected leaps of sudden alterations, including the birth of new phyla.[5] "Sudden" here is, of course, meant in evolutionary time scales. Some of these leaps, or saltations, resulted, at least partially, from rare kinds of mutations, such as whole-genome duplications in the origin of vertebrates,[6] or from insertions of transposons as in the development of mammalian pregnancy.[7]

Even the origin of eukaryotes, which apparently happened through the endosymbiosis of energy-producing bacteria by larger cells resulting in mitochondria and chloroplasts, must be considered an enormous leap through discontinuous evolutionary space.[8] While such examples of discontinuity clearly contributed to the evolutionary history of life on Earth, they should generally be viewed as part of that history, along with simultaneous gradual changes. The complexities of evolution of plants and animals do not allow any single mechanism to entirely account for the enormous diversity of structural and functional characteristics of any form of biota.

However, all of these (and many more) discoveries of discontinuity in the large-scale evolutionary stage in biology did *not,* as Darwin feared, destroy the value of the theory of evolution by natural selection. Gradualism by itself is not a required feature for evolution to work, since we now know (as Darwin did not) the mechanisms required for the variation that evolution depends on, and there is no reason to exclude those mutations that produce rare and impactful changes in phenotype from the overall theory. Biochemical mechanisms for dramatic evolutionary changes have been elucidated by James Shapiro under the rubric of "natural genetic engineering,"[9] as well as by many biologists working in several newer fields of evolutionary biology called the "Extended Evolutionary Synthesis."[10]

Self-Replication

When most people, including most biologists, think about evolution, they generally start and finish with the Darwinian concepts of variation (gene mutations) and natural selection as the principle drivers of evolution. But there is another crucial component to the evolutionary process that is often overlooked, assumed, or taken for granted. That component, as Darwin well understood, is inheritance:

> But if variations useful to any organic being do occur, assuredly individuals thus characterized will have the best chance of being preserved in the struggle for life; *and from the strong principle of inheritance these will tend to produce offspring similarly characterized* (italics added).[11]

Evolution requires that alleles be inherited in order for natural selection to work. It is the inherited alleles that determine the phenotype, which is the target of natural selection. And, as we now know, inheritance is produced by the highly complex biochemical processes of cellular self-replication, which are unique to biological cells.

Only living cells can copy themselves with high accuracy. A factory can make thousands of identical widgets, but no widget and no factory has ever made even a single copy of itself. Crystals grow, but they do not copy themselves. No chemical, including DNA or RNA, can copy itself without help from a myriad of enzymes.

Each cell contains thousands of molecules: nucleotides, proteins, lipids, carbohydrates, metabolites, precursors, breakdown products, cellular structures, and organelles. When a cell divides, the two new cells contain copies of all these molecules, and each of the two new daughter cells is almost exactly the same as the parent cell.

In all of life there is a mechanism for the accurate replication of the genotype and a mechanism for the conversion of the genotype information into the phenotype. The central dogma of molecular biology states that only the genotype can be directly replicated, and only the phenotype can interact with the environment to allow for natural selection. (Of course, as in all of biology, no "dogma" is without exceptions, as epigenetics research shows in this case.) Genes made of DNA are not only replicated themselves, but they also code for the replication of

all the cellular constituents, including all the enzymes (proteins) and RNAs that produce other cell constituents. In modern cells, genes and (indirectly) proteins are replicated, with over 99.9999% accuracy.

Evolution by natural selection depends on this high degree of replication fidelity from a parent organism to its offspring. If this value were much lower, then errors could have the potential of not accurately copying and transmitting beneficial alleles to the offspring. At lower levels of replication fidelity, an "error catastrophe"[12] would affect many genes, and thus many crucial proteins, and lead to death. If life requires a very high replication fidelity in order to survive and evolve, we can ask how this extraordinary feature of all life came to be.

Discontinuity in Evolution of Self-Replication in Early Life

Given the enormous complexity of the systems required for accurate replication of all the cellular components, questions about the origin of self-replication are likely to be very difficult to approach. Rather than focus on the molecular biological details, or assume any hypothetical scenario for protolife, I decided to try to develop a theoretical and statistical model. The goal was to investigate whether the evolution of high replication fidelity could have followed the continuity principle.[13] The model deals with two critical biological features possessed by all living cells, and presumably by protocells at the origin of life as well: the probability of cell survival between cell divisions and the degree of fidelity of replication.

Using a Monte Carlo approach to convert probabilities into simulated experimental findings, I found that a measure of population survival, the growth rate constant K, was a function of the two parameters described above. Values of K greater than 1.0 will allow for expansion and survival of a cellular population, whereas growth rates below 1.0 lead to population extinction. Both simulation data and theoretical derivations produced a relation between growth rate, survival probability (P_s), and replication fidelity (F), given approximately by the formula: $K \approx P_s (1 + F)$. Details of the model and methodology are given in two papers.[14] The main conclusions were that, in early life, continuous growth of a population of protocells requires minimum threshold probabilities of both survival and accurate replication.

The evidence for phase transitions with thresholds below which improvement of either survival or replication fidelity by evolution is not possible are consistent with saltation rather than a continuous, gradual process. Once these probabilities surpass the thresholds in the development of replication fidelity and survival, evolution to the very high levels of both parameters that we see in all modern life is possible, and in fact inevitable, by continuous evolution.

Biological Evolution as Simplification

In an article published in *PSCF* by Emily Boring, Randy Isaac, and Stephen Freeland, the case is made for life being a simplification of the nonliving universe.[15] This might at first appear to be counterintuitive and opposite to what most biochemists and molecular biologists would think. Every advance in understanding the detailed mechanisms by which living cells operate seems to point to a fractal-like picture of ever-increasing complexity at every scale of organization. Systems biology, neuroscience, and gene regulation are some of the areas under intensive study that exhibit astounding levels of complexity.

Yet, with further thought, I believe that there is truth in the simplification view, especially in the "filtering" or focusing sense that was stressed in the article.[16] Of all the possible genetic codes, there is only one (with a few very minor exceptions). Of all the possible mechanisms to translate the information in the DNA to make proteins, only one exists. The same is true for many of the basic required cellular systems in modern biological life. This narrowing down to one single system is probably traceable to, and helps support, both common ancestry and a selective mechanism for weeding out less efficient or reliable alternatives. The complexity of the successful systems is beyond controversy, but the biological process of selecting single complex systems is clearly a process of simplification to the best scenario. Perhaps one way of approaching this is to recognize that what biology does is simplify the possible collection of complex systems, resulting in simultaneous global simplification of systems with locally increasing complexity.

Simplification and Continuity

Both increasing complexity of systems and simplification by reduction of the number of systems can occur either by a continuous process of natural selection of variants, or by rapid saltations that are also selected for.

As an example of the latter, the discontinuities or phase transitions in the history of evolution may be directly related to the simplification process proposed by Boring, Isaac, and Freeland.[17] They represent barriers or roadblocks to straightforward, gradually improving solutions to biological problems in the course of evolution. In the case of high-accuracy self-replication, early life was faced with an almost insurmountable problem: how to replicate all the phenotypic components of a cell to allow for the inheritance required for evolution. The solution was the highly complex protein synthesis system, including a replicable information storage molecule (DNA) containing the information in the form of the genetic code to reproduce each of the enzymes necessary to create the phenotype. Once this system came into existence, evolution could proceed, and every living creature uses the same system.

It has been suggested that at one time there may have been other genetic codes, other protein synthesis systems, and only the most successful one survived in a standard evolutionary process. While this is certainly possible, an alternative view is that the difficulty in passing the self-replication barrier might have severely restricted the number of times such systems could arise. For example, the genetic code requires the simultaneous presence of aminoacyl-tRNA synthetases, tRNAs, transcription of DNA to mRNA, the ribosome, and a host of enzymes and other components. Therefore, when any working solution did arise, it became the universal process in all of life. Further refinement of the system then could occur through a gradual evolutionary process.

We can see something similar in many other examples of discontinuity in biology. The problem of survival in an increasingly toxic oxygen atmosphere was resolved by the saltation of endosymbiosis, whereby a cell engulfed an oxygen-metabolizing bacterium alive, which then allowed the cell to use the toxic gas to perform energy conversion far more efficiently than the original anaerobic creature could. Much later, the appearance of the vertebrate body plan followed a rare whole-genome duplication mutation event that allowed for the four-limbed bilateral body plan, which remained universal in all land animals.

An additional mechanism that clearly contributes to simplification during evolution is the process of convergence,[18] wherein common evolutionary pathways and solutions for specific problems are found in diverse phylogenetic branches. The evidence for this (including the degree of continuity) is found in multiple systems (the vertebrate eye, radar and sonar, flight using wings, and so on) that evolved independently in different phylogenetic lineages.[19]

A major biological innovation in this category was the origin of multicellularity. This required a difficult transition of cells from being independent units susceptible to all the rules of natural selection and individual fitness, to becoming parts of a greater organism whose fitness overrode that of the individual component cells. While an in-depth understanding of this major transition (including the degree of continuity) remains elusive, it apparently occurred at least twenty different times in early evolutionary history, and some postulate a fairly simple mechanism to explain its widespread occurrence.[20]

Contrary to the traditional neo-Darwinian gradualist view, these findings suggest a nonrandom direction in evolution and possibly the existence of unknown laws that can account for the constraints seen in the data (see below). It is notable that while operating with different mechanisms, the end result of convergence is the same—increasing simplification by constraining possible outcomes to a smaller set than might be expected.

Discontinuity and "God of the Gaps"

Saltational events should not be seen as leaps over "gaps" in what is known as a "God of the gaps" argument. In some cases, these unexpected punctuations in the process of evolution may be explained simply as rare events that needed to happen only once to have dramatic effects on the history of life. In many cases, detailed mechanisms for these events are known.[21] In other cases, including such phenomena during the origin of life as the development of high-accuracy self-replication, our level of ignorance

is more profound. Stating that these kinds of gaps imply a divine intervention or the work of a designer does little to address the scientific issues involved.

Need for Paradigm Shifts in Biology

As happened with physics starting in 1905, we may be seeing for such biological problems a need to employ new kinds of methods, new perspectives, and perhaps to bring back some concepts that might have been prematurely expelled from biological thought. As I have previously written,[22] teleology is one prime candidate for such a banished concept. Another is agency. To be clear, I am not advocating for "bringing religion" into science—these ideas have been put forth by nontheist biologists such as James Shapiro and Denis Noble.[23]

Teleology and agency are everywhere in biology.[24] Both terms have several definitions. Ernest Mayr has used the term "teleonomy" to mean purpose conveyed by a program rather than a conscious agent as the best way to describe biological teleology.[25] I have previously noted that the complex biochemical systems that had to be present in the first protocells in order to allow for the origin of evolution are a sign of teleological processes at the dawn of life.[26] There is also strong evidence that agency can be found throughout biology. While I am not aware of a suitable term to refer to unconscious agency (analogous to teleonomy), clearly such a term would be helpful. I would propose "agonomy" and the nonconscious agent (such as bacteria, plants, or primitive animals) as "agonomists" (from the Latin *agere*—to act).

Under stress, bacteria undergo directed hypermutation, a process whereby specific parts of the genome, for a limited time, experience a drastic increase in replication errors, leading to an increased chance of producing specific mutations to alleviate the danger of population collapse due to severe stress such as starvation or exposure to toxicants.[27] These experimental findings are backed up by theoretical treatments of the role of replication fidelity and survival probability in extreme stress.[28]

Teleology and agency are undeniably part of life, and they appear as indispensable to an understanding of evolution. Asa Gray and Darwin himself considered teleology to be part of the beauty of the evolutionary theory,[29] as attested to by the following quotes. Gray wrote about "… Darwin's great service to Natural Science in bringing back to it Teleology: so that instead of Morphology *versus* Teleology, we shall have Morphology wedded to Teleology."[30] According to Francis Darwin, his father Charles quickly responded to Asa with, "What you say about Teleology pleases me especially and I do not think anyone else has ever noticed the point.[31]

However, in the decades following, and especially with the modern attempt to divorce any semblance of vitalism, religious connotation, or anything other than strict reductionism and materialism from the science of biology, all hints of such things as purpose and agency have been expunged from scientific vocabulary related to biology, more so than for any other (perhaps less defensive) scientific field. Throwing out the baby of teleology along with the bath water of unscientific metaphysical ideology has been, in my view (shared by many such as Haldane, Mayr, and Dennett), a terrible mistake. Biological agonomy does not mean that (for example) bacteria decide based on free will to hypermutate; the hypermutation reaction is built in by standard evolutionary mechanisms and the process of natural selection to increase survival probability in the face of severe stress. But it remains true that bacteria act.

By the same token, denying that animals and plants act with purpose, or that the function of an enzyme is devoid of purpose is, to me, the essence of denial of the reality of existence. As stated above, bringing teleology and agency back into biological theory is not an attempt to shove the camel's nose of design or creationism into the tent, but a much-needed solution to a fuller understanding of how life works and evolves.

The Theology of Paradigm Shifts

Many of the phenomena that I have labelled as discontinuous (for example, endosymbiosis, multicellularity) are used as examples of continuity in another article by Boring, Stump, and Freeland, who proposed that evolutionary continuity is a fundamental principle in the universe that can be applied to all emergent phenomena since the big bang, including life and consciousness.[32] These authors were focused on how "viewed in this manner, abiogenesis becomes just one more subjectively chosen point on a continuum that now stretches back to the origin of the universe."[33]

This view of overall continuity in the history of our universe employs a different meaning of the word compared to my own discussion of continuity restricted to an evolutionary mechanism implying gradualism. One way to think of the difference is in the granularity of our respective perspectives on change. The unfolding of God's purposes may indeed be seen in the coarse-grained, overall, continuous process of change in the cosmos, the galaxy, and the origin and evolution of life on Earth.

My point is that a more fine-grained examination of biological origins and evolution reveals striking discontinuities that require scientific explanation. Unlike some intelligent design advocates, I do not see these phenomena as direct evidence of divine miracles, places where God steps in to correct or revise his original creation. Instead, I see them as opportunities to search for new laws and new paradigms that will ultimately bring us closer to understanding divine creation as a whole.

Findings of science that are consistent with a divine Creator have historically followed major paradigm shifts and the application of novel scientific approaches or methodology. These include the discoveries of natural laws governing the physical world that came with the new experimental approaches of methodological naturalism (the scientific method); the awareness of the majestic size of our universe following the use of telescopy; the appreciation of the wonders of the living world following discoveries in the new fields of physiology, microscopy, and biochemistry; the sense of overarching mystery about the nature of the universe following discoveries in physics using new mathematical and theoretical approaches in relativity and quantum mechanics; and the finding that the universe, as stated in Genesis, did indeed have a beginning and was not past-eternal—that is, this same idea of a "beginnning" also followed from the new theoretical and experimental physics, as did the discovery that many cosmological constants appear fine-tuned to allow for the kind of universe we see.

Perhaps the time has come for the science of biology, like the science of physics, to accept some new scientific perspectives in order to make further progress in areas where breakthroughs appear to be needed, such as the origin of life, the understanding of unknown biological laws that may be responsible for convergence in evolution, the nature and origins of consciousness, the mechanisms of gene regulation, and others.[34] It is my belief that, as in the past, such new understanding will serve as an inspirational pointer to the majesty of the divine Creator. Both teleology (or teleonomy) and agency (or agonomy), two potentially useful new paradigms for a new scientific philosophy of biology, are also of major theological and philosophical significance, as related to divine purpose, human free will, and determinism. Like teleology, agency is in general rejected by current science as part of natural law; this rejection is appropriate for the behavior of molecules and physical objects. But humans as well as animals (even plants, bacteria, and cells) make decisions and act, using either conscious will or biochemical receptor and effector systems. We are agents with purposes, as is the original Agent who created the universe, the Lord God.

Biology is a wonderful science, but, as the study of all aspects of life, it is also more than a scientific discipline—it is a window into something beautiful and transcendent in our universe.[35] It needs to be explored with every tool given to us by our Creator. Adam was given the task of naming the animals. We, his descendants, have the task of learning all we can about God's gift of life. ▼

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Stephen M. Contakes

Call for Papers

Chemistry to the Glory of God?

Stephen M. Contakes

Call for Papers

Readers are encouraged to take up one of the insights or questions in the following invitation essay and its extensive endnotes, or maybe a related one that was not yet mentioned, and draft an article (typically about 5,000–8,000 words) that contributes to the conversation. These can be sent as an attachment to scontakes@westmont.edu. An abstract should be included in the text of the email. The best essays will go on to peer review and the potential for publication in a chemistry theme issue of *Perspectives on Science and Christian Faith,* or independently in a variety issue of *PSCF.*

The lead editorial in the December 2021 issue of *PSCF* outlines what the journal looks for in the articles we publish. For best consideration for inclusion in the theme issue, manuscripts should be received electronically before February 28, 2023.

Looking forward to learning from your contributions,

James C. Peterson, *Editor-in-Chief*

Keywords: chemistry, Call for Papers, creation, *imago Dei*, created co-creator, theology of chemistry, natural theology, technology, social justice, pollution, ethics of chemistry, risk, responsibility, history of chemistry

Chemistry is sometimes defined as the study of matter and its changes, which, in a certain sense, means the study of everything material since all physical objects and materials, including ourselves, are made of chemicals. More precisely, chemistry is the study of matter and its changes at the level of atoms, molecules, and ions, composed of their next-lower-level components, protons, neutrons, and electrons. In this sense, chemistry is both reductionist and antireductionist; it seeks to reduce things to the atomic and molecular level but no more. This way of thinking about matter allows chemists to reason both "bottom up"—that is, starting from atoms and molecules—and "top-down"—that is, figure out things about atoms and molecules starting from what a larger system is like. To do this well, chemists translate the insights of physics into models of atoms and molecules that are useful for solving chemical problems, of which there are many in the biosciences, geosciences, and numerous branches of engineering. Because it links so many sciences together in this way, chemistry is called the central science.[1] Chemistry is also sometimes called an impure science, since chemists do not only seek to understand matter but also to manipulate it for useful ends.[2] In this, it has been remarkably successful. Because of its impact on agriculture, industry, medicine, and many other aspects of human culture, chemistry is also the workhorse science of what has sometimes been called the chemical age.[3]

Given chemistry's outsized impact, it would be reasonable to expect chemistry to loom large in discussions about science and Christianity. Nevertheless, with the exception of conversations involving origin of life and evolutionary biochemistry, the chemical sciences have played only a peripheral role. That such a societally influential and theologically relevant discipline has received so little attention is a topic worthy of careful consideration.

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What might the vast gap between chemistry's importance to society and Christian thinking indicate? Does it reflect sober judgment or inadequate views of science, Christianity, and the relationship between the two? Has the science-Christianity dialogue been well served by focusing on fundamental physics, biology, and neuroscience to the exclusion of chemistry? Or, putting things more positively, might anything be gained by bringing more chemistry into the conversation?

This essay is a call to explore how the chemical sciences might contribute to the science-Christianity conversation. Specifically, it solicits papers for a theme issue addressing the chemical enterprise and Christianity. To encourage an appropriately broad set of perspectives, the chemical sciences envisioned in this call for papers encompasses biochemistry, chemical engineering, chemistry, geochemistry, materials science, molecular pharmacology, polymer science, engineering, and other disciplines which employ atomic-molecular views of matter to comprehend and transform the material world. Similarly, since the relationship between chemistry and faith does not occur only at the level of conscious thought, the Christian faith envisioned in this call for papers includes background assumptions and clearly stated tenets of faith; it is intellectual, affective, and effective; and it is present-focused and resurrection-looking. So, contributions may address how any aspect of the chemical enterprise relates to Christian thought, practices, affections, spirituality, or any other aspect of Christianity, broadly defined.

As a help to potential respondents, the remainder of this essay will seek to sketch a selection of opportunities and challenges raised by chemistry.[4] Some of these are related to chemistry's understanding of matter and technologically promising avenues of chemical research such as solar energy conversion, green chemistry and engineering, gene editing, or efforts to develop new materials, therapies, diagnostic tools, and other products. Equally important, though, are issues associated with what chemists do and humankind's use of chemicals, things such as risk, responsibility, and chemistry's role in shaping both society and Earth's environment.

To get the conversation started I will point out a few reasons why Christians should care about the chemical sciences. Here I will try to explain what chemistry is, what chemists do, and how Christians have thought about the chemical sciences in the past, as well as to outline some of the theological and moral terrain that Christians might have to navigate. The idea is to raise questions and suggest perspectives that respondents might develop or challenge. Periodically, I will also note thorny issues or contributions that might be helpful. Other types of contributions would also be welcome.

God Values the Matter That Chemistry Studies

There is a need for theologies of chemistry that are robust enough to address the opportunities and challenges associated with chemicals.[5] In the interim, I suggest that the theological context of chemistry involves what matter is, what humans are, and what humans are called to do. Of these, Christianity teaches that God made, values, and has a purpose for matter. The preeminent example of this is the Incarnation, although throughout the scriptures matter is presented as a sovereign creation of the triune God, subject to God's care, a theater for God's encounter with humankind, a locus of right worship and malformed worship (including in our bodies), good (rather than something we are called to escape from), and something for which God intends fruitfulness. In the Genesis creation account alone, God is portrayed as ordering an originally formless and void creation, which, at times, responds by bringing forth new structures in the form of things such as plants and various creatures. This suggests a creation under God's care and control, developing its God-endowed potentialities and experiencing fruitfulness as it responds to the call of its maker, bringing forth a good, well-functioning creation.[6]

Christianity also values how we live out our embodied existence in a material world. Again, in the Genesis account, God's final creative act is presented as involving special intimacy (the breath of God) to give God's own "image" and "likeness" (*imago Dei*). Although a number of implications of this *imago Dei* have been proposed, the passage's immediate context suggests that humans are created co-creators[7]—that is, they are to reflect and represent a creative God who lovingly works with creation to order it, in part by bringing out matter's potentialities in ways that help make creation fruitful and function properly.[8]

Christians Are Called to Use Matter for God's Glory

The created co-creator concept would seem to validate the legitimacy of chemistry; chemists reflect something of God as they work with creation's potentialities to order matter in new ways.[9] The so-called culture,[10] stewardship,[11] and labor mandates[12] of the Genesis creation and Fall accounts (along with other passages) further develop what humans are generally called to do, how they are called to do it, and why. Humans are called to reflect God's care for creation as they fill up and lovingly govern the earth. Nevertheless, theirs is a delegated government. Humans are not to rule over creation recklessly or exploitatively as free agents. Rather, they are stewards called to govern in ways that recognize creation as God's and for God's glory.

The primeval history of Genesis 1–11 indicates that both our government of creation and the potentialities we are called to develop involve technology-infused culture building—with agriculture, animal husbandry, city building, metallurgy, and music mentioned directly.[13] Nevertheless, this does not mean that technology is presented as wholly salutary or unproblematic. It is alternatively associated with sin (for example, Adam and Eve's fig leaves, Noah's wine) and God's gracious provision for humankind (God's coat of animal skins, Noah's ark). That arts such as metallurgy are presented as derived from the ungodly Cainite line problematizes the possibility of achieving shalom through technology alone. This point is forcefully brought home in the development of novel brickmaking materials as an occasion for the rebellious building of the tower of Babel.[14] Outside of the primeval history, the biblical narrative repeats this pattern of matter as a potential locus of idolatry, worship, and God's provision for humanity through accounts such as the de-bittering of the water at Marah,[15] and the making of the golden calf, the tabernacle, and the bronze serpent until God's ultimate verdict is reached. In the Incarnation, Christ embodies, works with, and transforms matter in ways that demonstrate God's intention for human stewardship of the material world.

Thus, a distinctly Christian approach to chemistry will recognize the church's role in demonstrating the self-emptying and reconciling love of Christ to all creation as embodied materially in Christ's earthly ministry, death, and bodily resurrection and proclaimed by believers both verbally and through such activities as water baptism, the breaking of bread, and material acts of love. Within this context, distinctly Christian approaches to chemistry involve pursuing Christlike relationships of reconciliation, flourishing, and shalom throughout creation.[16] To do this well, it can be helpful to understand how creation works at the atomic and molecular level. This is a powerful reason for Christians to pursue the study and practice of chemistry.

In this respect, Christians should care about chemistry for the insights it brings into the nature of the material cosmos. Through modern chemical theories and a host of spectroscopic, crystallographic, microscopic, and wet chemical methods, chemists have gained a remarkably detailed understanding of what matter is like at the molecular level. This is true about molecules individually and about how molecules work in concert with one another as part of larger systems. These larger systems do not involve only things such as rocks, minerals, liquids, and gases, or even a chemical reaction taking place in a single flask. Chemistry works in concert with disciplines such as astronomy, engineering, and the geological, biological, and materials sciences to explain how everything from individual bacterial cells to entire planets work. Therefore, chemistry can provide insight into God's wisdom and power in creation at multiple levels.[17]

Further, chemistry remains a vibrant field of work, pregnant with possibilities for us to grow in our understanding of atoms, molecules, and how they work together.[18] With chemistry's success has come a growing awareness that only a small portion of the possible structures and reactions available to molecules has been explored. There is also a need to apply chemical theories and tools to ever-larger and more-complex living, environmental, supramolecular, nanoscale, and bulk materials and other systems, as well as to problems in molecular biology, biotechnology, and medicine, including rational drug design.

Chemistry Discloses God's Wisdom and Power in Creation

Chemistry does not seek to answer theological questions. Nevertheless, chemistry's insights into the atomic- and molecular-level workings of nature contribute to natural revelation, that is, what can be known about God through nature. In addition,

chemistry's picture of atoms and molecules, working in accordance with the principles of electromagnetism, quantum mechanics, and thermodynamics, is part of the cultural toolkit contemporary people use to think theologically. Chemistry influences how Christians think about God creating and acting through creation, how we encounter God in creation, what humans are, and how to live in accordance with what Christians are called to do. In this respect, chemistry helps inform conversations about issues such as origins, divine action, miracles, natural evil, free will, and similar topics, even when it is not a conscious lens through which these concerns are viewed. Equally, if not more importantly, chemistry helps shape how we think about things such as Jesus's Incarnation, death, and resurrection; the mission, calling, and worship of the church; our own hoped for bodily resurrection; and the life of the world to come.

The question of exactly how chemical knowledge currently affects Christian thinking has not been rigorously explored. Nevertheless, there are several clear indications of science's influence in this area. Unlike ancient and medieval believers, Christians today find the idea that matter is made of atoms theologically uncontroversial[19] and use various hermeneutical moves to interpret scriptural passages that employ classical matter concepts. Examples include passages that speak of the world being formed of water, and of resurrection in terms of "earthly" and "heavenly" bodies. It is also clear that contemporary physics has had some influence on Protestant views of baptism and other bodily aspects of Christian living and worship.[20]

Nevertheless, the best-documented cases of natural philosophy influencing the articulation of Christian doctrine do not involve modern chemistry but the role of Aristotelian, stoic, and other classical ideas about matter in late-Medieval Europe. During this period, classical matter theories were used to explain seemingly miraculous events, distinguish between legitimate miracles and diabolical activity, and explain the then-recently ratified doctrine of transubstantiation.[21] Particularly notable was Thomas Aquinas's effort to use Aristotelian matter theory to reconcile the Roman Catholic doctrine of Eucharistic real presence. For Aquinas, the Eucharistic bread and wine could transform into the body and blood of Christ while remaining materially indistinct from ordinary bread and wine because the change occurred at the level of Aristotelian substance, distinguishing what something is, from what it appears to be.[22] The medieval and early modern periods also witnessed the development of what have been called prophetic or visionary alchemical traditions in which alchemical transformations came to be viewed as parallel to Christian truths.[23] Eventually, early-modern alchemists such as Jan Baptist van Helmont[24] would seek divine illumination through the practice of chemistry, a quest echoed weakly in Robert Boyle's understanding of chemistry as priestly service in the temple of nature.[25]

The most prominent influence of chemistry on recent Christian thinking involves natural theology arguments intended to address materialist conceptions of reality.[26] The use of chemistry in this fashion can be traced to one of modern chemistry's principal founders, Robert Boyle.[27] Boyle not only looked to chemistry as a source of natural revelation, but he and contemporaries such as John Ray also advanced the idea that nature demonstrates God's existence and power.[28] Partly through the influence of annual lectures, financed by Boyle himself, Christian thinkers began to construct increasingly powerful and sophisticated arguments advocating for this "physico-theology." At first, these mainly employed examples from physics and biology, although since the nineteenth century, they began to include examples from chemistry, biochemistry, and geochemistry, too.[29] Then as now, they were nominally aimed at convincing unbelievers, but they also served to encourage the faithful.[30]

The flexibility of Boyle's natural theology program meant that it could be used to support a variety of orthodox and heterodox theological views, including deism among those who were willing to reject or reinterpret revealed theology. Interestingly, Darwin's problematizing of the biological design-based natural theology arguments that had become common by the early nineteenth century, contributed somewhat to a resurgence in chemistry-based design arguments. These often focused on various aspects of biogeochemistry (often with a special focus on water) and are somewhat akin to modern arguments that point to anthropic coincidences, although at least one also relied on methodological parallels between theology and science.[31] From the nineteenth century until today, they have been used to support a variety

of theistic antievolutionary, theistic evolutionary, and naturalistic positions.[32]

The late-twentieth century also saw the rise of various "creation science" and intelligent design movement arguments that broke from the tradition of offering well-attested science as evidence for God's wisdom. The most notable of these involved the efforts of the young earth creationist biochemist Duane Gish and the intelligent design movement biochemist Michael Behe, who argued that chemistry challenged accepted evolutionary and origin-of-life science.[33] Among these, Gish's use of chemistry was somewhat limited by his tendency to "gallop" through a range of arguments, most of which had little to do with chemistry.[34] Behe[35] (and to a lesser extent, other intelligent design movement biochemists such as Michael Denton[36]), however, offered elaborate arguments purporting to demonstrate that structural biochemistry contra-indicated naturalistic evolutionary accounts of life's development. So far their proposals have yet to find acceptance among the scientific community, even after extensive criticism and debate.

Papers addressing chemistry-based natural theology arguments could contribute productively to a theme issue devoted to chemistry and faith in several ways. New chemistry-based natural theology proposals would be welcome, as would critical analyses of existing proposals: for example, those in the recent intelligent design movement and old earth creationist literature;[37] Alister McGrath's argument that origin-of-life chemistry aligns with Augustinian ideas of creation as containing potential for development (logical seeds);[38] and arguments that the properties of atoms and molecules are echoes of the Trinity in nature.[39] Two approaches, in particular, have received surprisingly little attention. The first involves alignment between the chemistry's picture of probabilistically moving[40] atoms, molecules, and ions reacting and self-assembling to give larger structures and biblical themes of creation involving the ordering of chaos.[41] This theme (sans its probabilistic aspect) was prominent among the followers of Paracelsus, who even interpreted Genesis in terms of God acting as a synthetic chemist to order matter in creation.[42] The second approach involves natural theologies based on the existence of beauty in nature, which could align with contemporary chemists' propensity to talk about beautiful molecules, elegant syntheses, and otherwise to use aesthetic language. Some of the necessary groundwork for a chemical natural theology of beauty has been done by Timothy Weatherstone,[43] although little has been done to follow up on his proposal, even by way of critical analysis. Finally, there is also a need for reviews of the relevant background literature at a level suitable for a general science and faith audience. Tutorial reviews[44] that present the state of the origin of life, evolutionary biochemistry, geochemistry, supramolecular chemistry, and similar fields relevant to these natural theologies might be particularly valuable, as would reviews which summarize historical and social science analyses of chemistry-based natural theologies.

Chemistry Is an Opportunity to Live and Love Christianly

It is difficult to overestimate chemistry's impact on human welfare. Chemical technologies contribute to human health and welfare in so many ways[45] that a recent *Bloomberg Businessweek* editorial declared "we are well past the Stone Age, the Bronze Age, and the Iron Age, and into the Everything Age, because almost every entry on the periodic table is being put to some kind of use in today's economy."[46] According to the American Chemistry Council (a chemical manufacturers' association), over 96% of manufactured products are "directly touched by the business of chemistry."[47] Without Fritz Haber and Carl Bosch's development of industrial nitrogen fixation, it would be impossible to feed everyone alive today.[48] The US chemical industry alone[49] employs approximately 529,000 workers, and almost half of US chemists and materials scientists (49%) are involved in either manufacturing (33%), testing (11%), or administrative services such as waste management (4%), a total over three times larger than the number involved in basic research (14%).[50] Worldwide, the chemical industry consumes approximately 6.6% of the world's energy[51] while its direct products and precursors—that is, chemicals, minerals, and petroleum—together account for 21.4% of world trade.[52]

Historically, the largest uses of chemicals have been associated with agriculture (sulfuric acid, nitrogen, ammonia, nitrates, urea, and phosphoric acid), steel manufacture (through the oxygen used in smelting), polymers, detergents, dyestuffs, construction (cements), and chemicals used to make other chemicals (hydrogen, chlor-alkali products, etc.).[53] In

addition, chemical know-how is important for the production of pharmaceuticals, structural materials such as cement and concrete, protective coatings such as paint, cosmetic chemicals and disinfectants, pesticides and herbicides, fuels such as coal and petroleum, plastics,[54] and many other things, including virtually every part of the electronic devices which characterize contemporary life. Chemistry also contributes to human and environmental welfare by means of the application of electrochemical sensors, instruments, and wet chemical analysis to medicine, agriculture, industry, public health, and safety. Chemical scientists have revolutionized how we monitor human and animal health, track pollutants, ensure the safety and efficacy of numerous products, solve crimes, and detect medical and environmental problems wherever they occur.

That such an influential enterprise presents numerous opportunities for Christian service has long been recognized, despite Tertullian's early objection to synthetic dyes and recurring fears that (al)chemists were inappropriately altering nature.[55] Alchemy was a recognized pursuit in Byzantine and Latin Christendom, the latter especially after the recovery of Greco-Roman learning in the high Middle Ages. Many monks pursued alchemy,[56] and it proved a fit object of discussion for such luminaries as Albert the Great,[57] Robert Grosseteste,[58] and Roger Bacon.[59] Bacon even advocated alchemy as a promising source of wealth and human longevity both of which he considered important for the welfare of Christian Europe.[60] Later, the protestant reformer Martin Luther, who saw ordinary work as a Christian calling,[61] expressed appreciation for alchemy in part "for the profits it brings in melting metals, in decocting, preparing, extracting, and distilling herbs, roots."[62] For the early industrial chemist Johan Glauber, chemistry was a way to fulfil the golden rule, specifically by seeking others' welfare and prosperity.[63] Recently, the Roman Catholic Pontiff listed the chemical industry among the technological advances produced by "God-Given human creativity" about which "it is right to rejoice" and "be excited by the immense possibilities which they continue to open up."[64]

Today, chemists have a wealth of opportunities to follow Glauber as virtually every aspect of the chemical enterprise can be used to promote human welfare in some fashion. Nevertheless, as this issue has received little attention in the recent literature,[65] there is a pressing need for articles that explore how Christians might promote human welfare through chemistry, both in terms of providing general frameworks and an analysis of particular opportunities.

Early Christian medicinal chemists such as Paracelsus and Jan Baptiste van Helmont viewed their work as a holy calling; Paracelsus even considered Christlike love the "bedrock of medicine."[66] So, articles that explore chemists' efforts to promote human health through new pharmaceuticals and other therapies (including the recently developed mRNA vaccines), clinical analyses, and investigations into biochemical pathways of disease, would be welcomed, as would contributions addressing the role of chemistry in advancing public health through the monitoring of air, water, food, and consumer products.[67] Here there is precedent in Michael Faraday's efforts to improve water quality in the Thames, which seem congruent with his theology. For Faraday, since humanity was important in God's plan, science should be used for human betterment.[68] A more complicated example involves the chemist-physician Harvey Washington Wiley's efforts to curtail the use of toxic additives in the food and drug industry, although the fruits of his efforts are more controversial and the relationship between his mature religious beliefs and chemical work is less well explored.[69]

Chemistry is an important science for environmental stewardship. In addition to the traditional environmental monitoring and modelling work, chemists are addressing the need for a more sustainable and environmentally friendly chemical industry[70] through research and development work in green chemistry, renewable energy, carbon capture and storage, and similar fields. The 2015 Papal Encyclical *Laudato Si'*[71] addresses specific problems associated with chemical pollution and the use of fossil fuels, while the Greek Orthodox Church called on both researchers and governments to develop technologies aimed at alleviating environmental and agricultural problems.[72] There has also been considerable theological reflection on geoengineering (which includes carbon capture and storage) as an effort to deliberately alter climate (as opposed to incidentally affecting climate through pollution).[73] There has been much platitudinizing about green chemistry as an opportunity for Christians in chemistry to live out their faith, along with a few substantive articles arguing that the twelve principles of green chemistry and

engineering[74] are broadly congruent with Judeo-Christian productivity stewardship approaches to the environment.[75] Otherwise little effort has been made to explore how Christians might care for creation through green chemistry, despite long-standing Christian approaches to creation care[76] and development.[77]

Chemists also have opportunities to promote societal justice, either indirectly through caring for the environment or directly by seeking to advance human economic wellbeing.[78] There is a need for contributions that examine some of the recently identified opportunities[79] in the context of Christian teachings.[80] There is also a need to address the disproportionate harms that low-income communities and people of color experience[81] through fossil fuel burning,[82] chemical manufacture,[83] pesticide exposure,[84] and personal care product endocrine system disruptor exposure.[85] As the value of technological know-how[86] and Christian engagement in addressing chemistry-related issues of social justice are both well documented,[87] there is a particular need for contributions that suggest concrete ways in which Christians might leverage chemistry's ability to help address these issues.

Christians should also care about how chemical technologies advance or impede justice globally. Chemistry provides enormous opportunities for Christians in the sciences to improve human flourishing on a global scale. Through the development of chemical fertilizers, essential medicines, refined fuels, hygienic plastic objects, inexpensive fabrics, colorful dyes, and other medical, dental, energy, and commercial technologies, chemistry has done much to bring wealth and wellness to communities worldwide. Christians in chemistry can contribute to these efforts as well as address some of the ways chemistry's benefits and harms have been distributed unequally and unfairly. These include how chemical products have not always been made available to the communities that most need them[88] and how the harms of chemistry sometimes fall unevenly on the poor.[89]

Even when there is an effort to meet the needs of developing or marginalized communities, injustices can occur when the actual needs and contexts of the recipients are not thoroughly considered. In the 1986 Bhopal disaster, several thousand poor squatters were killed by the unimpeded release of toxic methyl isocyanate gas from a pesticide precursor plant that was built by Union Carbide to support Indian agriculture. Although both the cause and impacts of the disaster have been disputed, a failure to consider how North American plant design and operations principles might apply in an Indian context appears a contributing factor.[90] A more mundane but insidious example involves the increased toxin exposure that results when chemical technologies are transferred to developing nations without adequately addressing issues of pollution control and environmental monitoring.[91]

It is also likely that there are disparities in chemical research and development funding similar to the 10/90 gap, whereby only 10% of disease research funding is directed toward the diseases that most affect 90% of the world.[92] To my knowledge, none of these issues has been addressed in the science and faith literature. Perhaps the recent application of Roman Catholic social teachings to the 10/90 gap might provide a model for respondents to consider.[93]

Chemistry contributes to corrective justice through forensic chemists' everyday analysis of crime lab samples and analytical methods, such as DNA sequencing methods that allow for the high-fidelity identification and exoneration of suspects. Through these, chemists help keep people safe, and they advance or impede the conceptions of retributive and restorative justice embodied in legal systems. This work is extremely morally demanding, with bachelor degree-level forensic chemists placed in an "adversarial, crime-fighting culture" in which they "are tempted, many times in their career," to data fudging and fabrication.[94] Contributors might address how the church can support those engaged in forensic work. However, given the role played by reckless analytical practices and lax oversight in the Patricia Stallings and Annie Dookhan scandals,[95] contributors could also consider how Christians might promote more rigorous, truth-oriented, and humane standards in the forensic chemistry field.

Christians can also contribute to cultures which promote justice and equity within the chemical enterprise itself. This is particularly true with respect to longstanding issues associated with chemistry's self-image as the "marines of the sciences," which has been used to justify "weed-out" introductory

chemistry courses and academic research cultures that are so grueling, exclusive, exploitative, and otherwise psychologically and personally costly as to drive people from the profession.[96]

Any assessment of chemistry's potential to promote shalom should account for the reality of human fallibility and sin. The twentieth century presents clear cases of chemists and the chemical industry acting to advance parochial self-interest as even the best-intentioned efforts can go awry through chemists' inability to foresee unintended consequences or control how their work is used. Between excitement over the potential utility of new discoveries and the need for funding,[97] there can be a tendency to make overinflated claims. For instance, after nanotechnology was touted as a way to alleviate poverty and injustice, more sober analysts pointed out that it would be more readily available to the wealthy than to the medically, economically, and militarily vulnerable.[98]

Chemistry Is an Opportunity to Develop Appropriate Theologies of Risk

The realization of the intellectual and practical benefits of chemistry requires the stewardship of massive human, financial, and other resources as well as the management of risks. To do this well requires a great deal of discernment among the individual chemists, research teams, corporations, and governmental agencies involved in the discovery, development, manufacture, transport, storage, use, regulation, and monitoring of chemical technologies. So while contributors might address publication ethics and other professional norms,[99] it is perhaps even more vital to address the social responsibility of chemists and the consequences of public policy involving the risks of chemistry.[100] Although these present opportunities for Christian prophetic witness, many otherwise insightful writers have either avoided chemical use entirely, misrepresented the chemistry involved, or offered the sort of ill-informed blanket condemnation that is likely to alienate those who would most benefit from their message.[101] Consequently there is a need for both original chemically and theologically informed analyses of the social and ethical dimensions of chemistry and critical analyses that correct or strengthen existing analyses. A recent survey of the climate impacts of human energy use might serve as a useful model in this regard.[102]

The effective stewardship of chemistry requires the management of risks. That chemistry involves risk is powerfully illustrated by the chemical disasters of the twentieth century, which featured several instances in which a miracle chemical was later found to be an environmental disaster. Of these DDT is the best known. Originally lauded for its role in the eradication of disease, it was used carelessly for nearly 20 years and banned only after Rachel Carson highlighted its deleterious environmental impacts.[103] Chlorofluorocarbon refrigerants experienced a similar fate: until they were found to be responsible for the Antarctic ozone hole, they were hailed as safe replacements for earlier toxic refrigerants.

There is also a need for theologies of risk that address the range of concerns and cases articulated in the recent ethics of chemistry[104] and chemical risk-management fields.[105] One way forward might be to develop Gregerson's argument that Jesus's two parables of the talents and grain of wheat support an ethics of risk-taking.[106] However, the simple application of this principle to chemical technology would seem to be at odds with the broader ethic implied by passages such as the Levitical law of the goring ox,[107] the book of Proverbs' commending of risk avoidance,[108] Jesus's enjoinder toward spiritual quality assurance in calling us to "watch and pray" lest we "fall into temptation."[109] So, Gregerson's account might be supplemented with theological assessments of risk similar to those made in the context of debates over biotechnology.[110] More-ambitious contributors might also seek to address issues associated with the disproportionate distribution of chemical risks onto the poor and vulnerable,[111] or theologically evaluate the perspectives that underlie chemical risk management regimes.[112] Possible starting points include Mullins's and Sani's efforts to Christianize secular risk management principles as congruent with Christian understandings of how God acts in creation[113] and the efforts of Susan Bratton[114] and the Presbyterian Church USA (PCUSA)[115] to address deficiencies in Christian approaches to agricultural and marine chemicals. However, much more chemically informed work is needed to help Christians adequately navigate between the benefits and riskiness[116] of chemical use even in these limited spheres.

The "risk discourses" that are put in place to manage risk should also be considered.[117] Some of the issues involved can be nicely illustrated by considering the

dual-use dilemmas that can arise over technologies such as protein engineering,[118] directed evolution studies,[119] combinatorial chemistry,[120] microreactors,[121] drug discovery AI,[122] and published chemical syntheses[123] that can be repurposed for illicit ends. At issue is whether to help a potential recipient by providing them with a beneficial technology or to prevent a foreseeable harm by withholding it. In most cases, the decision involves questions of security and is typically made by individual researchers, businesses, and governments (who help decide whether to develop technologies) or corporations and governments (who control access and export). Typically, the decision makers are wealthier more-powerful entities whose interests differ somewhat from the poorer less-powerful prospective recipients. Ethical issues can arise in the decision itself, how the decision-making process is constructed (Should chemists have a say? What about the prospective recipient?), and in the actions of the decision makers themselves (Do they honestly communicate likely risks and benefits? Disclose conflicts of interest? Consider other stakeholders' perspectives?). The importance of a carefully constructed risk discourse was recently illustrated by recent bans on plastic straws, resulting in a decision that was environmentally responsible but disregarded the needs of disabled people.[124] There are also questions about how the wealthy and powerful might justly withhold from the poor. Can they do so for their own security? If they do so, do they have an obligation to provide for the poor in other ways, such as through safer technologies?

Christians Are Called to Be Salt and Light[125] in a Chemical World

Christians should also care about chemistry because the church is called to equip its members to live out the gospel in a world that is profoundly shaped by chemistry. While some Christians may be engaged directly in chemical work,[126] all use synthetic chemicals in one way or another, even if only indirectly through goods such as concrete cityscapes, asphalt roadways, clean water, food, and other products made with chemicals. The environmental and social impacts of these are simultaneously the responsibility of everyone and no one in particular. This situation is sometimes referred to as organized irresponsibility,[127] but ideally the different actors all have some responsibility to see to it that chemicals are used responsibly. For example, governments regulate who has access to chemicals; R&D scientists investigate safety and provide instructions as to proper use; manufacturers perform quality control checks to make sure chemical products function properly and do not contain harmful impurities; the products are marketed honestly to appropriate users; end-users use the chemicals responsibly; appropriate health and environmental monitoring is undertaken; and harms are detected and remedied as soon as they occur.

In practice, these steps can be costly, sometimes prohibitively, so tradeoffs are made; breakdowns can occur due to malfeasance or ignorance, and it can be difficult to know where and how Christians might be called to act differently or exert a prophetic voice. Further, ethical issues that have nothing to do with professional norms can be even harder to recognize. It is one thing to conscientiously object to military research that violates international treaties, another for a cosmetic chemist to know what to do when the demand for their work is manufactured by making 400 million Chinese women feel self-conscious about their body hair.[128]

Even when a potential problem is identified, chemists need wise guidance. During controversies over Dow's role in supplying napalm to US forces in Vietnam, Dow President Ted Doan complained about a book on Christian ethics that he had consulted, noting its focus on "personal responsibility" to the exclusion of "corporate responsibility."[129] In this regard, there is a need for ethical resources suitable for use by Christians in chemistry, whether in the form of general approaches, analyses of various chemical codes of conduct,[130] or case studies similar to those given in the recent *Ethics of Chemistry* volume.[131]

Although it is hoped that contributors will explore a range of chemical enterprises, a possible starting point might be chemists' involvement in military work. Christian just war and pacifist traditions might serve as ready-made analytical frameworks. The moral arguments involved might be more accessible since chemists involved in military work are sometimes called upon to explain the moral rationale for their work publicly. The issues involved are likely to be usefully complex. Chemical products can be used for offensive, defensive, and medical purposes,[132] and chemists engage in military work for a variety

of reasons. Some do it opportunistically or out of nationalism. Others see military work as a way to seek the security of the place God placed them, either as a way to help deter potential aggressors or mitigate war's adverse impacts.[133] Some conscientiously refuse to do any military work[134]—or they seek out projects that promote peace and security. Examples include the ion mobility mass spectrometry systems that monitor for chemical and biological threats in airports, and methods for spectroscopically "fingerprinting" conflict minerals that make it harder for violent groups to profit from their extraction.[135]

The cases which have been examined so far seem to illustrate several features of moral dialogue in chemistry. The first is the need for cultural and self-awareness and to guard against moral slippage. Although poison gas research engenders considerable moral horror today, many World War I era chemists enthusiastically pursued it.[136] Nominally, they employed a mix of just war and realist arguments that map nicely onto those used by political and military leaders[137]—in this case, supported by a mix of nationalism and Pollyannaish reasoning about the effects of the gas. Known cases of possible moral slippage by degrees include Louis Fieser's work on napalm[138] and the "devil's chemists" of the holocaust. Few deliberately set out to run the holocaust's only privately run concentration camp or knowingly sell the Zyklon B for murderous purposes; most seem to have more or less unwittingly become involved and only later became willingly complicit.[139] Apart from the complicated case of the confessing church member and disinfectant specialist Kurt Gerstein,[140] the role Christianity played in chemists' sustained and deliberate involvement in these crimes has yet to be studied,[141] although "Christian" nationalism is known to have played a role in other Third Reich atrocities.[142]

Contributors might explore how chemists could use their professional influence to promote human flourishing. Examples include the Quaker crystallographer Kathleen Lonsdale's personal efforts to promote peace through relationship building, or the much more public and professionally costly activism of the secular humanist quantum chemistry pioneer Linus Pauling. The Methodist quantum chemist Charles Coulson promoted flourishing in multiple arenas. He succored refugees and sought after peace, equitable global development, church unity, and the end of poverty, unemployment, and racism.[143]

The relationship between chemistry and idolatry is a particularly thorny one. Chemists' many contributions to medicine, commerce, culture, and many other aspects of everyday life should be rightly celebrated.[144] However, as with all powerful technologies, there is always a danger of technological messianism. Sometimes the messianism is explicit. Margaret Sanger, anticipating chemists' successful development of oral contraceptives, proclaimed "science, the only possible savior of humankind, must put it in the power of woman to decide for herself whether she will or will not become a mother."[145] Other times, it is implied, as with the quasi-religious depictions of chemists and chemical plants in Abraham Cressy Morrison's *Man in a Chemical World*.[146] More often it involves shaping practices and affections. As a number of commentators have noted, chemical fertilizers, antibiotics, and contraceptives have alleviated people's sense of dependence on God and made it easier for them to live as if God did not exist.[147] However, here chemistry does not replace the God of Christianity but a "god in the gaps of our technological powers."[148] More serious, then, are things such as Du Pont's "better living through chemistry" ad campaign, which did not offer chemistry as a messiah directly so much as to help encourage a culture of consumerism.[149]

Although chemists, among other humans, are subject to hubris and other vices common to humanity, the connection between idolatry and what chemists do is far from simple. Chemists, chemicals, and chemical institutions should not be stereotyped as particularly idolatrous or vice-filled, for such caricatures will seem foreign to most practicing chemists, and hazard not showing due regard for the image of God in every human. The need to be careful in this regard is illustrated by the Nobel prize winner Fritz Haber. In 1909, Haber solved one of the defining scientific challenges of his time by developing an effective ammonia production process. Without his work, it would be impossible to feed the world. Yet, less than a decade after his discovery, Haber would become known as the "father" of modern chemical warfare. By all accounts his was an amazing life, in some respects worthy of being called a "morality tale for those who hope to see technology used to improve civilization, not destroy it."[150] Yet as his godson the

historian Fritz Stern reminds us, the story of Haber has often been told flatly and uncharitably, without due regard for Haber, the legendry scientific mentor, diplomat, friend of the pacifist Einstein, resister against Nazi demands to fire his Jewish subordinates, and, like many scientists, someone eager to use his talents to help meet the needs of his time.[151]

It is similarly difficult to draw a straight line between particular advances in chemistry and right worship or idolatry. Polymers and plastics may have contributed to cultures of consumerism, waste, and wastefulness in which "throwaway living" is celebrated.[152] However, they also contribute much to human health, wealth, and cleanliness. Polymers are also fundamentally expressions of scientific knowledge and know-how, and consequently, of both the wisdom of God and the God-imaging creativity of humanity. So, the real issue is not chemistry but the human heart. Issues of idolatry are not about chemistry per se but about how we think, live, and organize society, the church, and our individual lives.[153] As Carl Djerassi noted, synthetic oral contraceptives' role in transforming culture was "partly causative, though mostly facultative, by the simple fact that at precisely the right time in Western social history, a convenient oral contraceptive became available that completely divorced contraception from sex."[154] In other words, it is not only about chemistry's benefits and harms but also about whether we are shaping and using chemistry in ways that reflect robustly Christian "notions of the good, or the right, or the fitting."[155] In this regard, there is a need for contributions that address the theological outlooks we express through movements such as green chemistry, the risk discourses surrounding chemistry, and technologies such as plastics, adhesives, pesticides, food additives, fuels, solar energy technologies, and CRISPR/Cas9.[156]

Chemistry Enriches Our Understanding of Science and How It Relates to Religion

Chemistry's multifaceted approach to the study of matter not only reveals the richness of creation, but it also helps illuminate the richness of the human quest for understanding through science. Chemists engage in a variety of activities. In terms of basic research alone, some chemists use analytical instruments such as spectrometers and chromatographs to probe the composition of matter, while others use experiments or computational models to figure out how atoms and molecules behave or work together as part of larger systems. Nevertheless, overall, relatively few chemists seek to probe the fundamental structure of matter like some physicists do. Rather, to the extent chemists seek to explain how matter works, they do so at the level of atoms and molecules. Further, even then, chemists do not always use the most sophisticated scientific tools and models that are available. Some chemists make measurements with exacting accuracy and precision or employ highly sophisticated models in their efforts to understand chemical structure. However, even when reasonably reliable computational models are available, many chemists find simple models of chemical structure and reactivity more useful as everyday reasoning tools.[157] The general rule is that chemists seek to use whatever tool or model is most helpful in a given situation.

So, chemistry is at once exacting and flexible, objective and personal, a search for truth and a search for utility. It recognizes that humanity's search for understanding, whether in science or theology, engages a multifaceted reality that is no less true when described at different levels of detail or by using analogies or approximations. In this respect, it pushes back against simplistic notions of science as either a monolithic search for truth or a disinterested enterprise. Nevertheless, it does not do so in ways that would permit ideologues to legitimately challenge chemistry's established conclusions.[158] Rather, it does so in ways that suggest it may be fruitful to explore parallels between chemical reasoning and various forms of theological thinking, including areas such as practical theology that are not normally considered dialogue partners for the sciences.[159]

The long tradition of Christian thinking about matter may be fruitfully explored.[160] The ancient, medieval, and early modern church all engaged Aristotelian, Platonic, Epicurean, and Stoic philosophies of matter[161] as well as theory-driven experimental work in the form of craft and alchemical-chemical traditions.[162] Examples of the use of classical element theory in the New Testament include the description of bodies in 1 Corinthians 15:35–58 as "earthly" and "heavenly" and possibly the mention of the world being formed out of the classical element water in 2 Peter 3:5. The story of atomic ideas (atomism) is particularly notable.[163] Classical and early medieval

thinkers were wary of atomism since it was associated with the major ateleological system of the ancient world, Epicureanism,[164] and since atomists were unable to explain why anything orderly happened in nature (until the twentieth century, atomic theory could not explain how and why atoms associated in the way they did). Thus, although some of the church fathers employed atomic ideas to explain things such as God's creation of the cosmos or how the resurrection might have taken place, atomism was not seriously considered until the modern period. Until the work of Robert Boyle, Antoine Lavoisier, John Dalton, and many others from the seventeenth century onwards, various Stoic and Aristotelian ideas seemed more promising, both theologically and as a guide for chemical experimentation. Nevertheless, the church's commitment to these ideas was kept tenuous by the ecclesiastical denial of Aristotelian dogmatism amidst political and philosophical strife at the University of Paris (which also encouraged Christians to consider that the void of atomism might exist[165]) and alchemists' failure to produce either gold or immortality. This made it considerably easier for the French priest Pierre Gassendi to recast atoms as created by God as part of his efforts to rehabilitate Epicureanism.[166] Ultimately, however, the tradition of quantitative experimentation initiated by Boyle undergirded the Quaker schoolmaster John Dalton's proposal of the first chemically significant atomic theory.[167] So, the story of atomic theory *might* be taken as an example of science and faith interacting in constructive ways, even though it has sometimes been inaccurately portrayed as an example of conflict by advocates of the warfare model.[168]

Chemistry Is Also an Opportunity for the Church to Learn from Chemists

The book of Hebrews presents us with a cloud of witnesses of those who have gone before and then later enjoins us to remember our teachers, consider their way of life, and imitate their faith.[169] To that end, contributions outlining the lives of Christians in chemistry could also be worthwhile. Those from the modern period onward that have been documented include Paracelsus,[170] Oswald Croll,[171] Jan Baptist van Helmont,[172] Johan Glauber,[173] Robert Boyle,[174] John Dalton,[175] Benjamin Silliman Sr., Michael Faraday,[176] Josiah Parsons Cooke,[177] John Draper,[178] Hermann Kolbe,[179] George Washington Carver,[180] Charles Stine,[181] José María Albareda,[182] Edward Francis Caldin,[183] Percy Lavon Julian,[184] Michael Polanyi,[185] Kathleen Lonsdale,[186] Charles Coulson,[187] Arthur Peacocke,[188] Rustem Roy, Colin Russell,[189] Alister McGrath,[190] John Goodenough,[191] James Tour,[192] Fritz Schaeffer,[193] Edgar Andrews, Duane Gish,[194] Michael Behe,[195] Fazale Rana,[196] Marcos Eberlin,[197] Robert Fay,[198] Gary Patterson, Daniel Romo, Troy Van Voorhis,[199] David Vosburg,[200] Sy Garte,[201] Jorge Mario Bergoglio,[202] and others of whom I am only dimly aware.

Even though the relationship between science and Christianity in actual human lives is always somewhat messy, it may be enlightening to consider how chemists might express their beliefs through the sort of problems they choose to work on or the way they talk about their work.[203] One chemist whose life seems inadequately explored in this regard is the steroid chemist Percy Lavon Julian, who was widely respected as a humanist for the practical benefits of his work. Yet Julian did not talk directly about his faith in public or scientific arenas, even though its importance was evident to those of his colleagues who talked about and remembered him. It might similarly be instructive to evaluate these chemists' efforts to relate their faith and work with respect to contemporary views about how the church should engage with culture,[204] the meaning and value of work,[205] and whether and how the church should engage politically charged issues.[206] One incompletely explored example in which differences about these issues seems to be in play is the Dow napalm controversy, which involved a clash between the Clergy and Laity against Vietnam organization and devout Episcopalian and Presbyterian managers on Dow's board over the latter's supplying of napalm to the American military.[207] Historical context should also be considered.[208] For example, although the Franciscan friar Roger Bacon's advocacy of lethal alchemical warfare might be regarded as cringeworthy today, it made sense in the context of the apocalyptic speculations circulating in thirteenth-century Latin Christendom.[209]

Atheist and agnostic chemists provide opportunities for chemists to help the church understand and respond to materialist pictures of reality. Although the most prominent examples of scientism are usually associated with biology, neuroscience, and

physics, there is also a notable tradition of skepticism and agnosticism in chemistry. The crystallographer John Desmond Bernal,[210] textbook writer Peter Atkins,[211] spectroscopist Harold Kroto,[212] theoretical chemist Roald Hoffmann[213] and historian of chemistry William Jensen[214] have all explained their thinking in enough detail to be thoughtfully engaged. Other historical examples include Marcelin Berthelot,[215] Svante Arrhenius,[216] and Wilhelm Ostwald.[217] Arrhenius and Ostwald are also interesting on account of their association with the Monist League and, in Ostwald's case, the German church withdrawal movement. Joseph Priestley, Humphrey Davy, and Edward Frankland had more-complicated relationships with orthodox Christian belief that may be worth pondering.[218] In this regard, it might be valuable for Christians in the chemical sciences to expand on some of the existing analyses of scientific materialism in chemistry in ways that graciously and thoughtfully engage the arguments of these and similar thinkers. [219]

Final Reflections

As a partially reductionist culture-shaping central science, chemistry offers to enrich our understanding of how science and faith interact. From the standpoint of chemistry, the science-Christianity relationship cannot and should not be conceived in exclusively cognitive terms.[220] Chemistry is too important a locus for what one astute observer has called "the meeting of science and religion in real life."[221] How churches and individuals think about chemistry and use chemicals can reflect either defective or sound thinking about God, creation, and the gospel.[222] It is hoped that contributions to this call for papers will, in however small a measure, contribute to sound thinking. ▼

Notes

[1]In this connection chemistry has also been called the keystone science. Ivor Griffith, "Chemistry as a Source of New Wealth," *The Annals of the American Academy of Political and Social Science* 115 (1924): 38, https://www.jstor.org/stable/1015788.

[2]The characterization of chemistry as an "impure science" also refers to how chemistry has altered the environment through waste and pollution. See Bernadette Bensaude-Vincent and Jonathan Simon, *Chemistry: The Impure Science* (London, UK: Imperial College Press, 2008). For those who dislike the word "impure," another term that chemistry has been called (but does not give exactly the same idea) is the "cardinal creative science" (Griffith, "Chemistry as a Source of New Wealth").

[3]Roughly from the late nineteenth century onward, Hugh D. Crone, *Chemicals and Society: A Guide to the New Chemical Age* (Cambridge, UK: Cambridge University Press, 1988); and Frank A. von Hippel, *The Chemical Age: How Chemists Fought Famine and Disease, Killed Millions, and Changed Our Relationship with the Earth* (Chicago, IL: University of Chicago Press, 2020).

[4]For other general Christian reflections on issues and approaches in chemistry, see Jonathan Foster and Bob Slade, "Studying Chemistry as a Christian," Christians in Science, 2013, https://www.bethinking.org/your-studies/studying-chemistry; Michael Newton and Andrew Halestrap, "Studying Biochemistry as a Christian," Christians in Science, n.d., https://www.cis.org.uk/upload/Resources/Students/Biochemistry_text_only.pdf; Walter R. Hearn, "Chemistry," *Journal of the American Scientific Affiliation* 11, no. 2 (1959): 10–12, https://www.asa3.org/ASA/PSCF/1959/JASA6-59Hearn.html; Russell Maatman, "Chemistry," *Journal of the American Scientific Affiliation: Science in Christian Perspective* 17, no. 1 (1965): 27–28, https://www.asa3.org/ASA/PSCF/1965/JASA3-65Maatman.html; ___, "Chemistry: A Gift of God," *Perspectives on Science and Christian Faith* 38, no. 4 (1986): 232–36, https://www.asa3.org/ASA/PSCF/1986/PSCF12-86Maatman.html; ___, "Suggestion: Use a World-and-Life View in the Teaching of Chemistry," *Journal of Chemical Education* 65, no. 10 (1988): 885–86, https://doi.org/10.1021/ed065p885; Peter K. Walhout, "How Does Chemistry Impact Human Society?," in *Not Just Science: Questions Where Christian Faith and Natural Science Intersect,* ed. Dorothy F. Chappell and E. David Cook (Grand Rapids, MI: Zondervan, 2005): 223–28; Arie Leegwater, "Loving the Kingdom and Responsible Technology," *Perspectives on Science and Christian Faith* 62, no. 4 (2010): 233–34, https://www.asa3.org/ASA/PSCF/2010/PSCF12-10Leegwater.pdf; ___, "A Brief Excursion in Chemistry: 'God-Talk' in Chemistry?," *Perspectives on Science and Christian Faith* 63, no. 3 (2011): 145, https://www.asa3.org/ASA/PSCF/2011/PSCF9-11Leegwater.pdf; and Stephen Contakes, "Wisdom in and for Chemistry," in *Where Wisdom May Be Found,* ed. Edward P. Meadors (Eugene, OR: Wipf & Stock, 2019): 187–201.

[5]For an inspiring reflection on matter, see Dallas Willard, "The Material World and the Rule of God: Matter or Physical Substance as Understood Today," 1982 Staley Lecture Series for Bethel College, Kansas, September 20, 1982, https://conversatio.org/the-material-world-and-the-rule-of-god-matter-or-physical-substance-as-understood-today/. It is noteworthy that popular-level theologies of making have been developed for the arts and business, such as Makoto Fujimura, *Art and Faith: A Theology of Making* (New Haven, CT: Yale University Press., 2020); and Jordan Raynor, *Called to Create: A Biblical Invitation to Create, Innovate, and Risk* (Grand Rapids, MI: Baker Books, 2017). Some starting points for a theology of chemistry might be found in general introductory perspectives on technology such as John Dyer, *From the Garden to the City: The Redeeming and Corrupting Power of Technology* (Grand Rapids, MI: Kregel Publications, 2011); Noreen L. Herzfeld, *Technology and Religion: Remaining Human in a Co-Created World* (West Conshohocken, PA: Templeton Press, 2009); John H. Thomas, "A New Voice Arising: A Pastoral Letter on Faith Engaging Science and Technology" (Cleveland, OH: United Church of Christ, 2008), https://www.ucc.org/wp-content/uploads/2021/01/pastoral-letter-on-faith

-and-science.pdf; and Egbert Schuurman, *The Technological World Picture and an Ethics of Responsibility: Struggles in the Ethics of Technology* (Sioux Center, IA: Dordt College Press, 2005). More specific proposals and issues are developed in Stephen V. Monsma, ed., *Responsible Technology: A Christian Perspective* (Grand Rapids, MI: Eerdmans, 1986); Jack Clayton Swearengen, *Beyond Paradise: Technology and the Kingdom of God* (Eugene, OR: Wipf & Stock, 2007); Willem Drees, "Introduction: Technological and Moral Creatures or Creators?," in *Creative Creatures: Values and Ethical Issues in Theology, Science, and Technology,* ed. Ulf Görman, Willem B. Drees, and Hubert Meisinger (London, UK: T & T Clark International, 2005): 1–12. Helpful article-length perspectives are found in Leegwater, "Loving the Kingdom"; Michael J. Clifford, "Appropriate Technology: The Poetry of Science," *Science and Christian Belief* 17, no. 1 (2005): 71–82; Denis Alexander, "Worshipping God with Technology," *Cambridge Papers* (December 2003); and Tom McLeish, "Medieval Lessons for the Modern Science/Religion Debate," chap. 15 in *Robert Grosseteste and the Pursuit of Religious and Scientific Learning in the Middle Ages*, ed. Jack P. Cunningham and Mark Hocknull (Switzerland: Springer, 2016): 281–300. For an interesting exploration of historical Christian attitudes toward technology, see John Hedley Brooke, "Detracting from Divine Power? Religious Belief and the Appraisal of New Technologies," in *Re-Ordering Nature: Theology, Society, and the New Genetics*, ed. Celia Deane-Drummond, Bronislaw Szerszynski, and Robin Grove-White (London, UK: T&T Clark, 2003), 43–64.

[6]For more on the idea of creation's goodness as involving proper functioning, see Robert C. Bishop, "Recovering the Doctrine of Creation: A Theological View of Science," BioLogos Foundation, January 31, 2011, https://biologos.org/articles/recovering-the-doctrine-of-creation-a-theological-view-of-science.

[7]Some resources that develop this point, albeit more in light of the biological and social sciences than chemistry, include Philip J. Hefner, *The Human Factor: Evolution, Culture, and Religion* (Minneapolis, MN: Fortress Press, 1993); and ___, *Technology and Human Becoming* (Minneapolis, MN: Fortress Press, 2003). Subsequent to Hefner's work the created co-creator concept has also been applied to work in the arts, business, and other fields. For thoughts on its application to chemistry, see Willem B. Drees, "'Playing God? Yes.' Religion in the Light of Technology," *Zygon*® 37, no. 3 (2002): 643–54, https://doi.org/10.1111/1467-9744.00442.

[8]Note that I am not claiming that humans should be understood as "created co-Creators" in the sense of independent free agents. Rather, I am claiming they are "creative creatures" with God-given creativity which they are called to exercise under God. For more on this point, see James C. Peterson, *Changing Human Nature: Ecology, Ethics, Genes, and God* (Grand Rapids, MI: Eerdmans, 2010), 46; and Willem B. Drees, *Religion and Science in Context: A Guide to the Debates* (New York: Routledge, 2010): 122–24. For the theological implications of different views of human calling on a technological issue, see Forrest Clingerman, "Geoengineering, Theology, and the Meaning of Being Human," *Zygon*® 49, no. 1 (2014): 6–21, https://doi.org/10.1111/zygo.12072.

[9]For an example of a chemist who understands their work in this way, see David Vosburg, "What Does Christ Have to Do with Chemistry?," The Faraday Institute for Science and Religion, February 27, 2014. http://scienceandbelief.org/2014/02/27/what-does-christ-have-to-do-with-chemistry/

[10]For a brief treatment of the culture mandate as a call to bring out creation's potentialities, see Naomi Noguchi Reese, "Culture Mandate," in *Dictionary of Christianity and Science,* ed. Paul Copan et al. (Grand Rapids, MI: Zondervan, 2017), 149. Useful popular treatments of the culture mandate include Andy Crouch, *Culture Making: Recovering Our Creative Calling* (Downers Grove, IL: InterVarsity Press, 2008); and ___, *Playing God: Redeeming the Gift of Power* (Downers Grove, IL: Intervarsity Press, 2013).

[11]For an exploration of the stewardship mandate, see Sandra L. Richter, *Stewards of Eden: What Scripture Says about the Environment and Why It Matters* (Downers Grove, IL: InterVarsity Press, 2020), especially pp. 5–14.

[12]Genesis 1:28; 2:15; cf. Psalm 8.

[13]Genesis 1:28; 4:17–22 (cf. 3:17–23, 4:11–12; 5:29).

[14]For a readable account of these bricks as a materials science achievement, see Stephen L. Sass, *The Substance of Civilization: Materials and Human History from the Stone Age to the Age of Silicon* (New York: Arcade, 1998), 125–27.

[15]For an interesting chemistry-laden discussion of the debittering of the waters of Marah, see Roald Hoffmann and Shira Leibowitz Schmidt, *Old Wine, New Flasks: Reflections on Science and Jewish Tradition* (New York: W. H. Freeman, 1997), 123–57.

[16]For examples of Christians in science who view their work as promoting shalom, see Elaine Howard Ecklund, *Why Science and Faith Need Each Other: Eight Shared Values That Move Us Beyond Fear* (Grand Rapids, MI: Brazos, 2020), 133–44.

[17]For a magisterial treatment on science as a source of wisdom, see Tom McLeish, *Faith and Wisdom in Science* (Oxford, UK: Oxford University Press, 2015). For more on chemistry as a source of wisdom, see Contakes, "Wisdom in and for Chemistry." For an exploration of one area of chemistry, see Gary Patterson, "Theology and Thermodynamics: In Praise of Entropy," *Perspectives on Science and Christian Faith* 64, no. 4 (2012): 242–49, https://www.asa3.org/ASA/PSCF/2012/PSCF12-12Patterson.pdf.

[18]For a slightly dated but still very useful summary of the challenges and research needs facing chemistry, see National Research Council, *Beyond the Molecular Frontier: Challenges for Chemistry and Chemical Engineering* (Washington, DC: National Academies Press, 2003).

[19]Atoms differ markedly from the indivisible classical particles envisioned by Epicurus, Leucippus, and Democritus. A failure to understand this basic distinction has led to significant misunderstandings about early Christian objections to atomism. In fact, their objections were right to the point. Because the Epicureans lacked a coherent theory of chemical structure and bonding, their atomic ideas did not actually explain why matter forms the structures that it does.

[20]For an interesting article from a Lutheran perspective, see George Murphy, "The Impact of Science on Christian Worship," *Seminary Ridge Review* 1, no. 2 (1999): 63–74. For Roman Catholicism, see Rev. Michael J. Ahern, S.J., "Liturgical Chemistry," *Bulletin of the American Association of Jesuit Scientists*, Eastern Section 11, no. 4 (1934): 218–21, https://jesuitonlinelibrary.bc.edu/?a=d&d=aajses19340501-01.2.14&e=-------en-20--1--txt-txIN-------. For private examples of chemistry informing a worshipful attitude toward scripture and nature, see Therese Southgate, "A

Chemist's Prayer," *Journal of Chemical Education* 23, no. 10 (1946): 507, https://doi.org/10.1021/ed023p507; Roy Berkenbosch, "Good Chemistry in a Fallen World: A Service Planned and Led by Chemists," *Reformed Worship* 83 (March 2007), https://www.reformedworship.org/article/march-2007/good-chemistry-fallen-world; Kaylee Hill, "Synthesis," *God & Nature* (Summer 2018), https://godandnature.asa3.org/hill-poem-synthesis.html; Stacy A. Trasancos, "Atoms, Elements, and the Grandeur of God," *U.S. Catholic*, November 1, 2016, https://uscatholic.org/articles/201611/atoms-elements-and-the-grandeur-of-god/; and Allison Dick, "A Prayer for Chemists," *InterVarsity Emerging Scholars Network Blog*, November 9, 2020, https://blog.emergingscholars.org/2020/11/a-prayer-for-chemists/. In addition, chemistry textbooks written for a Christian homeschool audience often incorporate chemistry-based devotional elements.

[21]For examples, see Caroline Walker Bynum, *Christian Materiality: An Essay on Religion in Late Medieval Europe* (Cambridge, MA: MIT Press, 2011), 217–65; and William R. Newman, "Alchemy and the Art-Nature Debate," in *Promethean Ambitions: Alchemy and the Quest to Perfect Nature* (Chicago, IL: University of Chicago Press, 2004), 34–114. For the continuation of these trends in the early modern period, see John Henry, "Theology and the Meaning of Matter in the Early Modern Period: A Response to Peter Harrison," in *Matter and Meaning: Is Matter Sacred or Profane?,* ed. Michael Fuller (Newcastle upon Tyne, UK: Cambridge Scholars, 2010), 57–66.

[22]On scholastic efforts to reconcile late medieval matter theory with the then-recently ratified doctrine of transubstantiation, see Marilyn McCord Adams, *Some Later Medieval Theories of the Eucharist: Thomas Aquinas, Gilles of Rome, Duns Scotus, and William Ockham* (Oxford, UK: Oxford University Press, 2010). For aspects of the debate in modern Roman Catholicism, see Stephen M. Barr, "Does Quantum Physics Render Transubstantiation Meaningless?," *First Things* (May 25, 2010), https://www.firstthings.com/blogs/firstthoughts/2010/05/does-quantum-physics-render-transubstantiation-meaningless; Richard G. Cipolla, "Selvaggi Revisited: Transubstantiation and Contemporary Science," *Theological Studies* 35, no. 4 (1974): 667–91, https://doi.org/10.1177%2F004056397403500403; Joseph T. Clark, "Physics, Philosophy, Transubstantiation, Theology," *Theological Studies* 12, no. 1 (1951): 24–51, https://doi.org/10.1177%2F004056395101200102; and Cyril Vollert, "The Eucharist: Controversy on Transubstantiation," *Theological Studies* 22, no. 3 (1961): 391–425, https://doi.org/10.1177%2F004056396102200302.

[23]Chiara Crisciani, "Opus and Sermo: The Relationship between Alchemy and Prophecy (12th–14th Centuries)," *Early Science and Medicine* 13, no. 1 (2008): 4–24, http://dx.doi.org/10.1163/157338207X242447; Tara Nummedal, "Alchemy and Religion in Christian Europe," *Ambix* 60, no. 4 (2013): 311–12, and references therein, https://doi.org/10.1179/0002698013Z.00000000036; and Lawrence Principe, *The Secrets of Alchemy* (Chicago, IL: University of Chicago Press, 2013), 190–206.

[24]Following 2 Peter 3:5, van Helmont's famous tree experiment was an attempt to uncover how things could be formed of water.

[25]See Edward Davis, "A Priest Serving in Nature's Temple: Robert Boyle's Career Blended Faith, Doubt, and the Use of Science to Heal Disease and Fight Atheism," *Christian History* (November 2002): 28–31, https://www.christianitytoday.com/history/issues/issue-76/priest-serving-in-natures-temple.html; and Robert Boyle, "Some Considerations Touching the Usefulness of Experimental Natural Philosophy," in *The Works of the Honourable Robert Boyle*, 6 vols., ed. Thomas Birch (Hildesheim, Germany: Georg Olms, 1966), 2.31. For an account of Boyle's notion of the priest-scientist, see Harold Fisch, "The Scientist as Priest: A Note on Robert Boyle's Natural Theology," *Isis* 44, no. 3 (1953): 252–65, https://doi.org/10.1086/348227; and Peter Harrison, "Sentiments of Devotion and Experimental Philosophy in Seventeenth-Century England," *Journal of Medieval and Early Modern Studies* 44, no. 1 (2014): 113–33, https://doi.org/10.1215/10829636-2389515.

[26]For more on these arguments, see John Hedley Brooke, "Chemistry," in *The History of Science and Religion in the Western Tradition: An Encyclopedia*, ed. Gary B. Ferngren, Edward J. Larson, and Daniel W. Amundsen (New York: Garland, 2000), 378–83; David M. Knight, "Chemical Sciences and Natural Theology," in *The Oxford Handbook of Natural Theology*, ed. Russell Re Manning (Oxford, UK: Oxford University Press, 2013), 434–48.

[27]Known among chemists as the discoverer of Boyle's law.

[28]Notably, Boyle did not believe nature offered knockdown arguments for God's existence. For an accessible introduction to Boyle, see William Eaton, "Boyle, Robert (1627–1691)," *The Internet Encyclopedia of Philosophy*, https://iep.utm.edu/robert-boyle/. For a book-length study, see Michael Hunter, *Boyle: Between God and Science* (New Haven, CT: Yale University Press, 2010). For a study of the relationship between Boyle's theology and its role in the development of chemistry through de-spiritualized views of matter, see Eugene M. Klaaren, *Religious Origins of Modern Science: Belief in Creation in Seventeenth-Century Thought* (Grand Rapids, MI: Eerdmans, 1977).

[29]Some that address chemistry are William Prout, *Chemistry, Meteorology, and the Function of Digestion, Considered with Reference to Natural Theology* (London, UK: W. Pickering, 1834); George Fownes, *Chemistry, As Exemplifying the Wisdom and Beneficence of God* (New York: Wiley and Putnam, 1844); Josiah Parsons Cooke, *Religion and Chemistry; or, Proofs of God's Plan in the Atmosphere and its Elements* (New York: Scribner, 1864)—this was revised in 1880 as *Religion and Chemistry; a Re-Statement of an Old Argument*, with a third edition following in 1891; John Phin, *Chemical History of the Six Days of Creation* (New York: Handicraft Publication Co, 1872); Josiah Parsons Cooke, *The Credentials of Science, the Warrant of Faith,* 2nd edition (New York: Appleton, 1893); Simon Conway Morris, *Life's Solution: Inevitable Humans in a Lonely Universe* (Cambridge, UK: Cambridge University Press, 2003); Ruth M. Lynden-Bell et al., eds., *Water and Life: The Unique Properties of H_2O* (Boca Raton, FL: CRC Press, 2010); Alister E. McGrath, *A Fine-Tuned Universe: The Quest for God in Science and Theology* (Louisville, KY: Westminster John Knox Press, 2009); and Fazale Rana, *Fit for a Purpose: Does the Anthropic Principle Include Biochemistry?* (Covina, CA: Reasons to Believe Press, 2021). For an interesting fine-tuning argument that focuses on fine-tuning through quantum mechanics as necessary for a life-supporting chemistry, see also Stephen M. Barr, "Anthropic Coincidences and the Multiverse Idea," https://washtheocon.org/wp-content/uploads/2013/12/Universe-Designed-for-Life.pdf.

[30]Then as now, this was sometimes made more or less explicit. Among modern examples, for a theologically

sophisticated and historically aware program that merges homiletic, apologetic, and contemplative approaches by a polymer physicist, is McLeish, *Faith and Wisdom in Science*; and ___, "The Re-Discovery of Contemplation through Science," *Zygon*® 56, no. 3 (2021): 758–76, https://doi.org/10.1111/zygo.12719. Homiletic popular-level examples of varying credibility include George Wilson and Jessie A. Wilson, *Religio Chemici Essays* (London: Macmillan and Co., 1862); M. R. DeHaan, *The Chemistry of the Blood and Other Stirring Messages* (Grand Rapids, MI: Zondervan, 1943); A. Cressy Morrison, *Man Does Not Stand Alone* (New York: Fleming H. Revell Company, 1944) [This work was later republished as *Seven Reasons Why a Scientist Believes in God* (Westwood, NJ: Revell, 1962)]; Charles M. A. Stine, *A Chemist and His Bible,* 3rd edition (Philadelphia, PA: Sunday School Times, 1947); Sylvia Slaughter, *Messages from Matter: Finding God's Word in the Fundamentals of Chemistry* (Bloomington, IN: Westbow Press, 2015); and George B. Hill, *Discovering Jesus in a Chemistry Lab* (Self-published through LULU, 2017). For a respectable work of popular apologetics that touches on chemistry, see Henry F. Schaefer, *Science and Christianity: Conflict or Coherence?* (Athens, GA: University of Georgia, 2010). In addition to these, many chemistry textbooks written for Christian homeschooling audiences present an implicit natural theology. For an early example, see J. Carrington Sellars, *Chemistianity* (Birkenhead: Self-Published, 1873), https://elements.vanderkrogt.net/chemistianity.php.

[31]Cooke, *Religion & Chemistry*; and ___, *Credentials of Science*. For my analysis, see Stephen M. Contakes and Christopher Willard Kyle, "Josiah Parsons Cooke Jr.: Epistemology in the Service of Science, Pedagogy, and Natural Theology," *Hyle—International Journal for the Philosophy of Chemistry* 17, no. 1 (2011): 1–23, PhilArchive copy v1: https://philarchive.org/archive/CONJPCv1. For another chemistry-inspired example, see Daniel Luzon Morris, *Possibilities Unlimited: A Scientist's Approach to Christianity* (New York: Harper, 1952).

[32]A section on chemistry was included in Barrow and Tipler's classic work on the anthropic principle: John D. Barrow and Frank J. Tipler, *The Anthropic Cosmological Principle* (Oxford, UK: Oxford University Press, 1986), 510–75, although it had earlier been offered as an example of the anthropic principle in Cooke, *Religion and Chemistry*; and in Lawrence Joseph Henderson, *The Fitness of the Environment; an Inquiry into the Biological Significance of the Properties of Matter* (New York: The Macmillan Company, 1913). For a theistic evolutionary approach based on Augustine's seed principle, see Alister E. McGrath, *A Fine-Tuned Universe: The Quest for God in Science and Theology* (Louisville, KY: Westminster John Knox Press, 2009). For a chemistry-based natural theology based on beauty in chemistry, see Timothy Weatherstone, *Reconstructing Wonder: Chemistry Informing a Natural Theology* (Frankfurt am Main, Germany: Peter Lang, 2017). For a recent old earth perspective, see Rana, *Fit for a Purpose*. For intelligent design movement perspectives, see Marcos Eberlin, *Foresight: How the Chemistry of Life Reveals Planning and Purpose* (Seattle, WA: Discovery Institute Press, 2019); also Ryan Huxley and Casey Luskin, "Evidence of the Design of the Universe through the Anthropic Principle," Intelligent Design and Evolution Awareness Center, http://www.ideacenter.org/contentmgr/showdetails.php/id/837. For examples of past and present natural theology approaches based on the unique properties of water, see the essays in Lynden-Bell et al., *Water & Life*.

[33]In the UK, the chemist A. E. Wilders-Smith and materials scientist Edgar Andrews performed similar roles.

[34]While a comprehensive review of creationist (and other antievolutionist) uses of chemistry is beyond the scope of this article, for examples see Richard B. Bliss, *In Search of the … Origin of Life: Evolution, Creation* (San Diego, CA: Creation-Life Publishers, 1979); Duane Gish, "Thermodynamics and the Origin of Life (Part II)," *Acts & Facts* 7, no. 4 (1978), https://www.icr.org/article/thermodynamics-origin-life-part-ii/; and Duane T. Gish, *Speculations and Experiments Related to Theories on the Origin of Life: A Critique* (San Diego, CA: Institute for Creation Research, 1972).

[35]Michael J. Behe, *Darwin's Black Box: The Biochemical Challenge to Evolution* (New York: Free Press, 1996); ___, *The Edge of Evolution: The Search for the Limits of Darwinism* (New York: Free Press, 2008); and ___, *Darwin Devolves: The New Science about DNA That Challenges Evolution* (New York: HarperOne, 2020).

[36]Michael Denton, *Evolution: A Theory in Crisis* (Bethesda, MD: Adler & Adler, 1986).

[37]Fazale Rana and Hugh Ross, *Origins of Life: Biblical and Evolutionary Models Face Off* (Colorado Springs, CO: NavPress, 2004); Fazale Rana, *The Cell's Design: How Chemistry Reveals the Creator's Artistry* (Grand Rapids, MI: Baker Books, 2008); Eberlin, *Foresight*; and Rana, *Fit for a Purpose* and Change Laura Tan and Rob Stadler, *The Stairway of Life: An Origin-of-Life Reality Check* (Self-Published, 2020).

[38]McGrath, *A Fine-Tuned Universe.*

[39]W. Ross Hastings, *Echoes of Coinherence: Trinitarian Theology and Science Together* (Eugene, OR: Cascade Books, 2017), 128–35; and José M. Romero-Baró, "God's Mark on Nature. A Trinitarian Approach," Metanexus Institute. Science and Religion: Global Perspectives Conference, June 4–8, 2005, Philadelphia, PA, https://www.newdualism.org/papers/J.Romero-Baro/gods-mark.htm.

[40]Random in the sense of probabilistic.

[41]For my own nonrigorous efforts to suggest such correspondence, see Contakes, "Wisdom in and for Chemistry."

[42]For examples of God as a chemist in creation, see Allen G. Debus, *The Chemical Philosophy: Paracelsian Science and Medicine in the Sixteenth and Seventeenth Centuries* (New York: Science History Publications, 1977); and Michael Thomson Walton, *Genesis and the Chemical Philosophy: True Christian Science in the Sixteenth and Seventeenth Centuries* (Brooklyn, NY: AMS Press, 2011).

[43]Weatherstone, *Reconstructing Wonder*. For another important analysis, see Peter K. Walhout, "The Beautiful and the Sublime in Natural Science," *Zygon*® 44, no. 4 (2009): 757–76, https://doi.org/10.1111/j.1467-9744.2009.01032.x. The theologian Ross Hastings also mentions chemistry in connection with theologies of beauty, albeit in connection with his experience as an organometallic chemist. See Hastings, *Echoes of Coinherence*, 182–84, 220.

[44]Tutorial reviews are introductory reviews specifically intended for use as educational tools. For more on tutorial reviews, see the tutorial review guidelines for *Chemical Society Reviews* at https://www.rsc.org/journals-books-databases/about-journals/chem-soc-rev/. A suitable review may exist for origin of life chemistry: H. James Cleaves, *The Origins of Life: A Review of Scientific Inquiry* (West Conshohocken, PA: John Templeton Foundation, 2020), https://www.templeton.org/wp-content/uploads/2021/07/JTF_Origins_of_Life_Final.pdf.

[45]Although it is not written from a Christian or even a social justice perspective, various ways in which chemistry

impacts human wellbeing are described in John Emsley, *A Healthy, Wealthy, Sustainable World* (Cambridge, UK: RSC Publishing, 2010). For an interesting, if dated, account of chemistry's societal benefits written by a sometime Christian apologist, see A. Cressy Morrison, *Man in a Chemical World: The Service of Chemical Industry* (New York: C. Scribner's Sons, 1937).

[46]Peter Coy, "Why the Periodic Table of Elements Is More Important than Ever," *Bloomberg Businessweek*, August 28, 2019, https://www.bloomberg.com/news/features/2019-08-28/the-modern-triumph-of-the-periodic-table-of-elements. This article is part of a special issue on *The Elements* that describes many economic uses of the elements, https://www.bloomberg.com/features/2019-periodic-table-elements-issue/.

[47]American Chemistry Council, *2021 Guide to the Business of Chemistry*, https://www.americanchemistry.com/chemistry-in-america/data-industry-statistics.

[48]For more on the Haber-Bosch process, see Vaclav Smil, *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production* (Cambridge, MA: MIT Press, 2001); Dietrich Stoltzenberg, *Fritz Haber: Chemist, Nobel Laureate, German, Jew* (Philadelphia, PA: Chemical Heritage Press, 2004); Daniel Charles, *Master Mind: The Rise and Fall of Fritz Haber, the Nobel Laureate Who Launched the Age of Chemical Warfare* (New York: Ecco, 2005); and Henry Harris, "To Serve Mankind in Peace and the Fatherland in War. The Case of Fritz Haber," *German History* 10, no. 1 (1992): 24–38, https://doi.org/10.1093/gh/10.1.24. For Christian perspectives, see Daniel Charles, "The Idol of Progress," *Sojourners Magazine* (2006): 24–27, and Darren Brouwer, "Better Living through Chemistry? Why Chemists Need to Be Humanists," *Comment* [Online], June 23, 2016, https://comment.org/better-living-through-chemistry/.

[49]That is, not counting petroleum, pharmaceuticals, and the biotech industry.

[50]The proportion of chemical engineers engaged in research and development is perhaps even lower (10% according to the US Bureau of Labor Statistics). See Bureau of Labor Statistics, U.S. Department of Labor, *Occupational Outlook Handbook*, Chemical Engineers, https://www.bls.gov/ooh/architecture-and-engineering/chemical-engineers.htm (visited March 28, 2022). Note that these numbers do not include those for petroleum engineers, chemical technicians, or for chemists involved in nonchemistry jobs, such as management and technical sales.

[51]Elizabeth Sendich, "Energy Products Are Key Inputs to Global Chemicals Industry," US Energy Information Administration, June 21, 2019, https://www.eia.gov/todayinenergy/detail.php?id=39952#.

[52]From the observatory of economic complexity data based on Alexander James Gaspar Simoes and Cesar A. Hidalgo, "The Economic Complexity Observatory: An Analytical Tool for Understanding the Dynamics of Economic Development," Paper from a workshop at the Twenty-Fifth AAAI Conference on Artificial Intelligence: Scalable Integration of Analytics and Visualization, San Francisco, California, August 7, 2011, https://www.researchgate.net/profile/Cesar-Hidalgo-2/publication/221605462_The_Economic_Complexity_Observatory_An_Analytical_Tool_for_Understanding_the_Dynamics_of_Economic_Development/links/54f472430cf24eb8794e8a6d/The-Economic-Complexity-Observatory-An-Analytical-Tool-for-Understanding-the-Dynamics-of-Economic-Development.pdf.

[53]For more on the chemical industry, see James Albert Kent, ed., *Handbook of Industrial Chemistry and Biotechnology,* 12th edition (New York: Springer, 2012); Mark Anthony Benvenuto, *Industrial Chemistry: For Advanced Students* (Boston, MA: De Gruyter, 2015); and Alan Heaton, *The Chemical Industry,* 2nd edition (London, UK: Blackie Academic & Professional, 1994). Readable accounts that are not accurate in every detail but which might be more accessible to nonchemist respondents include Ben Selinger and Russell Barrow, *Chemistry in the Marketplace,* 6th edition (Clayton South, VIC, Australia: CSIRO Publishing, 2017); and Donald L. Burdick and William L. Leffler, *Petrochemicals in Nontechnical Language,* 4th edition (Tulsa, OK: PennWell Corp, 2012).

[54]The impact of plastics has yet to be systematically explored in science and religion discourse. For some of the issues, see Jeffrey L. Meikle, *American Plastic: A Cultural History* (New Brunswick, NJ: Rutgers University Press, 1995); Susan Freinkel, *Plastic: A Toxic Love Story* (Boston, MA: Houghton Mifflin Harcourt, 2011); and Wiebe E. Bijker, *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change* (Cambridge, MA: MIT Press, 1995). For a survey of some of the issues from someone with "catholic scientific interests" along with ways forward, see Christopher J. Rhodes, "Solving the Plastic Problem: From Cradle to Grave, to Reincarnation," *Science Progress* 102, no. 3 (2019): 218–48, https://doi.org/10.1177/0036850419867204.

[55]Joachim Schummer, "'Are You Playing God?': Synthetic Biology and the Chemical Ambition to Create Artificial Life," *HYLE – International Journal for the Philosophy of Chemistry* 22, no. 1 (2016): 149–72, http://www.hyle.org/journal/issues/22-1/schummer.htm. See also Peter Dabrock, "Playing God? Synthetic Biology as a Theological and Ethical Challenge," *Systems and Synthetic Biology* 3 (1–4) (2009): 47–54, https://doi.org/10.1007%2Fs11693-009-9028-5; Ted Peters, *Playing God?: Genetic Determinism and Human Freedom,* 2nd edition (London, UK: Routledge, 2014); and Alexander Massmann and Keith R. Fox, *Modifying Our Genes: Theology, Science and "Playing God"* (La Vergne, UK: Hymns Ancient & Modern, 2014). A summary of the influence of theology on these discussions is given in Henk van den Belt, "Playing God in Frankenstein's Footsteps: Synthetic Biology and the Meaning of Life," *Nanoethics* 3, no. 3 (2009): 257–68, https://doi.org/10.1007%2Fs11569-009-0079-6.

[56]Wilfred Theisen, "The Attraction of Alchemy for Monks and Friars in the 13th–14th Centuries," *The American Benedictine Review* 46, no. 3 (1995): 239–53, https://www.scribd.com/document/364620582/THEISEN-Wilfrid-The-attraction-of-alchemy-for-monks-and-friars-in-the-13th-14th-centuries-pdf. For a cleric-alchemist who thought of his work in terms of the created co-creator concept, see Wilfred Theisen, "John Dastin: The Alchemist as Co-Creator," *Ambix* 38, no. 2 (1991): 73–78, https://doi.org/10.1179/amb.1991.38.2.73.

[57]For details of Albert's thought, see Albertus Magnus, *Book of Minerals,* trans. Dorothy Wyckoff (Oxford, UK: Clarendon Press, 1967); and Albert The Great, *On the Causes of the Properties of the Elements* [Liber de Causis Proprietatium Elementorum], Mediaeval Philosophical Texts in Translation, trans. Irven Michael Resnick (Milwaukee, WI: Marquette University Press, 2010). Important secondary sources include Adam Takahashi, "Nature, Formative Power and Intellect in the Natural Philosophy of Albert the Great," *Early Science and Medicine* 13, no. 5 (2008),

https://www.jstor.org/stable/20617751; the essays in Francis Joseph Kovach and Robert W. Shahan, *Albert the Great: Commemorative Essays* (Norman, OK: University of Oklahoma Press, 1980); and Irven Michael Resnick, ed., *A Companion to Albert the Great: Theology, Philosophy, and the Sciences* (Leiden, The Netherlands: Brill, 2013). Also Albert The Great's eight-volume discussion of Aristotle's physics; *On the Causes and the Procession of the Universe from the Prime Cause* and account of creation (*De IV coaequaevis*) are important for understanding his approach to matter but unfortunately not available in English translation. They may be accessed via the Alberti Magni e-corpus at http://albertusmagnus.uwaterloo.ca/.

[58]For Grosseteste's view of matter, see Nicola Polloni, "Early Robert Grosseteste on Matter," *Notes and Record: The Royal Society Journal of the History of Science* 75, no. 3 (2021): 397–414, https://doi.org/10.1098/rsnr.2020.0017; Giles E. M. Gasper et al., "The Use of the Stars: Alchemy, Plants, and Medicine," in *The Scientific Works of Robert Grosseteste. Vol. 1, Knowing and Speaking: Robert Grosseteste's 'De artibus liberalibus'* [on the Liberal Arts] *and 'De generatione sonorum'* [on the Generation of Sounds], ed. Giles E. M. Gasper et al. (Oxford, UK: Oxford University Press, 2019), 166–95.

[59]For Bacon's advocacy of alchemy and similar pursuits, see Roger Bacon, *The Opus Majus of R. Bacon*, trans. John Henry Bridges (London, UK: Williams & Norgate, 1900). For a summary of Bacon's thought in context, see Amanda Power, *Roger Bacon and the Defence of Christendom* (Cambridge, UK: Cambridge University Press, 2013), 96; Athanasios Rinotas, "The Interplay among Alchemy, Theology and Philosophy in the Late Middle Ages: The Cases of Roger Bacon and John of Rupescissa," *Vegueta. Anuario de la Facultad de Geografía e Historia* 17 (2017): 161–73, https://www.academia.edu/34085595/; Zachary Matus, "Reconsidering Roger Bacon's Apocalypticism in Light of His Alchemical and Scientific Thought," *The Harvard Theological Review* 105, no. 2 (2012): 189–222, https://www.jstor.org/stable/41474572; and ___, "Resurrected Bodies and Roger Bacon's Elixir," *Ambix* 60, no. 4 (2013): 323–40, https://doi.org/10.1179/0002698013Z.00000000037.

[60]Bacon's argument can be seen in the dedicatory preface to Bacon, *The Opus Majus of R. Bacon*, trans. Bridges. For other examples of prophecy-influenced alchemical programs, see Leah DeVun, *Prophecy, Alchemy, and the End of Time: John of Rupescissa in the Late Middle Ages* (New York: Columbia University Press, 2009); and Walter W. Woodward, *Prospero's America: John Winthrop Jr., Alchemy, and the Creation of New England Culture, 1606–1676* (Chapel Hill, NC: University of North Carolina Press, 2010).

[61]Martin Luther and Scott H. Hendrix, *Treatise on Good Works* (Minneapolis, MN: Fortress Press, 2012). See also Ian Hart, "The Teaching of Luther and Calvin about Ordinary Work: 1. Martin Luther (1483–1546)," *The Evangelical Quarterly* 67, no. 1 (1995): 35–52, https://vdocuments.net/the-teaching-of-luther-and-calvin-about-ordinary-work-1-martin-luther-2013-7.html?page=1. Luther and many of his contemporaries also linked alchemical and Christian thought, as explained in Nummedal, "Alchemy & Religion in Christian Europe."

[62]Luther also recognized resonances between alchemical and Christian imagery—for example, how chemical transformations could act as allegories of death and resurrection, an idea that survives in the form of terms such as crucible. On Luther's thought, see Martin Luther, *Table Talk,* trans. William Hazlitt (London: G. Bell, 1902), 326. See also Hart, "The Teaching of Luther and Calvin about Ordinary Work: 1. Martin Luther (1483–1546)." In addition, Luther appreciated alchemy for the way alchemical transformations could be seen as allegories of Christian truths. For more on this and related themes, see Nummedal, "Alchemy & Religion in Christian Europe" and references therein. For more on alchemical signification, see Crisciani, "Opus and Sermo."

[63]For an accessible account of Glauber's thinking, see Walton, *Genesis and the Chemical Philosophy*, 97–100.

[64]Pope Francis, *Laudato Si': On Care for Our Common Home* (Vatican City, Italy: Libreria Editrice Vaticana, 2015), 102.

[65]Contributions that do address this issue include Foster and Slade, "Studying Chemistry as a Christian"; Walhout, "How Does Chemistry Impact Human Society?"; Leegwater, "Loving the Kingdom"; Contakes, "Wisdom in and for Chemistry"; and Darren Brouwer, "Better Living through Chemistry? Why Chemists Need to Be Humanists," *Comment* (2016), published electronically June 23, 2016, https://comment.org/better-living-through-chemistry/.

[66]Bruce T. Moran, *Paracelsus: An Alchemical Life* (London, UK: Reaktion Books, 2019); and Walton, "Genesis and the Chemical Philosophy."

[67]The latter might be especially timely, given the increased recognition of the importance of water analysis in the wake of the Flint water crisis. Michael Torrice, "How Lead Ended Up in Flint's Tap Water," *Chemical & Engineering News* 94, no. 7 (2015), https://cen.acs.org/articles/94/i7/Lead-Ended-Flints-Tap-Water.html. A popular account is Anna Clark, *The Poisoned City: Flint's Water and the American Urban Tragedy* (New York: Picador, 2019).

[68]For connections between Faraday's faith and applied science, see G. N. Cantor, *Michael Faraday: Sandemanian and Scientist: A Study of Science and Religion in the Nineteenth Century* (London, UK: Macmillan, 1993): 193–95.

[69]Wiley had a Stone-Campbell restorationist and abolitionist upbringing. Some starting points for an exploration of Wiley's thought and work include Philip J. Hilts, *Protecting America's Health: The FDA, Business, and One Hundred Years of Regulation* (New York: Alfred A. Knopf, 2003); Deborah Blum, *The Poison Squad: One Chemist's Single-Minded Crusade for Food Safety at the Turn of the Twentieth Century* (London, UK: Penguin Press, 2018); Harvey Washington Wiley, *An Autobiography* (Emmaus, PA: Rodale Books, 1957); and for a critical appraisal of the value of Wiley's efforts, see Jonathan Rees, *The Chemistry of Fear: Harvey Wiley's Fight for Pure Food* (Baltimore, MD: Johns Hopkins University Press, 2021).

[70]For an assessment of the needs, see National Research Council (U.S.) Committee on Grand Challenges for Sustainability in the Chemical Industry, *Sustainability in the Chemical Industry—Grand Challenges and Research Needs: A Workshop Report* (Washington, DC: The National Academies Press, 2006). For an interesting survey of the state of the chemical industry's sustainability efforts through 2012, see Eric Johnson, *Sustainability in the Chemical Industry* (Dordrecht, The Netherlands: Springer, 2012).

[71]Francis, *Laudato Si'*.

[72]The Greek Orthodox Archdiocese of America, *For the Life of the World: Toward a Social Ethos of the Orthodox Church*, https://www.goarch.org/social-ethos?fbclid=IwAR2RSPrgYRhPfAgT9p2iIQkd9wqtOYJ74Gtjnpmyq9xYdxshwqr6U1FJFiY, §71 and §76.

[73]For an introduction, see the essays in Forrest Clingerman and Kevin J. O'Brien, eds., *Theological and Ethical Perspectives on Climate Engineering: Calming the Storm. Religious Ethics and Environmental Challenges* (Lanham, MD: Lexington Books, 2016); Christopher J. Preston, ed., *Engineering the Climate: The Ethics of Solar Radiation Management* (New York: Lexington Books, 2012); Clingerman, "Geoengineering, Theology, and the Meaning of Being Human"; Forrest Clingerman and Gary Gardner, eds., *Playing God? Multi-faith Responses to the Prospect of Climate Engineering* (Highland Park, NJ: GreenFaith, 2018); Celia Deane-Drummond, Sigurd Bergmann and Bronislaw Szerszynski, eds., *Technofutures, Nature and the Sacred: Transdisciplinary Perspectives* (Surrey, UK: Ashgate Publishing, 2015); and Meric A. Srokosz, "Geoengineering or Planet Hacking?," *Perspectives on Science and Christian Faith* 66, no. 4 (2014): 213–20, https://www.asa3.org/ASA/PSCF/2014/PSCF12-14Srokosz.pdf.

[74]The American Chemical Society maintains many excellent resources on green chemistry at https://www.acs.org/content/acs/en/greenchemistry.html. In addition, see the classic text, Paul T. Anastas and John Charles Warner, *Green Chemistry: Theory and Practice* (Oxford, UK: Oxford University Press, 1998); and M. Lancaster, *Green Chemistry: An Introductory Text,* 2nd edition (Cambridge, UK: Royal Society of Chemistry, 2010).

[75]George D. Bennett, "A Comparison of Green Chemistry to the Environmental Ethics of the Abrahamic Religions," *Perspectives on Science and Christian Faith* 60, no. 1 (2008): 16–25, https://www.asa3.org/ASA/PSCF/2008/PSCF3-08Bennett.pdf; George D. Bennett, "Green Chemistry as an Expression of Environmental Ethics," in *Green Chemistry for Environmental Sustainability,* ed. Sanjay Kumar Sharma and Ackmez Mudhoo (New York: CRC Press, 2010): 105–25.

[76]Some of the issues were helpfully outlined by Ian Barbour half a century ago: Ian G. Barbour, *Technology, Environment, and Human Values* (New York: Praeger, 1980); and ___, *Ethics in an Age of Technology* (San Francisco, CA: HarperSanFrancisco, 1993).

[77]For a well-referenced summary of the main issues from a pro-development perspective, see Edd S. Noell and Stephen L. S. Smith, "Economics, Theology, and a Case for Economic Growth: An Assessment of Recent Critiques," *Christian Scholar's Review* 50, no. 1 (2020): 5–23, https://christianscholars.com/economics-theology-and-a-case-for-economic-growth-an-assessment-of-recent-critiques/. Additional considerations from Christians involved in land management and energy development may be found in Ian Hore-Lacy, *Responsible Dominion: A Christian Approach to Sustainable Development* (Vancouver, BC: Regent College Publishing, 2006); and Richard W. Gijsbers, "Christian Voices in the Environment Debate," *Christian Perspectives on Science and Technology (ISCAST Online Journal)*, no. 11 (2016), https://iscast.org/uncategorized/christian-voices-in-the-environment-debate/. For a survey of different visions that influence how people address environmental issues, see Jennifer Clapp and Peter Dauvergne, *Paths to a Green World: The Political Economy of the Global Environment*, 2nd edition (Cambridge, MA: The MIT Press, 2011), 227–49.

[78]In most cases, caring for the environment and economic wellbeing are interconnected. This can be seen in Francis, *Laudato Si'*.

[79]For examples, see Grace A. Lasker and Edward J. Brush, "Integrating Social and Environmental Justice into the Chemistry Classroom: A Chemist's Toolbox," *Green Chemistry Letters and Reviews* 12, no. 2 (2019): 168–177, https://doi.org/10.1080/17518253.2019.1609602; Grace A. Lasker et al., "Social and Environmental Justice in the Chemistry Classroom," *Journal of Chemical Education* 94, no. 8 (2017): 983–87, https://doi.org/10.1021/acs.jchemed.6b00968; Aren E. Gerdon, "Connecting Chemistry to Social Justice in a Seminar Course for Chemistry Majors," *Journal of Chemical Education* 97, no. 12 (2020): 4316–20, https://doi.org/10.1021/acs.jchemed.0c01043; and Fiona Case, "Chemists on a Mission," *Chemistry World* (February 20, 2014), https://www.chemistryworld.com/features/chemists-on-a-mission/7105.article.

[80]For an extremely short overview of biblical teachings on justice from an Anabaptist perspective, see Christopher D. Marshall, *The Little Book of Biblical Justice: A Fresh Approach to the Bible's Teachings on Justice* (Intercourse, PA: Good Books, 2005). For a popular-level Presbyterian one, see Timothy Keller, *Generous Justice: How God's Grace Makes Us Just* (New York: Dutton, 2010). Others include Walter Brueggemann, *The Prophetic Imagination* (Minneapolis, MN: Fortress Press, 2018); and Cynthia L. Westfall and Bryan R. Dyer, eds., *The Bible and Social Justice: Old Testament and New Testament Foundations for the Church's Urgent Call* (Hamilton, ON: McMaster Divinity College Press, 2015). For issues of economic justice that can be applied to chemistry, see Stephen Mott and Ronald J. Sider, "Economic Justice: A Biblical Paradigm," *Transformation* 17, no. 2 (2000): 50–63, https://www.jstor.org/stable/43070241; and Richard A. Horsley, *Covenant Economics: A Biblical Vision of Justice for All* (Louisville, KY: Westminster John Knox Press, 2009).

[81]For a historical overview, see Francois Jarrige, *Contamination of the Earth: A History of Pollutions in the Industrial Age* (Cambridge, MA: MIT Press, 2021), 280–86.

[82]Christopher W. Tessum et al., "Inequity in Consumption of Goods and Services Adds to Racial & Ethnic Disparities in Air Pollution Exposure," *Proceedings of the National Academy of Sciences* 116, no. 13 (2019): 6001–6, https://www.pnas.org/doi/full/10.1073/pnas.1818859116.

[83]Jill Johnston and Lara Cushing, "Chemical Exposures, Health, and Environmental Justice in Communities Living on the Fenceline of Industry," *Current Environmental Health Reports* 7, no. 1 (2020): 48–57, https://doi.org/10.1007/s40572-020-00263-8.

[84]Nathan Donley et al., "Pesticides and Environmental Injustice in the USA: Root Causes, Current Regulatory Reinforcement and a Path Forward," *BMC Public Health* 22, no. 1 (2022): article number 708, https://doi.org/10.1186/s12889-022-13057-4.

[85]Erika Raley, Lesliam Quirós-Alcalá, and Elizabeth C. Matsui, "Chemical Exposures via Personal Care Products and the Disproportionate Asthma Burden among the U.S. Black Population," *The Journal of Allergy and Clinical Immunology: In Practice* 9, no. 9 (2021): 3290–92, https://doi.org/10.1016/j.jaip.2021.04.063.

[86]Gwen Ottinger and Benjamin R. Cohen, eds., *Technoscience and Environmental Justice: Expert Cultures in a Grassroots Movement* (Cambridge, MA: MIT Press, 2011).

[87]For an example, see Steve Lerner, *Diamond: A Struggle for Environmental Justice in Louisiana's Chemical Corridor* (Cambridge, MA: MIT Press, 2006); and Amy M. Hay, "A New Earthly Vision: Religious Community Activ-

ism in the Love Canal Chemical Disaster," *Environmental History* 14, no. 3 (2009): 502–26, https://www.jstor.org/stable/40608502. For an important early example of a church seeking to address racial and economic justice issues associated with chemistry, see Commission for Racial Justice, "Toxic Wastes and Race in the United States: A National Report on the Racial and Socio-Economic Characteristics of Communities with Hazardous Waste Sites" (New York: United Church of Christ, 1987), https://www.nrc.gov/docs/ML1310/ML13109A339.pdf. The follow up report is Robert D. Bullard, Paul Mohai, Robin Saha, and Beverly Wright, Toxic Waste and Race at Twenty, 1987–2007 (Cleveland, OH: Justice and Witness Ministries, United Church of Christ, 2007), https://www.ucc.org/wp-content/uploads/2021/03/toxic-wastes-and-race-at-twenty-1987-2007.pdf. In addition, although I could find no evidence that she was religious, the polaroid chemist Caroline Hunter also sought to leverage the influence of church members in her efforts to convince her employer to stop supplying the materials that the Apartheid regime in South Africa used for producing passbooks to track black South Africans. For more on Hunter, see Ainissa Ramirez, *The Alchemy of Us: How Humans and Matter Transformed One Another* (Cambridge, MA: The MIT Press, 2021), 108–118; and Michael McCanne, "When Polaroid Workers Fought Apartheid," *Dissent* (August 14, 2020), https://www.dissentmagazine.org/online_articles/when-polaroid-workers-fought-apartheid. On the ripple effect of Polaroid's divestment in South Africa, see Eric J. Morgan, "The World Is Watching: Polaroid and South Africa," *Enterprise & Society* 7, no. 3 (2006): 520–49, https://www.jstor.org/stable/23700835.

[88]The most common examples involve pharmaceuticals. For a particularly gripping opportunity, now resolved, that chemists had to address, see Albert Sjoerdsma and Paul J. Schechter, "Eflornithine for African Sleeping Sickness," *The Lancet* 354, no. 9174 (1999): 254, https://doi.org/10.1016/S0140-6736(05)66324-6.

[89]For an introduction to some of the problems, see Jarrige, *Contamination of the Earth*, 306–10; Jennifer Clapp, *Toxic Exports: The Transfer of Hazardous Waste from Rich to Poor Countries* (Ithaca, NY: Cornell University Press, 2001); David N. Pellow, *Resisting Global Toxics: Transnational Movements for Environmental Justice* (Cambridge, MA: MIT Press, 2007); and Yogi Hale Hendlin, "Surveying the Chemical Anthropocene," *Environment and Society: Advances in Research* 12, no. 1 (2021): 181–202, https://doi.org/10.3167/ares.2021.120111. For an evangelical perspective, see Cynthia D. Moe-Lobeda, *Resisting Structural Evil: Love as Ecological-Economic Transformation* (Minneapolis, MN: Fortress Press, 2013).

[90]Among the many references addressing the Bhopal disaster, good places to start are Ingrid Eckerman, *The Bhopal Saga: Causes and Consequences of the World's Largest Industrial Disaster* (Hyderabad, India: Universities Press, 2005); and Edward Broughton, "The Bhopal Disaster and Its Aftermath: A Review," *Environmental Health* 4, no. 1 (2005): 6, https://doi.org/10.1186/1476-069X-4-6.

[91]William A. Suk et al., "Environmental Pollution: An Under-recognized Threat to Children's Health, Especially in Low- and Middle-Income Countries," *Environmental Health Perspectives* 124, no. 3 (2016): A41–A45, https://doi.org/10.1289/ehp.1510517.

[92]Daniel Berman and Suerie Moon, eds., *Fatal Imbalance: The Crisis in Research and Development for Drugs for Neglected Diseases* (Geneva, Switzerland: Médecins sans Frontières Access to Essential Medicines Campaign and the Drugs for Neglected Diseases Working Group, 2001), https://msfaccess.org/fatal-imbalance-crisis-research-and-development-drugs-neglected-diseases; and Marco Luchetti, "Global Health and the 10/90 Gap," *British Journal of Medical Practitioners* 7, no. 4 (2014): a731, accessed June 24 2022, https://www.researchgate.net/publication/270048142_Global_health_and_the_1090_gap.

[93]Jorge José Ferrer, "*Research as a Restorative Practice: Catholic Social Teaching and the Ethics of Biomedical Research,*" in M. T. Lysaught and M. McCarthy, eds., *Catholic Bioethics and Social Justice* (Collegeville, MN: Liturgical Press Academic, 2018), 363–75.

[94]Michael J. Saks and Jonathan J. Koehler, "The Coming Paradigm Shift in Forensic Identification Science," *Science* 309, no. 5736 (2005): 893, in part quoting Andre A. Moenssens, "Novel Scientific Evidence in Criminal Cases: Some Words of Caution," *Journal of Criminal Law & Criminology* 84, no. 1 (1993), https://scholarlycommons.law.northwestern.edu/jclc/vol84/iss1/. Chemists tempted to think that issues like this are confined to forensic science would do well to read Walter R. Hearn, "Whole People and Half-Truths," in *The Scientist and Ethical Decision*, ed. Charles Hatfield (Downers Grove, IL: InterVarsity Press, 1973), 83–96.

[95]Here it should be noted that the faithful work of forensic chemists receives little attention while the effects of malpractice and malfeasance can be public and devastating. For a summary of the issues facing forensic science, see Suzanne Bell et al., "A Call for More Science in Forensic Science," ed. Solomon H. Snyder, The Johns Hopkins University School of Medicine, Baltimore, MD, *Proceedings of the National Academy of Sciences* 115, no. 18 (2018): 4541–44, https://www.pnas.org/doi/pdf/10.1073/pnas.1712161115; and National Research Council of the National Academies, *Strengthening Forensic Science in the United States: A Path Forward* (Washington, DC: The National Academies Press, 2009). For the Patricia Stallings case, see Stanley Fields and Mark Johnston, "Proteins Are the Workhorses of the Cell: Misdiagnosis of a Metabolic Malady," in *Genetic Twists of Fate* (Cambridge, MA: MIT Press, 2010), 21–32. For an introduction to the Annie Dookhan case, see Sam Kean, "Why Did Annie Dookhan Lie?," *Distillations* (2021), published electronically, July 13, 2021, https://www.sciencehistory.org/distillations/why-did-annie-dookhan-lie.

[96]For notes on these practices and their connection with the accessibility of chemistry careers, see Celia Henry Arnaud, "Clearing the Way for Reform of General Chemistry Classes," *Chemical and Engineering News* 99, no. 19 (2021), https://cen.acs.org/education/undergraduate-education/Clearing-way-reform-general-chemistry/99/i19; Marjorie Caserio et al., "Responses to Changing Needs in U.S. Doctoral Education," *Journal of Chemical Education* 81, no. 12 (2004): 1698–1703, https://doi.org/10.1021/ed081p1698.1; Michael T. Ashby and Michelle A. Maher, "The Mantra of Graduate Education Reform: Why the Prayers Aren't Answered," *Journal of Chemical Education* 95, no. 7 (2018): 1083–85, https://doi.org/10.1021/acs.jchemed.8b00354; Ale Palermo et al., *Breaking the Barriers: Women's Retention and Progression in the Chemical Sciences* (Cambridge, UK: Royal Society of Chemistry, 2018), https://www.rsc.org/globalassets/02-about-us/our-strategy/inclusion-diversity/womens-progression/media-pack

/v18_vo_inclusion-and-diversity-_womans-progression_report-web-.pdf; Linda Wang and Andrea Widener, "Confronting Sexual Harassment in Chemistry," *Chemical and Engineering News* 95, no. 37 (2017), https://cen.acs.org/articles/95/i37/Confronting-sexual-harassment-chemistry.html; and Roald Hoffmann, "Tension in Chemistry and Its Contents," *Accountability in Research* 22, no. 6 (2015): 330–45, https://doi.org/10.1080/08989621.2015.1047708. For an example of issues that Christian chemists in academic chemistry navigate that contributed to one leaving the profession, see Hearn, "Whole People and Half-Truths," in *The Scientist and Ethical Decision*, ed. Hatfield, 83–96.

[97]Ibid.

[98]Guillermo Foladori and Noela Invernizzi, "Nanotechnology for the Poor?," *PLOS Medicine* 2, no. 8 (2005): e280, https://doi.org/10.1371/journal.pmed.0020280.

[99]For these see Jeffrey Kovac, *The Ethical Chemist: Professionalism and Ethics in Science* (Upper Saddle River, NJ: Pearson Prentice Hall, 2004).

[100]For an important recent summary of key social issues, see Jan Mehlich et al., "The Ethical and Social Dimensions of Chemistry: Reflections, Considerations, and Clarifications," *Chemistry–A European Journal* 23, no. 6 (2017): 1210–18, https://doi.org/10.1002/chem.201605259. A textbook that addresses these issues is Jan Mehlich, *Good Chemistry: Methodological, Ethical, and Social Dimensions* (London, UK: Royal Society of Chemistry, 2021). For a collection of ethical cases, see Joachim Schummer and Tom Børsen, eds, *Ethics of Chemistry: From Poison Gas to Climate Engineering* (London, UK: World Scientific Publishing, 2021). Most of these have been reproduced from special issues of *Hyle—International Journal for the Philosophy of Chemistry* between 2016 and 2020. Hyle published a similar special issue in 2001 that is worth consulting. Notably, it includes Joachim Schummer, "Ethics of Chemical Synthesis," *HYLE—International Journal for the Philosophy of Chemistry* 7, no. 2 (2001): 103–24, https://www.hyle.org/journal/issues/7/schummer.htm. Additional general treatments of the social dimensions of chemistry include Luciano Caglioti, *The Two Faces of Chemistry* (Cambridge, MA: MIT Press, 1985); Roald Hoffmann, *The Same and Not the Same* (New York: Columbia University Press, 1995); ___, "Tension in Chemistry and Its Contents"; and Jeffrey Kovac, "Ethics in Science: The Unique Consequences of Chemistry," *Accountability in Research* 22, no. 6 (2015): 312–29, https://doi.org/10.1080%2F08989621.2015.1047709.

[101]For a well-intentioned example that raises important issues about chemical sensitivity while badly mishandling the chemistry involved, see Martha McLaughlin, *Chemicals and Christians: Compassion and Caution* (Enumclaw, WA: Redemption Press, 2020).

[102]Normand M. Laurendeau, "An Energy Primer: From Thermodynamics to Theology," *Zygon*® 46, no. 4 (2011): 890–914, https://doi.org/10.1111/j.1467-9744.2011.01222.x.

[103]One caveat is that DDT was not a case of unforeseeable harms but of moving forward without considering foreseeable harms. Afterwards, cases of DDT's adverse effects were documented but widely ignored—at least prior to the publication of Rachel Carson's *Silent Spring*. For details, see Thomas R. Dunlap, *DDT, Silent Spring, and the Rise of Environmentalism: Classic Texts* (Seattle, WA: University of Washington Press, 2008).

[104]Mehlich et al., "The Ethical and Social Dimensions of Chemistry"; Claus Jacob and Adam Walters, "Risk and Responsibility in Chemical Research: The Case of Agent Orange," *HYLE—International Journal for the Philosophy of Chemistry* 11, no. 2 (2005): 147–66, https://www.researchgate.net/publication/282676052_Risk_and_Responsibility_in_Chemical_Research_The_Case_of_Agent_Orange; and many of the cases in Schummer and Børsen, eds., *Ethics of Chemistry*. Respondents might also consider the intersection between chemistry, business ethics, and law, and some of the issues raised in Apostolos K. Gerontas, "Review of 'Ethics of Chemistry: From Poison Gas to Climate Engineering' by Joachim Schummer & Tom Børsen, eds. World Scientific Publishing, Singapore, 2021," *Substantia* 5, no. 2 (2021): 165–67, https://doi.org/10.36253/Substantia-1372.

[105]For an outstanding summary of the issues, see Anne Chapman, *Democratizing Technology: Risk, Responsibility and the Regulation of Chemicals* (London, UK: Routledge, 2016). On risk analysis, see Joseph V. Rodricks, *Calculated Risks: The Toxicity and Human Health Risks of Chemicals in Our Environment,* 2nd edition (Cambridge, UK: Cambridge University Press, 2007). On the application of chemical risk-management in industrial chemistry and chemical engineering, see David Shonnard et al., "Green Engineering: Integration of Green Chemistry, Pollution Prevention, and Risk-Based Considerations," chap. 6 in *Kent and Riegel's Handbook of Industrial Chemistry and Biotechnology,* 11th edition, ed. James A. Kent (New York: Springer, 2007), 210–70.

[106]Niels Henrik Gregersen, "Risk and Religion: Toward a Theology of Risk Taking," *Zygon*® 38, no. 2 (2003): 355–76, https://doi.org/10.1111/1467-9744.00504.

[107]Exodus 21:28–36.

[108]Proverbs 22:3; 27:12.

[109]Matthew 26:41. Notice also Jesus's salutary mention of prudence in building and diplomacy when discussing the cost of discipleship in Luke 14:25–34.

[110]For an example, see Donald M. Bruce, "Playing Dice with Creation: How Risky Should the New Genetics Be?," in *Reordering Nature: Theology, Society, and the New Genetics,* ed. Celia Deane-Drummond and Bronislaw Szerszynski, with Robin Grove-White (London, UK: T & T Clark, 2003): 151–64; and Donald Bruce, *Modifying Creation? GM Crops and Foods: A Christian Perspective* (Carlisle, UK: Paternoster Press, 2001), 61–83.

[111]For an example of theological concerns over differential impacts of climate mitigation on the poor, see Arianne van Andel, "Geoengineering, Sacrifice, and the Scale of Love," in Clingerman and Gardner, eds., *Playing God? Multi-faith Responses to the Prospect of Climate Engineering*, 43–48.

[112]Amy Donovan, "Finding Security in the Risk Society," *Cambridge Papers* 24, no. 4 (2015): 1–6.

[113]R. T. Mullins and Emanuela Sani, "Open Theism and Risk Management: A Philosophical and Biological Perspective," *Zygon*® 56, no. 3 (2021): 591–613, https://doi.org/10.1111/zygo.12723.

[114]Susan Bratton, "Marine Contaminants, Environmental Chemistry and Toxicology: The Virtues of Christian Vigilance and Accountability," *Christian Scholar's Review*, *Christ Animating Learning Blog*, posted October 21, 2021, https://christianscholars.com/marine-contaminants-environmental-chemistry-and-toxicology-and-the-virtues-of-christian-vigilance-and-accountability/. Some of the ideas therein were expounded in more detail in an earlier article that more superficially addressed chemicals: Susan Power Bratton, "The Precautionary Principle and the

Book of Proverbs: Toward an Ethic of Ecological Prudence in Ocean Management," *Worldviews: Global Religions, Culture, and Ecology* 7, no. 3 (2003): 253–73, https://doi.org/10.1163/156853503322709137.

[115]For an example, see The Advisory Committee on Social Witness, PCUSA, "The Precautionary Principle: Managing Technological Risks to Protect Humanity and Our Planet," Presbyterian Church USA, 2018.

[116]I deliberately use riskiness here to indicate a combination of both probabilistic risk and potential for harm. For more on this point, see Chapman, *Democratizing Technology*, 84–86.

[117]Jan Mehlich, "Chemistry and Dual Use: From Scientific Integrity to Social Responsibility," *Helvetica Chimica Acta* 101, no. 9 (2018): e1800098, https://doi.org/10.1002/hlca.201800098.

[118]Catherine Jefferson, "Protein Engineering," in *Innovation, Dual Use, and Security: Managing the Risks of Emerging Biological and Chemical Technologies,* ed. Jonathan B. Tucker (Cambridge, MA: MIT Press, 2012), 119–32.

[119]Gerald L. Epstein, "DNA Shuffling and Directed Evolution," in *Innovation, Dual Use, and Security*, ed. Tucker, 101–16.

[120]Jonathan B. Tucker, "Combinatorial Chemistry and High-Throughput Screening," in *Innovation, Dual Use, and Security*, ed. Tucker, 89–100.

[121]Amy E. Smithson, "Chemical Micro Process Devices," in *Innovation, Dual Use, and Security*, ed. Tucker, 235–48.

[122]Jamie Durrani, "Drug Discovery AI That Developed New Nerve Agents Raises Difficult Questions," *Chemistry World* (March 31, 2022), https://www.chemistryworld.com/news/drug-discovery-ai-that-developed-new-nerve-agents-raises-difficult-questions/4015462.article.

[123]Roald Hoffman, *Should've*, http://www.roaldhoffmann.com/shouldve.

[124]Lorraine Cuddeback-Gedeon, "On Plastic Straws and the Preferential Option," *Catholic Moral Theology,* July 27, 2018, https://catholicmoraltheology.com/on-plastic-straws-and-the-preferential-option/.

[125]Although it is incidental to the main themes of this paper, for an interesting discussion of the soil chemistry behind Jesus's description of believers as salt, see Eugene P. Deatrick, "Salt, Soil, Savior," *The Biblical Archaeologist* 25, no. 2 (1962): 41–48, https://doi.org/10.2307/3210991. An even-broader-ranging discussion of chemical substances in the scriptures is Mary Elvira Weeks, "An Exhibit of Chemical Substances Mentioned in the Bible," *Journal of Chemical Education* 20, no. 2 (1943): 62–76, https://doi.org/10.1021/ed020p63. On perfume in the Bible, see Charles Sell, *Perfume in the Bible* (London, UK: Royal Society of Chemistry, 2019).

[126]This number is likely considerable given that a half million people work in chemistry or chemistry-related industries in the USA alone.

[127]This phenomenon is sometimes termed "organized irresponsibility." See Ulrich Beck, "Risk Society Revisited: Theory, Politics and Research Programmes," in *The Risk Society and Beyond: Critical Issues for Social Theory*, ed. Barbara Adam, Ulrich Beck, and Joost van Loon (London, UK: SAGE Publications Ltd, 2000), 211–29. For a concrete chemical example, see Jacob and Walters, "Risk and Responsibility in Chemical Research."

[128]One observer even described the actual marketing campaign as "very similar to the role of the apple in the Bible." See Matthew Boyle, "Convincing Women in China They're Too Hairy," *Bloomberg Businessweek,* October 2012, published electronically October 18, 2012, http://www.businessweek.com/articles/2012-10-18/convincing-women-in-china-theyre-too-hairy; https://www.sfgate.com/business/article/Veet-s-hairy-strategy-for-Chinese-women-3969580.php. The company was trying to gain market share in China's $1.5 trillion dollar SHEconomy, in which there is growing demand for cosmetic products. See Li Xiaoyang, "Sheconomy surges as females show greater financial clout and independence," *Beijing Review* (April 9, 2021), https://www.bjreview.com/Business/202104/t20210409_800243136.html.

[129]This is from a report by Richard Fernandez as reported in Tom Wells, *The War Within: America's Battle over Vietnam* (La Vergne, TN: Open Road Distribution, 2016), 452. The book in question is almost certainly Joseph F. Fletcher, *Situation Ethics: The New Morality* (Philadelphia, PA: Westminster Press, 1966). For a case of another Christian business leader who struggled over the ethics of his company's actions, see Benjamin Ross and Steven Amter, *The Polluters: The Making of Our Chemically Altered Environment* (London, UK: Oxford University Press, 2010), 68 and 146.

[130]American Chemical Society, "Chemical Professional's Code of Conduct," 2007, https://www.acs.org/content/dam/acsorg/careers/profdev/ethics/chemical-professionals-code-of-conduct-2012.pdf; American Chemical Society, "Global Chemists' Code of Ethics," 2016, https://www.acs.org/content/dam/acsorg/global/international/scifreedom/global-chemists-code-of-ethics-fi-2016.pdf; and American Institute of Chemists, "Code of Ethics," 1983, https://www.theaic.org/about_ethics.html.

[131]Schummer and Børsen, eds., *Ethics of Chemistry*.

[132]One starting place is Michael Freemantle, "Chemistry & War: How Chemistry Underpinned the Great War," *Chemistry International* 38, no. 1 (2016): 8–12, https://www.degruyter.com/document/doi/10.1515/ci-2016-0106/html?lang=en#:~:text=Various%20types%20of%20chemical%20warfare,such%20as%20bromine%20or%20iodine. For more extensive treatments, see Michael Freemantle, *Gas! Gas! Quick Boys! How Chemistry Changed the First World War* (Stroud, UK: Spellmount, 2013); and ___, *The Chemists' War: 1914–1918* (Cambridge, UK: Royal Society of Chemistry, 2015).

[133]For a summary of how such views featured in early chemical weapons research, see Hugh R. Slotten, "Humane Chemistry or Scientific Barbarism? American Responses to World War I Poison Gas, 1915–1930," *The Journal of American History* 77, no. 2 (1990): 476–98, https://doi.org/10.2307/2079180. Some starting points for the vast literature on the morality of weapons research are Joachim Schummer, "Ethics of Chemical Weapons Research: Poison Gas in World War One," *HYLE – International Journal for Philosophy of Chemistry* 24 (2018): 5–28, http://www.hyle.org/journal/issues/24-1/schummer.pdf; Jeffrey Kovac, "The Ethics of Chemical Research (1)," *Bulletin for the History of Chemistry* 41, no. 1/2 (2016): 56–63; and Stephen M. Contakes and Taylor Jashinsky, "Ethical Responsibilities in Military-Related Work: The Case of Napalm," *HYLE – International Journal for the Philosophy of Chemistry* 22, no. 1 (2016): 31–53, https://www.hyle.org/journal/issues/22-1/contakes.htm.

[134]For an example, see Kylie Miller and Stephen M. Contakes, "Crystallographer, Quaker, Pacifist, & Trailblazing Woman of Science: Kathleen Lonsdale's Christian Life 'Lived Experimentally,'" *God and Nature* (Summer 2014), https://

godandnature.asa3.org/essay-crystallographer-quaker-pacifist--trailblazing-woman-of-science-kathleen-lonsdalersquos-christian-life-lived-experimentallyrdquo-by-kylie-miller-and-stephen-m-contakes.html.

[135]For a review of issues and opportunities, see C. J. Rhodes, "Endangered Elements, Critical Raw Materials and Conflict Minerals," *Science Progress* 102, no. 4 (2019): 304–50, https://doi.org/10.1177/0036850419884873. For a recent example of chemists addressing this issue, see Celia Henry Arnaud, "Fingerprinting Conflict Minerals," *Chemical and Engineering News* 90, no. 18 (2012), published electronically April 30, 2012, https://cen.acs.org/articles/90/i18/Fingerprinting-Conflict-Minerals.html; Frank Melcher et al., "Fingerprinting of Conflict Minerals: Columbite-Tantalite ('Coltan') Ores," *SGA News* 23 (2008): 1, 7–14, http://www.e-sga.org/fileadmin/sga/newsletter/news23/SGANews23.pdf; and Alireza K. Somarin, "Geochemical Fingerprinting of Conflict Minerals Using Handheld XRF: An Example for Coltan, Cassiterite, and Wolframite Ores from Democratic Republic of the Congo, Africa," *Minerals* 9, no. 9 (2019): 564, https://doi.org/10.3390/min9090564.

[136]Some Christians did publicly object to early poison gas work. For an example, see Anonymous, "Christian Conscience and Poison Gas," *The Literary Digest* (1921): 38.

[137]Haber seems to have employed a mix of just war and "Supreme Emergency" similar to those that Second World War leaders offered to justify civilian bombing. For those see Michael Walzer, *Just and Unjust Wars: A Moral Argument with Historical Illustrations,* 4th edition (New York: Basic Books, 2006). Among the numerous books detailing chemists' involvement in chemical warfare, some good places to start are Freemantle, *The Chemists' War;* ___, *Gas! Gas! Quick Boys!*; and L. F. Haber, *The Poisonous Cloud: Chemical Warfare in the First World War* (Oxford, UK: Oxford University Press, 1986). For an account that explores the racially charged and medically and environmentally insensitive context in which mustard gas was used in the United States, see Susan Lynn Smith, *Toxic Exposures: Mustard Gas and the Health Consequences of World War II in the United States* (New Brunswick, NJ: Rutgers University Press, 2017). For an interesting study of US chemists' moral understanding of First World War chemical research, see Gilbert F. Whittemore, "World War I, Poison Gas Research, and the Ideals of American Chemists," *Social Studies of Science* 5, no. 2 (1975): 135–63, and Slotten, "Humane Chemistry or Scientific Barbarism?" For a more formal ethical analysis, see Schummer, "Ethics of Chemical Weapons Research."

[138]Contakes and Jashinsky, "Ethical Responsibilities in Military-Related Work."

[139]On chemists operating the holocaust's only privately run concentration camp, see Josiah Ellis DuBois, *The Devil's Chemists: 24 Conspirators of the International Farben Cartel Who Manufacture Wars* (Boston, MA: Beacon Press, 1952); John Cornwell, *Hitler's Scientists: Science, War, and the Devil's Pact* (New York: Viking, 2003); and Diarmuid Jeffreys, *Hell's Cartel: IG Farben and the Making of Hitler's War Machine* (New York: Metropolitan Books, 2008). On chemists' involvement in providing warning malodorant-free Zyklon B for use in the gas chambers, see Peter Hayes, *From Cooperation to Complicity: Degussa in the Third Reich* (Cambridge, UK: Cambridge University Press, 2005).

[140]Pierre Joffroy, *A Spy for God: The Ordeal of Kurt Gerstein* (New York: Grosset & Dunlap, 1972); Saul Friedländer, *Kurt Gerstein: The Ambiguity of Good* (New York: Knopf, 1972); and Valerie Hébert, "Disguised Resistance? The Story of Kurt Gerstein," *Holocaust and Genocide Studies* 20, no. 1 (2006): 1–33, https://doi.org/10.1093/hgs/dcj001.

[141]DuBois, *The Devil's Chemists*, 40. For a case of a pharmacist who claimed to have maintained a "Christian worldview," see Patricia Posner, *The Pharmacist of Auschwitz: The Untold Story of Victor Capesius* (United Kingdom: Crux Publishing, 2017), 128.

[142]On the role of theology in the justification of atrocities by Christians in the military, see David A. Harrisville, *The Virtuous Wehrmacht: Crafting the Myth of the German Soldier on the Eastern Front, 1941–1944* (Ithaca, NY: Cornell University Press, 2021), 90–125. On the theological and social factors which contributed, see Robert P. Ericksen, *Theologians under Hitler: Gerhard Kittel, Paul Althaus, and Emanuel Hirsch* (New Haven, CT: Yale University Press, 1985); and Doris L. Bergen, *Twisted Cross: The German Christian Movement in the Third Reich* (Chapel Hill, NC: University of North Carolina Press, 1996).

[143]For accessible treatments of Coulson's social thought, see David Hawkin and Eileen Hawkin, *The Word of Science: Religious and Social Thought of C. A. Coulson* (London, UK: Epworth Press, 1989); Arie Leegwater, "Charles Alfred Coulson: Mixing Methodism and Quantum Chemistry," in *Eminent Lives in Twentieth-Century Science and Religion,* 2nd edition, ed. Nicolaas A. Rupke (Frankfurt am Main, DEU: Peter Lang AG, 2009), 73–103; C. A. Coulson, *Science, Technology, and the Christian* (New York: Abingdon Press, 1960); and ___, *Science and Christian Belief* (Chapel Hill, NC: University of North Carolina Press, 1955).

[144]While most popular biology and physics books (and *Physics Today*) highlight new scientific developments, a large proportion of popular chemistry books (and many articles in *Chemistry World* and *Chemical & Engineering News*) celebrate chemistry's impacts. Among the more provocatively titled are Sharon Bertsch McGrayne, *Prometheans in the Lab: Chemistry and the Making of the Modern World* (New York: McGraw-Hill, 2001); K. C. Nicolaou and T. Montagnon, *Molecules That Changed the World: A Brief History of the Art and Science of Synthesis and Its Impact on Society* (Weinheim, Germany: Wiley-VCH, 2008); and John Emsley, *Better Looking, Better Living, Better Loving: How Chemistry Can Help You Achieve Life's Goals* (Weinheim, Germany: Wiley-VCH, 2007).

[145]Margaret Sanger, *The Pivot of Civilization* (London, UK: Humanities Press, 2022); Sanger was quoting the "Great Agnostic" Robert Ingersoll's anti-religion address, "What Is Religion?," which may be found in *The Works of Robert G. Ingersoll* (New York: The Dresden Publishing Company, 1902).

[146]Morrison, *Man in a Chemical World*. It is not clear to what extent Morrison was responsible for the illustrations, given his later authorship of works of Christian apologetics. For more details, see Andrew Ede, "Abraham Cressy Morrison in the Agora: Bringing Chemistry to the Public," *HYLE – International Journal for Philosophy of Chemistry* 12, no. 2 (2006): 193–214. For Morrison's apologetics work, see Morrison, *Man Does Not Stand Alone (Seven Reasons Why a Scientist Believes in God).*

[147]Peter Burke, *The New Cambridge Modern History. Vol. XIII, Companion Volume* (Cambridge, UK: Cambridge University Press, 1994); and Drees, "Playing God? Yes.," 652.

[148]Drees, "Playing God? Yes.," 645.

[149]On the role of Dow, Du Pont, Bakelite, and other companies in promoting consumerism, see Hillary S. Kativa, "It's

a Mad, Mad World: Dow and the Age of Consumption," *Distillations* (2015), published electronically September 22, 2015, https://www.sciencehistory.org/distillations/its-a-mad-mad-world-dow-and-the-age-of-consumption. A sober analysis of the ad campaigns reveals that they were not necessarily driven by chemistry but involved wider business aims. See Andrew M. Shanken, "Better Living: Toward a Cultural History of a Business Slogan," *Enterprise & Society* 7, no. 3 (2006): 485–519, https://doi.org/10.1093/es/khl001. The relationship between consumerism and idolatry forms a theme in Francis, *Laudato Si',* and is developed in suggestive ways in Richard Lints, *Identity and Idolatry* (Downers Grove, IL: InterVarsity Press, 2015): 158–72.

[150]This quote from Frank von Hippel is taken from the dust jacket to Daniel Charles, *Between Genius and Genocide: The Tragedy of Fritz Haber, Father of Chemical Warfare* (London, UK: Jonathan Cape, 2005). For Christian evaluations of Fritz Haber, see Daniel Charles, "The Idol of Progress," *Sojourners Magazine* (2006): 24–27, https://sojo.net/magazine/august-2006/idol-progress; Vern Thiessen, *Einstein's Gift* (Toronto, ON: Playwrights Canada Press, 2003); and Brouwer, "Better Living through Chemistry."

[151]Fritz Stern, "Fritz Haber: Flawed Greatness of Person and Country," *Angewandte Chemie International Edition* 51, no. 1 (2012): 50–56, https://doi.org/10.1002/anie.201107900.

[152]"Throwaway Living," *Life* (August 1, 1955): 43–44, https://books.google.com/books?id=xlYEAAAAMBAJ&pg=PA#v=onepage&q&f=false.

[153]For a discussion of how materialist conceptions of reality can fuel ecological exploitation, see Alister McGrath, *The Reenchantment of Nature: The Denial of Religion and the Ecological Crisis* (New York: Image, 2013).

[154]Carl Djerassi, *This Man's Pill: Reflections on the 50th Birthday of the Pill* (Oxford, UK: Oxford University Press, 2003), 293.

[155]Michael C. Banner, *The Ethics of Everyday Life: Moral Theology, Social Anthropology, and the Imagination of the Human* (Oxford, UK: Oxford University Press, 2014), 9. An analysis of technology similar to Banner's is Brian Brock, *Christian Ethics in a Technological Age* (Grand Rapids, MI: Eerdmans, 2010).

[156]For calls to focus on practices in science and religion dialogue, see Matthew Walhout, "Looking to Charles Taylor and Joseph Rouse for Best Practices in Science and Religion," *Zygon*® 45, no. 3 (2010): 558–74, https://doi.org/10.1111/j.1467-9744.2010.01113.x; and James K. A. Smith, "Our Chalcedonian Moment: Christological Imagination for Scientific Challenges," chapter 10 in *Christ and the Created Order: Perspectives from Theology, Philosophy, and Science*, vol. 2, ed. Andrew B. Torrance and Thomas H. McCall (Grand Rapids, MI: Zondervan, 2018), 179–93. Note that it may be possible to read more than one theological narrative into a given technology. For an analysis of Christian responses to carbon capture and solar radiation management as falling between concerns over hubris and optimism over humanity's ability to control nature, see Forrest Clingerman, "Between Babel and Pelagius: Religion, Theology and Geoengineering," in *The Ethics of Solar Radiation Management*, ed. Christopher J. Preston (New York: Lexington Books, 2012), 201–19. For a third metaphor, see the discussion of geoengineering as an opportunity to pastor Earth in Matthew Kearnes, "Miraculous Engineering and the Climate Emergency: Climate Modification as Divine Economy," in *Technofutures, Nature and the Sacred: Transdisciplinary Perspectives,* ed. Celia Deane-Drummond, Sigurd Bergmann, and Bronislaw Szerszynski (Surrey, UK: Ashgate Publishing, 2015), 219–37. In terms of the green chemistry movement, respondents might consider whether it reinforces those secular "mastery of nature"-approaches to the environment which arose in the early modern period as explained in James C. Ungureanu, "Retrieving an Ancient Sacramental Ecology, Part 3: 'On the Dignity of Man' and the New World," *Credo* (June 11, 2021), https://credomag.com/2021/06/retrieving-an-ancient-sacramental-ecology-part-3-on-the-dignity-of-man-and-the-new-world/. In terms of risk discourses a helpful start has been made by Tom McLeish. See McLeish, *Faith and Wisdom in Science*, 248–59; and ___, "The Science-and-Religion Delusion," in *Christ and the Created Order: Perspectives from Theology, Philosophy, and Science*, vol. 1, ed. Andrew B. Torrance and Thomas H. McCall (Grand Rapids, MI: Zondervan, 2018), 305–25.

[157]For example, chemists generally employ fuzzy concepts such as oxidation states and hard and soft acid-base theory and employ simple bonding models such as Lewis structures, valence bonds, and linear combinations of "hydrogenlike" atomic orbitals to describe molecular structure. Even the concept of a chemical bond itself is flexible. For more examples of this tendency in chemistry, see Michael Weisberg, Paul Needham, and Robin Hendry, "Philosophy of Chemistry," *The Stanford Encyclopedia of Philosophy* (Spring 2019 Edition), ed. Edward N. Zalta, https://plato.stanford.edu/archives/spr2019/entries/chemistry/. For the conceptual difficulties involved in developing chemically useful quantum mechanical models for chemical systems, see Gavroglou Kōstas and Ana Simões, *Neither Physics nor Chemistry: A History of Quantum Chemistry* (Cambridge, MA: MIT Press, 2012). For a philosophical analysis that addresses the main issues but, in my judgment, goes a bit too far in denying realism in chemistry, see Bensaude-Vincent and Simon, *Chemistry: The Impure Science*, 201–14.

[158]This is not to say that this absolutely precludes ideological challenges. For an example of an ideological challenge to chemistry and its applications to science-faith dialogue, see Stephen M. Contakes and Garrett Johnson, "Suggestions for Thinking and Talking about Science and Religion from the Soviet Resonance Controversy, a Chemical Counterpoint to Lysenkoism," *Perspectives on Science and Christian Faith* 65, no. 4 (2013): 219–32, https://www.asa3.org/ASA/PSCF/2013/PSCF12-13Contakes.pdf.

[159]The classical discussion of methodological parallels between theological and scientific reasoning is Nancey C. Murphy, *Theology in the Age of Scientific Reasoning* (Ithaca, NY: Cornell University Press, 1993).

[160]Among these, the writings of John Hedley Brooke, David Knight, Lawrence Principe, and William R. Newmann are perhaps the most useful starting points. These include Brooke, "Chemistry"; ___, "Chemistry with and without God," in *Science without God? Rethinking the History of Scientific Naturalism*, ed. Peter Harrison and Jon H. Roberts (Oxford, UK: Oxford University Press, 2019), 110–29; ___, *Science and Religion: Some Historical Perspectives* (Cambridge, UK: Cambridge University Press, 1991); ___, "Science and Theology in the Enlightenment," in *Religion and Science: History, Method, Dialogue*, ed. W. M. Richardson and W. J. Wildman (London, UK: Routledge, 1996); ___ and G. N. Cantor, "Improving on Nature?," in *Reconstructing Nature: The Engagement of Science and Reli-*

gion (Oxford, UK: Oxford University Press, 2000): 314–46; Knight, "Chemical Sciences and Natural Theology"; ___, "Chemistry," in *Encyclopedia of Science and Religion*, ed. Jay Wentzel van Huyssteen (New York: Macmillan Reference, 2003), 103–6; ___, *Ideas in Chemistry: A History of the Science* (New Brunswick, NJ: Rutgers University Press, 1992); Peter Harrison, "Theology and the Meaning of Matter in the Early Modern Period," in *Matter and Meaning: Is Matter Sacred or Profane?,* ed. Michael Fuller (Newcastle upon Tyne, UK: Cambridge Scholars, 2010), 40–56; John Henry, "Theology and the Meaning of Matter"; Principe, *The Secrets of Alchemy*; ___ and Robert Boyle, *The Aspiring Adept: Robert Boyle and His Alchemical Quest: Including Boyle's "Lost" Dialogue on the Transmutation of Metals* (Princeton, NJ: Princeton University Press, 1998); and William R. Newman, *Promethean Ambitions: Alchemy and the Quest to Perfect Nature* (Chicago, IL: University of Chicago Press, 2004).

[161]For a broad overview of Early Christian thinking about nature and its relevance for contemporary applications, see Paul M. Blowers, *Drama of the Divine Economy: Creator and Creation in Early Christian Theology and Piety* (Oxford, UK: Oxford University Press, 2013).

[162]Here it should be noted that there is no sharp dividing line in time at which chemistry became differentiated from alchemy. For more on this point, see Principe, *The Secrets of Alchemy*; William R. Newman, *Atoms and Alchemy* (Chicago, IL: University of Chicago Press, 2010); and William R. Newman and Lawrence M. Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* (Chicago IL: University of Chicago Press, 2010).

[163]It would detract from the purposes of this essay to present the vast literature on the history of atomism. An accessible, if slightly dated, starting point is Bernard Pullman, *The Atom in the History of Human Thought* (Oxford, UK: Oxford University Press, 1998).

[164]Modern chemical atoms differ markedly from the indivisible classical atoms of Epicurus, Leucippus, and Democritus; unlike classical atoms, they can explain the structure and properties of matter at the molecular level. A failure to understand this has led to significant misunderstandings about early Christian objections to atomism. In fact, to the extent the church fathers addressed atomism (which was not often) they rightly objected that atomic thinkers (namely, Epicureans) lacked the sort of coherent theory of chemical structure and bonding needed to actually explain chemistry. Similar objections also undergirded many nineteenth-century chemists' reluctance to fully accept Dalton's ideas as true. The classic statement of ateleological Epicurean atomism is Titus Lucretius Carus, *On the Nature of Things,* trans. Martin Ferguson Smith (Indianapolis, IN: Hackett Publishing, 2001). For the early Christian reception of atomism, see John W. Haas Jr., "Atoms and Atheism: The Changing Ways That Christians Have Viewed the Nature of Matter," American Scientific Affiliation, June 2007, http://www.asa3.org/ASA/topics/Physical%20Science/atomism.html; and Karissa D. Carlson, "The Other 'Atom' in Christianity and Science," *God and Nature* (Fall 2014) and the references therein, https://godandnature.asa3.org/essay-the-other-atom-in-christianity-and-science-by-karissa-d-carlson.html. On the connection between teleology and atomism, see David Sedley, *Creationism and Its Critics in Antiquity* (Berkeley, CA: University of California Press, 2008). For early Christian engagement with ateleological thinking, see Arthur Stanley Pease, "Caeli Enarrant," *The Harvard Theological Review* 34, no. 3 (1941): 163–200, https://www.jstor.org/stable/1508031.

[165]On the rehabilitation of the vacuum and its consequences for the development of atomism, see Edward Grant, *Much Ado about Nothing: Theories of Space and Vacuum from the Middle Ages to the Scientific Revolution* (Cambridge, UK: Cambridge University Press, 1981); and Andrew Pyle, *Atomism and Its Critics: From Democritus to Newton* (Bristol, UK: Thoemmes Press, 1997).

[166]Gassendi's program was part of a larger revival of interest in classical learning (humanism) and mechanistic explanations (the mechanical philosophy). For more on Gassendi, see Lynn Sumida Joy, *Gassendi the Atomist: Advocate of History in an Age of Science* (Cambridge, UK: Cambridge University Press, 1987). On the Christian appropriation of Epicureanism more generally, see Ada Palmer, "Humanist Dissemination of Epicureanism," in *The Oxford Handbook of Epicurus and Epicureanism*, ed. Phillip Mitsis (Oxford, UK: Oxford University Press, 2020), https://doi.org/10.1093/oxfordhb/9780199744213.013.34. For more on the early modern rehabilitation of atomism, see William B. Ashworth Jr., "Christianity and the Mechanistic Universe," in *When Science & Christianity Meet*, ed. David C. Lindberg and Ronald L. Numbers (Chicago, IL: University of Chicago Press, 2003), 61–84; and Carlson, "The Other 'Atom' in Christianity and Science."

[167]Stoichiometric chemistry research would culminate in the recognition of the laws of mass conservation by Lavoisier, definite proportions by Proust, and multiple proportions by Dalton, and ultimately atomic-molecular theory.

[168]Frank M. Turner, "Ancient Materialism and Modern Science: Lucretius among the Victorians," in *Contesting Cultural Authority: Essays in Victorian Intellectual Life* (Cambridge, UK: Cambridge University Press, 1993), 262–83. For a modern example of a highly selective revisionist history, see Victor J. Stenger, *God and the Atom* (Amherst, NY: Prometheus Books, 2013).

[169]Hebrews 13:7.

[170]Moran, *Paracelsus;* Debus, *The Chemical Philosophy;* Walton, *Genesis and the Chemical Philosophy*; Charles Webster, *Paracelsus: Medicine, Magic and Mission at the End of Time* (New Haven, CT: Yale University Press, 2008); and Walter Pagel, *Paracelsus: An Introduction to Philosophical Medicine in the Era of the Renaissance,* 2nd, revised edition (Basel, Switzerland: Karger, 1982).

[171]Debus, *The Chemical Philosophy,* 117–26.

[172]Walter Pagel, *Jan Baptista van Helmont: Reformer of Science and Medicine* (Cambridge, UK: Cambridge University Press, 2002); and Walton, *Genesis and the Chemical Philosophy.*

[173]Walton, Ibid.

[174]For starting points, see Hunter, *Boyle: Between God and Science*; R. Hooykaas, *Robert Boyle: A Study in Science and Christian Belief* (Lanham, MD: University Press of America, 1997); Davis, "A Priest Serving in Nature's Temple"; and Principe, *The Aspiring Adept.*

[175]The literature on Dalton's religious views is sparse. For starting points, see A. L. Smyth, *John Dalton, 1766–1844: A Bibliography of Works by and about Him,* 2nd edition (London, UK: Routledge, 2020).

[176]For starting points, see Cantor, *Michael Faraday: Sandemanian and Scientist*; Colin A. Russell, "Faraday Paper No. 13: Science and Faith in the Life of Michael Faraday," Cambridge, UK: The Faraday Institute for Science and

Religion, 2007, https://www.faraday.cam.ac.uk/shop/paper-13-science-and-faith-in-the-life-of-michael-faraday/; and the references in Stephen M. Contakes, "Faraday, Michael," in *Dictionary of Christianity and Science*, ed. Paul Copan et al. (Grand Rapids, MI: Zondervan, 2017), 279–80.

[177]Contakes and Kyle, "Josiah Parsons Cooke Jr." Cooke's work was well received by some leading Protestant thinkers, but as a Unitarian, he might also be considered to have a more complicated relationship with orthodox Christianity.

[178]For starting points on Draper's thought, see James C. Ungureanu, *Science, Religion, and the Protestant Tradition: Retracing the Origins of Conflict* (Pittsburgh, PA: University of Pittsburgh Press, 2019); Donald Fleming, *John William Draper and the Religion of Science* (New York: Octagon Books, 1972); and Stephen M. Contakes, "Draper, John," in *Dictionary of Christianity and Science*, ed. Copan et al., 190–91.

[179]Alan J. Rocke, *The Quiet Revolution: Hermann Kolbe and the Science of Organic Chemistry* (Berkeley, CA: University of California Press, 1993), 39–41, and Brooke, "Chemistry with and without God."

[180]Judah Ginsberg, "George Washington Carver: Chemist, Teacher, Symbol" (Washington, DC: American Chemical Society, 2006), https://www.acs.org/content/dam/acsorg/education/whatischemistry/landmarks/carver/george-washington-carver-commemorative-booklet.pdf; and Gary R. Kremer, *George Washington Carver: In His Own Words,* 2nd edition (Columbia, MO: University of Missouri Press, 2017).

[181]Charles M. A. Stine, *A Chemist and His Bible*, 3rd edition (Philadelphia, PA: Sunday School Times, 1947).

[182]Agustí Nieto-Galan, *The Politics of Chemistry: Science and Power in Twentieth-Century Spain* (Cambridge, UK: Cambridge University Press, 2019), 126–35; and Antoni Malet, "José María Albareda (1902–1966) and the Formation of the Spanish Consejo Superior de Investigaciones Científicas," *Annals of Science* 66, no. 3: 307–32, https://doi.org/10.1080/00033790902961819.

[183]E. F. Caldin, "The Structure of Chemistry in Relation to the Philosophy of Science," *Hyle – International Journal for the Philosophy of Chemistry* 8, no. 2 (2002): 103–21, http://www.hyle.org/journal/issues/8-2/caldin.pdf.

[184]Bernhard Witkop, *Biographical Memoir of Percy Lavon Julian* (Washington, DC: National Academy of Sciences, 1980). See also the essays by and about Julian in *The Chemist* 42, no. 3 (1965), https://archive.org/details/sim_chemist_1965-03_42_3.

[185]The literature on Polanyi is too vast to do justice here. For starting points, see the references in Stephen M. Contakes, "Polanyi, Michael," in *Dictionary of Christianity and Science*, ed. Copan et al., 519–21.

[186]Miller and Contakes, "Crystallographer, Quaker, Pacifist."

[187]Hawkin and Hawkin, *The Word of Science*; and Leegwater, "Charles Alfred Coulson."

[188]Alister McGrath, "Arthur Peacocke (1924–2006)," in *Science and Religion: A New Introduction,* 2nd edition (Chichester, UK: Wiley-Blackwell, 2010). 209–12; and T. A. Smedes, "Arthur Peacocke," in *The Blackwell Companion to Science and Christianity*, ed. J. B. Stump and Alan G. Padgett (Chichester, UK: Wiley-Blackwell, 2012), 589–99.

[189]Peter J. T. Morris, "Professor C. A. Russell CChem FRSC, 1928–2013," Royal Society of Chemistry, Obituaries of RSC Members, 2010–2015, https://www.rsc.org/membership-and-community/member-obituaries/2010-2015/professor-c-a-russell-cchem-frsc/.

[190]Alister McGrath, "Brief Biography," http://alistermcgrath.weebly.com/biography.html.

[191]John B. Goodenough, *Witness to Grace* (Baltimore, MD: PublishAmerica, 2008).

[192]Richard Greene, "Renowned Chemist Is a Bold Witness for Christ," *Decision* (March 1, 2019), https://decisionmagazine.com/renowned-chemist-is-a-bold-witness-for-christ/.

[193]A slightly dated starting point is Stephen M. Contakes, "Henry F. Schaefer III," in *Dictionary of Christianity and Science*, ed. Copan et al., 585–87.

[194]Jonathan Howard Fisher, "Gish, Duane," in *Dictionary of Christianity and Science*, ed. Paul Copan et al., 332–33.

[195]One starting point is Stephen M. Contakes, "Behe, Michael," in *Dictionary of Christianity and Science*, ed. Paul Copan et al., 62–64.

[196]Fazale "Fuz" Rana, President and CEO of Reasons to Believe, https://reasons.org/team/fazale-rana.

[197]Eberlin, *Foresight*.

[198]Karl E. Johnson and Keith Yoder, "Chemist as Complementarian: An Interview with Robert C. Fay," *Perspectives on Science and Christian Faith* 61, no. 4 (2009): 233–39, https://www.asa3.org/ASA/PSCF/2009/PSCF12-09Johnson.pdf.

[199]Troy Van Voorhis, *Certainty: Is Science All You Need?* (Cambridge, MA: The Veritas Forum, 2014).

[200]David A. Vosburg, "The Personal Journey of a Faith-Filled Scientist," *The Claremont Ekklesia: A Journal of Christian Thought at the Claremont Colleges* (Fall 2013), https://issuu.com/claremontekklesia/docs/the-claremont-ekklesia-fall-2013/2; also on *BioLogos* (September 24, 2013), https://biologos.org/personal-stories/the-personal-journey-of-a-faith-filled-scientist; and David A. Vosburg and Kate Vosburg, *Jesus, Beginnings, and Science: A Guide for Group Conversation* (Farmville, VA: Pier Press, 2017).

[201]Sy Garte, *The Works of His Hands: A Scientist's Journey from Atheism to Faith* (Grand Rapids, IL: Kregel Publications, 2019).

[202]Ashutosh Jogalekar, "Jesuits, Science and a Pope with a Chemistry Degree: A Productive Pairing?," *Scientific American* (March 13, 2013), https://blogs.scientificamerican.com/the-curious-wavefunction/jesuits-science-and-a-pope-with-a-chemistry-degree-a-productive-pairing/.

[203]Leegwater, "A Brief Excursion in Chemistry." Examples include Leegwater, "Charles Alfred Coulson"; Contakes and Kyle, "Josiah Parsons Cooke"; Nieto-Galan, *The Politics of Chemistry*; and Malet, "José María Albareda."

[204]The debate is framed by H. Richard Niebuhr, *Christ and Culture* (New York: Harper & Brothers, 1956) which has been nuanced in D. A. Carson, *Christ and Culture Revisited* (Cambridge, UK: Eerdmans, 2013); with additional influential perspectives in Stanley Hauerwas and William H. Willimon, *Resident Aliens: Life in the Christian Colony* (Nashville, TN: Abingdon Press, 1989); and James Davison Hunter, *To Change the World: The Irony, Tragedy, and Possibility of Christianity in the Late Modern World* (Oxford, UK: Oxford University Press, 2010).

[205]For more on work and vocation, see Miroslav Volf, *Work in the Spirit: Toward a Theology of Work* (New York: Oxford University Press, 1991); Darrell Cosden, *A Theology of Work: Work and the New Creation* (Eugene, OR: Wipf & Stock, 2006); Timothy Keller, *Every Good Endeavor: Con-*

necting Your Work to God's Work (New York: Dutton, 2012); and Scott Waalkes, "Rethinking Work as Vocation," *Christian Scholar's Review* 44, no. 2 (2015): 135–53.

[206]On chemistry as a political activity, see Nieto-Galan, *The Politics of Chemistry*. For science as politics more generally, see Sheila Jasanoff, *States of Knowledge: The Co-Production of Science and Social Order* (London, UK: Routledge, 2004). For Anabaptist, Lutheran, Black Church, Calvinist, and Catholic Natural Law perspectives on Christian engagement with politics, see Amy E. Black, ed., *Five Views on the Church and Politics* (Grand Rapids, MI: Zondervan, 2015).

[207]This incident also awaits adequate exploration. The contours of the debate may be gleaned from my account of the Dow Napalm controversy in Contakes and Jashinsky, "Ethical Responsibilities in Military-Related Work"; along with insights into the religious perspectives of the main actors given in E. N. Brandt, *Chairman of the Board: A Biography of Carl A. Gerstacker* (East Lansing, MI: Michigan State University Press, 2003), 93–103, 206; and Wells, *The War Within*, 449–52. For a concise summary of Dow's position, see "1968 Dow Chemical Response to Its Production of Napalm," *Resistance and Revolution: The Anti-Vietnam War Movement at the University of Michigan, 1965–1972*, http://michiganintheworld.history.lsa.umich.edu/antivietnamwar/items/show/139.

[208]For more on this point, see Kristen Deede Johnson, "Justice, Creation, and New Creation: In Christ All Things Hold Together," in *Creation and Doxology: The Beginning and End of God's Good World,* ed. G. Hiestand and Todd Wilson (Downers Grove, IL: IVP Academic, 2018), 183–200.

[209]For more on Bacon's context, see Power, *Roger Bacon and the Defence of Christendom.* Note also that the moral status of chemical weapons was in flux prior to the twentieth century. Some early twentieth-century advocates even claimed chemical weapons would be more humane than conventional weapons and recently it has even been argued that there is a taboo over chemical weapons rather than a considered moral judgment. See Richard M. Price, *The Chemical Weapons Taboo* (Ithaca, NY: Cornell University Press, 1997).

[210]Peter J. Bowler, "Ideology and Futurology in Early 20th-Century Britain: Wells, Haldane, Bernal, and Their Critics," in *Defending the Faith: Global Histories of Apologetics and Politics in the Twentieth Century,* ed. Todd Weir and Hugh McLeod (Oxford, UK: Oxford University Press, 2020), published online at British Academy Scholarship Online, January 11, 2021, https://doi.org/10.5871/bacad/9780197266915.001.0001; and J. D. Bernal, *The World, the Flesh and the Devil: An Enquiry into the Future of the Three Enemies of the Rational Soul* (London, UK: Kegan Paul, Trench & Trübner, 1929).

[211]P. W. Atkins, "Awesome Versus Adipose: Who Really Works Hardest to Banish Ignorance?," *Free Inquiry* 18, no. 2 (1998): 18; ___, *The Creation* (Oxford, UK: W.H. Freeman, 1981); ___, *Creation Revisited* (London, UK: Penguin Books, 1994); and ___, *On Being: A Scientist's Exploration of the Great Questions of Existence* (Oxford, UK: Oxford University Press, 2011).

[212]Harry Kroto, "An Essay on My Present 'Skeptical' Philosophical Perspective and 'Good Enough Theories,'" The Nobel Prizes 1996, ed. Tore Frängsmyr (1997), https://www.sheffield.ac.uk/kroto/legacy/life/opinions.

[213]L. Cardellini, "Looking for Connections: An Interview with Roald Hoffmann," *Journal of Chemical Education* 84, no. 10 (2007): 1634.

[214]William B. Jensen, *Frankenstein's Cat and Other Assorted Lectures on Skepticism and Secular Humanism,* rev. edition (Cincinnati, OH: The Epicurean Press, 2015).

[215]Reino Virtanen, *Marcelin Berthelot: A Study of a Scientist's Public Role* (Lincoln, NE: University of Nebraska, 1965).

[216]Arrhenius put forward an early argument for panspermia in "The Transmission of Life through the Universe," *The Monist* 18, no. 2 (1908): 161–75, https://doi.org/10.5840/monist190818224, as well as secular views of the universe as infinite in "Infinity of the Universe," *The Monist* 21, no. 2 (1911): 161–73, https://doi.org/10.5840/monist191121228.

[217]Caspar Hakfoort, "Science Deified: Wilhelm Ostwald's Energeticist World-View and the History of Scientism," *Annals of Science* 49 (1992): 525–44, https://doi.org/10.1080/00033799200200441. Among the more interesting of Ostwald's works are Wilhelm Ostwald, *Monism as the Goal of Civilization,* ed. The International Committee of Monism (Leipzig, DEU: Druck der Spamerschen, 1913); and Wilhelm Ostwald, *Monistische Sonntagspredigten, Reihe 1–5* [Monist Sunday Sermons] (Leipzig, DEU: Unesma, 1911–1916).

[218]For examples, see Colin A. Russell, *Edward Frankland: Chemistry, Controversy and Conspiracy in Victorian England* (Cambridge, UK: Cambridge University Press, 2003); Robert E. Schofield, *The Enlightenment of Joseph Priestley: A Study of His Life and Work from 1733 to 1773* (University Park, PA: Pennsylvania State University Press, 1997); ___, *The Enlightened Joseph Priestley: A Study of His Life and Work from 1773 to 1804* (University Park, PA: Pennsylvania State University Press, 2004); John Brooke, "Joining Natural Philosophy to Christianity: The Case of Joseph Priestley," *Heterodoxy in Early Modern Science and Religion,* ed. John Brooke and Ian Maclean (Oxford, UK: Oxford University Press, 2005), 319–36; and David Knight, *Humphrey Davy: Science & Power* (Cambridge, UK: Cambridge University Press, 1996).

[219]For an attempt to engage materialism in chemistry, see Greta Bryson, "Is There Meaning beyond the Biomolecular?," in *Not Just Science: Questions Where Christian Faith and Natural Science Intersect,* ed. Dorothy F. Chappell and E. David Cook (Grand Rapids, MI: Zondervan, 2005), 234–42. For an analysis of noncognitive elements in organized skepticism, see Jay A. Labinger, "Organized Skepticism, Naive Methodism, and Other -ISMS," *Foundations of Chemistry* 8, no. 2 (2006): 97–110, https://doi.org/10.1007/s10698-004-3531-2.

[220]Drees, "Playing God? Yes."

[221]Noah J. Efron, "The Meeting of Science and Religion in Real Life," *The BLOG*, published electronically January 28, 2011, and updated May 25, 2011, http://www.huffingtonpost.com/noah-efron/what-science-religion-are_b_814295.html.

[222]To my knowledge, this connection has not been explored in the literature, although some authors have explored the connection between plastics and materialist culture, albeit sometimes in only analogical terms. See Dave Bookless, "Plastic Theology," *A Rocha Blog,* July 31, 2018, https://blog.arocha.org/en/plastic-theology/; and Lints, *Identity and Idolatry*, 153–65.

Animal Science

GOD'S FUTURE FOR ANIMALS: From Creation to New Creation by Raymond R. Hausoul. Eugene, OR: Wipf & Stock, 2021. 284 pages. Paperback; $34.00. ISBN: 9781666703405.

Raymond Hausoul's new book, *God's Future for Animals*, argues that the place of animals as part of God's intention for the world has not received enough attention as it pertains to how animals have fit into creation in the present time or as a part of the eschaton. It is derived from the author's doctoral dissertation and, as such, it is scholarly in tone and well sourced, at least from the standpoint of theology and church history. Hausoul takes the reader on a journey from the creation as described in Genesis and through biblical history: the consideration of animals by the early church fathers, modern society's relationship with animals, and on to how animals will be viewed during the end times. This is an ambitious task and it makes for very dense reading. The book is about animals but there are lengthy sections in which animals are hardly mentioned, primarily because the author takes considerable time to include details (outlined in a previous book) about the new heaven and new earth. Hausoul also takes a lot of time expanding on the creation story.

At this point in the review, I think that it is fair to be transparent about myself so my biases are clear. I have spent the last 42 years teaching, doing research, and assisting livestock producers in the ways that genetics can be used to improve the efficiency of producing animal products that can benefit humans. With few exceptions, my experience was with livestock producers who took impeccable care of their animals because to do otherwise would compromise the economics of their farm or ranch. I also witnessed producers who cared deeply about the welfare of the animals in their charge. I offer this background because the reader should know why I take considerable issue with the way that the author makes assertions about food that comes from animals, the production methods that are used to produce it, and the people who are involved in the production.

Unlike the detailed literature references concerning theology and church history, Hausoul makes numerous declarations about animals with little or no reference to the literature and, at times, with little or no reference to the reality I experienced and observed. His description of the foot-and-mouth outbreak of 2001 is a case in point (pp. 214–15). This is a very debilitating disease which is highly transmissible. The United States has taken extreme care to ensure that the disease does not enter the country since the last outbreak in 1929. Hausoul implies that it is not very severe and dismisses the need for dramatic measures to eradicate it. He is confused about whether horses are cloven-hoofed (they aren't) and seems puzzled by the fact that horses were not included in the eradication measures (they do not contract foot-and-mouth disease). He also suggests that the cattle producers saw the eradication measures only in economic terms because "they had no emotional bond with their animals" (p. 214). This assertion differs from nearly all of my observations of livestock producers. A simple search of the literature would reveal the considerable evidence of the mental health problems suffered by livestock producers following the outbreak. Unfortunately, there were no references to any outside literature in the paragraph describing the foot-and-mouth disease.

Hausoul's enthusiasm for a vegetarian diet is clear. The entire last chapter is devoted to the topic of vegetarianism. There are certainly ways to have a healthful diet without using animal products but the author takes that argument in directions which strain credulity. He writes extensively about efforts to assert that Jesus was a vegetarian and seems to lament the idea that the evidence does not support that conclusion (pp. 211–13). It is argued that vegetarian diets were becoming more popular in the first half of the twentieth century but the fact that Hitler was a vegan turned people against such diets (p. 210). It is asserted that "eating meat can evoke immoral lusts in a human being" (p. 209) without supporting evidence. It is implied that the extreme ages of the Patriarchs were due to their vegetarian diets and that the human life span reduced rapidly as soon as they started eating meat (p. 213). Proverbs 15:17 is quoted as support for a vegetarian diet (p. 210), although it would appear that the more important point of the verse is that any meal eaten in love is better than even an elaborate meal eaten in hate.

The author expresses views about scripture that are consistent with young-earth creationism. However, there is very limited reference to that literature and, for the most part, the writing does not resemble the young-earth literature I have read. It may be that he simply accepts all of the scripture at face value or that it is more straightforward, theologically, to describe events in the Bible exactly as written. I have already mentioned his acceptance of the extreme ages of the patriarchs (p. 213). Hausoul appears to accept

as factual the six-day timeline outlined in Genesis 1 and goes to considerable detail in describing some of the busier days. There is acceptance of the idea that there was no death in the original creation and that means that some of the original animals had to go through considerable change in order to start eating meat. There is in some, though not total, sense that whether animals (including humans) are herbivores or carnivores is simply a matter of choice. The topic in which this book most resembles the literature of young-earth creationism is in its consideration of the Genesis flood. There is considerable discussion (including tables) about how the ark could accommodate all of the necessary animals (pp. 93–96).

I will move toward closing this review with a sentence from the book which, frankly, stopped me in my tracks: "After having tried sex with all animals, Adam finally found his partner and extinguished his sexual urge" (p. 41). Hausoul goes on to suggest that the originators of that idea may have been referring to "intellectual or spiritual sex" (p. 41), as if that provides clarity about the idea or why it is a necessary addition to the book.

Overall, my conclusion about the book is that it edges very close to being an agenda that is searching for a theology. The theological discussion is quite deep but it is hard to avoid the notion that many theological points are driven to agree with preconceived conclusions about animals and the products they produce. Assessing this notion is not aided by the fact that almost all of the contemporary observations about animals are made as declarations without support from pertinent literature. This is, by far, my most significant criticism, especially for a book that is obviously presented as a scholarly contribution. Nonetheless, a reader with an interest in a theology of animals could benefit considerably from an examination of the sources discussed in the book.

Reviewed by David S. Buchanan, Professor of Animal Sciences, North Dakota State University, Fargo, ND 58108.

Evolutionary Science

THE HOURS OF THE UNIVERSE: Reflections on God, Science, and the Human Journey by Ilia Delio. Maryknoll, NY: Orbis Books, 2021. 242 pages, index. Paperback; $25.00. ISBN: 9781626984035.

In this exquisitely constructed book, Delio reveals the current state of her reflections on the central concern of her life and work: the relationship of God, humanity, and the universe in the context of the evolutionary process. Her unscripted career leading to this publication, narrated in her memoir *Birth of a Dancing Star: My Journey from Cradle Catholic to Cyborg Christian*, has exhibited the same sort of development and diversity that she finds woven into the fabric of the universe. A Franciscan sister who began her religious life as a cloistered member of the Carmelite order, Delio earned doctorates in pharmacology and historical theology and has taught at Trinity College, Washington Theological Union, Georgetown University, and Villanova University. Today, she is an award-winning author, best known for her Center for Christogenesis, which seeks to promote dialogue between faith and reason and stimulate a Christian spirituality fully infused with evolutionary consciousness.

Communicating the urgent need and prospects for that kind of spirituality is the burden of this, Delio's twentieth, book. A theology whose starting point is not evolution and the story of the universe, she insists, is a "useless fabrication" (p. xvi). Her work is rich in scriptural references, but the call to restore the book of nature to its primacy as the true first testament in Christianity's sacred canon is one of her signature themes. Though she displays no interest in apologetics or polemics, her basic assumption is the distinctively Catholic principle of the revelatory character of creation, a conviction at odds with the Protestant Reformers' suspicion of natural theology. A robust sacramental imagination permeates the entire book and provides its organizational design. Portraying the universe as the "new monastery" (p. xvii), Delio orders her reflections according to the liturgy of the hours that has structured daily prayer in Christian monastic communities for centuries: Matins, Lauds, Prime, Terce, Sext, None, Vespers, and Compline. Delio clusters her chapters—along with prologues of original poetry—around these times of contemplation and guides the reader through the prayers of one rotation of the earth and toward what she calls a new synthesis of faith and science.

Delio's thirty-two brief chapters, each a free-standing essay, cover a broad spectrum of topics from the cosmic to the autobiographical—from quantum physics, gravitational waves, and artificial intelligence to the Eucharist during the coronavirus pandemic and the death of her beloved cat Mango. Delio addresses a number of social issues such as racism, consumerism, and homophobia and sets the full scope of her reflections against the backdrop of the threat of climate change. Her main objective is the nurturing of a Christianity mature enough to match the

achievements and insights of contemporary science. In this effort, her primary dialogue partners include interfaith scholar Beatrice Bruteau, Passionist priest and self-styled geologian Thomas Berry, Hindu-Catholic mystic Raimon Panikkar, and luminaries from her elected Franciscan tradition such as Saint Francis, Bonaventure, and the contemporary spiritual writer and retreat leader Richard Rohr. Pope Francis's unprecedented encyclical on creation care, *Laudato Si'*, is a constant touchstone for Delio, but pride of place in her personal communion of saints is granted to the Jesuit paleontologist Pierre Teilhard de Chardin, whose transposition of Catholic Christianity into an evolutionary key animates virtually every page of the book.

Delio's essays orbit this Teilhardian view of things like planets in an intellectual galaxy characterized by both order and chaos. The overall effect is a prophetic warning regarding the irrelevance and near-obsolescence of any Christian system fixated on the categories of Aristotelian or Newtonian worldviews. Like her monastic and mendicant forebears, Delio calls for church reform and creative thinking. The dominant mood of the book, though, is a blend of hope and awe, even audacity. Delio's conclusion equates the rise of a "new species with a new God consciousness" (p. 240) with the second coming of Christ.

Delio's engaging book is limited by its scant attention to the menacing side of science and technology, its failure to reckon seriously with the dramatic rise of nonreligion that calls her privileging of Christian myth into question, its overestimation of the general reader's science literacy, and its tendency to align scholarly and homiletic modes of communication too closely and too uncritically. Readers seeking linear arguments for theistic evolution or Christian pantheism will have to look elsewhere. Clergy, advanced students, and believing specialists in theology and the natural sciences will find a provocative and prayerful statement of a unique Christian cosmology that informs and inspires.

Reviewed by Peter A. Huff, Professor of Religious Studies and Director of the Center for Benedictine Values, Benedictine University, Lisle, IL 60532.

Book Reviewers Welcome

If you would be open to being asked to write a book review, please send a brief email that describes your areas of expertise and preferred mailing address to Stephen Contakes at scontakes@westmont.edu.

Psychology

THRIVING WITH STONE AGE MINDS: Evolutionary Psychology, Christian Faith, and the Quest for Human Flourishing by Justin L. Barrett with Pamela Ebstyne King. Downers Grove, IL: IVP Academic, 2021. 160 pages, index. Paperback; $20.00. ISBN: 9780830852932.

I was looking forward to reviewing this book for several reasons. Firstly, I have been following the work of Justin Barrett for some time. As a clinical psychologist working in academia in the UK, I taught for several years an undergraduate module in psychology of religion in which I dedicated several hours to his work in cognitive science and developmental psychology of religion. Barrett, formerly director of the Thrive Center for Human Development at Fuller Theological Seminary and, prior to that, director of the Centre for Anthropology and Mind at the University of Oxford, has forged an unlikely career for a person of faith in a subdiscipline of psychology popularly considered the sole preserve of skeptics and nonbelievers.

Secondly, if I carry a bugbear about the empirical psychology of religion, it is that at times it tends to avoid application, a sense of the implications of its findings for human living. In this respect, Barrett's collaboration with Pamela Ebstyne King is a welcome addition to this project. Currently based at Fuller Theological Seminary as executive director of the Thrive Center and Professor of Applied and Developmental Science, King adds applied nuance and some succinct epigrams that bring home the implications of evolutionary psychology in everyday life.

Thirdly, it seems very important to me that people of faith generally, and Christians particularly, continue to explore and write about the field of evolutionary psychology, not least because it is often presented as a competing narrative of even nonliteral readings of the Genesis account, in direct opposition to a benevolent creator and a universe that could be considered in any way purposeful. I have lost count of the number of young adults I have encountered who refuse to consider the possibility of there being a creator, or who have lost faith in God, as a result of reading secular or atheistic accounts of human evolution.

Barrett and King have produced a short and well-informed book designed for any interested intelligent reader. No prior knowledge of evolutionary

psychology (EP) is required to follow their train of thought. In the early chapters of the volume, they state clearly the basic principles of EP and how the EP account of what it means to be human is remarkably consistent with the biblical understanding of the hallmarks of human life designed in the image of God. They focus on three overlapping domains of competency that are notably human—sociality, expertise acquisition, and self-control—or, as King pithily summarizes: the human capacities to relate, learn, and regulate (p. 46). The early chapters of the book convincingly argue that there is nothing incompatible with these elements of human nature, properly understood, and the Christian anthropology presented in the Bible. Barrett and King successfully side-step contention or sides of the evolution-creation debate. Their point about the compatibility of evolutionary and theological perspectives is well made, and will be of interest for those who are open to it from any faith or nonfaith perspective.

From there, the authors go on to outline their understanding of flourishing from this evolutionary psychology perspective. They note that human nature, with its social, intellectual, and regulatory capacities, has a dual aspect. On the one hand, these capabilities were forged in response to particular niches in evolutionary history; on the other hand, they offer human beings the possibility of redesigning the very niches which formed us. And therein lies the central dilemma of evolutionary psychology referred to in the title of the book. As a species we find ourselves facing the demands of twenty-first-century industrial life with minds designed to deal with the challenges of living in the stone age. Much of the failure in human thriving can therefore be attributed, the authors argue, to the gap that can open up between the social, intellectual, and regulatory capacities of human nature, and the requirements of the contemporary cultural landscape.

Each of the three capacities of human nature is treated to an entire chapter, examining how they can be inadequate to the demands placed upon them in our current context. Examples include the stretching of our social brain ability to breaking point by large populations, the failure of traditional pedagogies to utilize well-established cognitive biases and heuristics, and the overwhelming of our regulatory ability in the face of relentless advertising. We fail to thrive when the gap between human nature and human niche becomes too great, but human flourishing is promoted when we find ways of closing the gap between how we are designed and how we currently live. Barrett and King offer a raft of practical examples of how Christian faith and practice can contribute to this, such as network closure for socializing young people, age-appropriate education strategies for learning, and religious practices for building self-regulation. With these and many other evidence-based examples, the authors add evolutionary justification and theological depth to a common formulation in various forms of applied psychology, whether in clinical practice or the workplace, namely, that we flourish most when we fit our environment best.

The final two chapters take this proposition to its logical conclusion. Firstly, by querying what all this means for our status as bearers of the divine image, functionally commissioned to love God and one another, and to care for creation as God's representatives on Earth. And secondly, by giving space to a consideration of human purpose and telos. While Barrett and King avoid the suggestion that their book is aimed at those attempting to discern their vocation, the final chapter draws together the threads of their survey of human nature and its implications for flourishing with purpose and calling in life.

The book presents a convincing picture of consilience between evolutionary psychology and Christian theology applied in the real world. However, to my mind, it does leave a crucial question hanging. It is one thing to argue that the *outcome* of the evolutionary process is compatible with a Christian view of humanity, but what remains unaddressed, in this volume at least, is whether the evolutionary *process* is compatible with a Christian view of God. After all, this is what bothered Darwin. He was not wary of publication for fear of contradicting a literal reading of Genesis, but because his view of the origins of human life based on industrial-scale bloodshed was difficult to square with the existence of a benevolent creator. Once the conceptual problem of evolutionary creation is settled, the emotional problem of evolutionary creation emerges; the question of evolution morphs into the question of pain and evil. Personally, it would have helped this reviewer to more easily assimilate the message of the book if it had addressed this issue even briefly. But be that as it may, Barrett and King offer a coherent and elegant account of the confluence of evolutionary psychology and Christian faith in the quest for human flourishing, which is well worth reading.

Reviewed by Roger Bretherton, Associate Professor of Psychology, University of Lincoln, UK, and Chair of the British Association of Christians in Psychology.

THE SCIENCE OF CHILDREN'S RELIGIOUS AND SPIRITUAL DEVELOPMENT by Annette Mahoney. Cambridge, UK: Cambridge University Press, 2021. 86 pages. Paperback; $20.00. ISBN: 9781108812771.

The Science of Children's Religious and Spiritual Development by Annette Mahoney is a recent addition to the Cambridge Elements Child Development series. Between an introduction and conclusion, Mahoney has five sections to guide her summary. Overall, her approach is well conceived, approachable, and highly informative. Having taught undergraduate courses on child development for fifteen years at Christian liberal arts institutions, I found Mahoney's volume to be a thorough yet concise resource on religious and spiritual development from which I can draw resources as well as enrich discourse with engaged students.

In her introduction, Mahoney quickly sets the stage for the importance of religious and spiritual development in children. She notes how parents around the world desire to raise "good" (prosocial) children. Religion is frequently cited as influencing their parenting practices. The emphasis in research is on adolescence and adulthood for the specific study of religious and spiritual development, leaving a large gap when it comes to how these issues pertain to children's development.

Mahoney draws from Harold Koenig, Michael McCullough, and David Larson to define Religious/Religion (R) and Spiritual/Spirituality (S).[1] She acknowledges that this is not an agreed upon straightforward process, and that often R and S are not substantively different in the social science literature. With children, perceptions of God are commonly examined, though this only begins to scratch the surface of what's beneath their RS development.

After a quick historical look at RS, Mahoney offers a brief overview of Fowler's faith development theory, citing his 1981 book, *Stages of Faith: The Psychology of Human Development and the Quest for Meaning*.[2] She concludes that his "assumptions perhaps helped to dampen interest by mainstream developmental scientists in investigating children's RS" (p. 6). Here I wanted to better understand her conclusion and felt that more explanation would be beneficial for her argument.

Mahoney frequently reminds the reader that most of the research, both historically and currently, occurs in Western societies. There have been a handful of measures developed, which she presents in a table with the name, authors, definitions of R and S, subscales, and example items (pp. 11–19). This is followed by a helpful narrative of each measure and a comparison of four models that emerge. The reader quickly observes the murky state of measuring RS. Prosocial behaviors and positive psychology concepts are intertwined with RS, and Mahoney calls for clearer communication and increased transparency.

Due to the lack of studies with children, Mahoney reviews adolescents' RS and related psychosocial adjustment. RS appears to influence the views and choices of adolescents in areas such as risk taking, self-esteem, and depression. Mahoney presents a well-articulated description of the "muddled middle" (p. 28). Adolescents with either a high or a low state of RS are best adjusted. It appears that RS ambivalence places adolescents at greatest risk. Factors such as cognitive dissonance and moral inconsistencies appear to be at play.

The few studies on children's psychosocial adjustment and RS seem to suggest that children with significant life stressors (e.g., family conflict) may benefit from RS. The reciprocal nature of the parent-child relationship has relevance, as greater parental RS shows both positive and negative outcomes. On the upside, parents with higher levels of RS are more efficacious and warm, which in turn increases children's social and academic functioning. On the downside, greater parental RS predicts greater parental behavioral control and less autonomy in children. This in turn can be linked to more emotional problems in children, both internalizing (e.g., depression, anxiety) and externalizing (e.g., acting out, delinquency). It is important to note that these levels of problems are typically subclinical.

Mahoney also reviews the relationship between corporal punishment and parental RS. The research is clear on physical punishment (e.g., spanking) being ineffective, resulting in greater negative outcomes. The findings are mixed with regard to RS. Parents with higher RS, particularly those with lower education, implement harsher parenting strategies; however, greater attendance of religious services has been linked to less use of such strategies. Furthermore, higher religious attendance has been found to be a protective factor when it comes to child maltreatment (i.e., abuse and neglect).

When parents are asked specifically about their parenting goals, it becomes evident that not many place fostering a high level of RS to their children at the top of the list. Goals that surpass it include nurturing high self-esteem and interpersonal skills,

contributing to the larger society, carrying on family and cultural traditions, and providing the necessary education for a good future. Again, these are primarily Western reports and Mahoney reminds the reader that other countries' perspectives are needed. Like non-Western studies, studies of nontraditional parenting units, such as single parents, same-sex parents, and economically disadvantaged parents, are underrepresented. Furthermore, the type of theistic schema provides another area of diversity that is lacking, as children can be reared in polytheistic, nontheistic, atheist, or agnostic environments.

Mahoney's final section looks at social and cognitive-developmental research. Concepts such as theory of mind and attachment enter the scene. The primary area that has been studied in children's RS development is their concept of God. Preliminary findings suggest that children's perceptions of God mirror how they are being parented (e.g., punishing parents → punishing God, nurturing parents → nurturing God, powerful parents → powerful God, etc.). Examining children's prayers also sheds some light on RS development, though again findings are mixed and limited. There is more work to be done.

Mahoney calls on social scientists to take the lead in providing guidance to parents to uphold the United Nations' *1989 Convention on the Rights of the Child* Article 14, 1–2 that states: "States Parties shall respect the right of the child to freedom of thought, conscience and religion; States Parties shall respect the rights and duties of the parents and, when applicable, legal guardians, to provide direction to the child in the exercise of his or her right in a manner consistent with the evolving capacities of the child."[3] More intentional investigation of children around the globe can help parents directly but also inform policy makers. Mahoney states that "one central observation is that this literature is in its infancy stage" (p. 62).

Overall, Mahoney's review of children's RS development in this volume is thorough yet concise, troubling yet hopeful, vague yet nuanced. She concludes with six key areas and related findings to recap how the scientific study of children's RS development can be improved in the years to come. Thankfully, RS has begun to attract significant attention in the field, including from the Templeton Foundation's attempt to build a more global community of social scientists.[4] After reading this book, I feel much better equipped to elucidate what is known and what is yet to be discovered. This is important, not only in academic communities of colleagues and students, but also in the broader communities of church and society and in our personal communities.

Notes

[1]Harold G. Koenig, Michael E. McCullough, and David B. Larson, *Handbook of Religion and Health* (New York: Oxford University Press, 2001).

[2]James W. Fowler, *Stages of Faith: The Psychology of Human Development and the Quest for Meaning* (New York: HarperSanFrancisco, 1981).

[3]United Nations Human Rights, "Convention on the Rights of the Child," *Treaty Series* 1577, no. 3 (1989): 1–23, https://www.ohchr.org/en/professionalinterest/pages/crc.aspx.

[4]J. D. Warren, "$10 Million Grant Will Study Children's Religious Views," University of California, Riverside, February 19, 2020, https://news.ucr.edu/articles/2020/02/19/10-million-grant-will-study-childrens-religious-views.

Reviewed by Erin Mueller, Professor of Psychology, Northwestern College, Orange City, IA 51041.

Technology

GENIUS MAKERS: The Mavericks Who Brought AI to Google, Facebook, and the World by Cade Metz. New York: Dutton, 2021. 371 pages including notes, references, and index. Hardcover; $28.00. ISBN: 9781524742676.

As Cade Metz says in the acknowledgments section, this is a book "not about the technology [of AI] but about the people building it … I was lucky that the people I wanted to write about were so interesting and so eloquent and so completely different from one [an]other" (p. 314).

And, that's what this book is about. It is about people such as Geoff Hinton, founder of DNNresearch, who, once he reached his late fifties, never sat down because of his bad back. It is about others who came after him, including Yann LeCun, Ian Goodfellow, Andrew Ng, Yoshua Bengio, Jeff Dean, Jürgen Schmidhuber, Li Deng, Ilya Sutskever, Alex Krizhevsky, Demis Hassabis, and Shane Legg, each of whom had their strengths, weaknesses, and quirks.

The book also follows the development of interest in AI by companies like Google, Microsoft, Facebook, DeepMind, and OpenAI. DeepMind is perhaps the least known of these. It is the company, led by Demis Hassabis, that first made headlines by training a neural network to play old Atari games such as Space Invaders, Pong, and Breakout, using a new technique called reinforcement learning. It attracted a lot of attention from investors such as Elon Musk, Peter Thiel, and Google's Larry Page.

While most companies were interested in the application of AI to improve their products, DeepMind's goal was AGI, "Artificial General Intelligence"—technology that could do anything the human brain could do, only better. DeepMind was also the first company to take a stand on two issues: if the company was bought out (which it was, by Google), (1) their technology would not be used for military purposes, and (2) an independent ethics board would oversee the use of DeepMind's AGI technology, whenever that would arrive (p. 116).

Part One of the book, "A New Kind of Machine," follows the early players in the field as they navigate the early "AI winters," experiment with various new algorithms and technologies, and have breakthroughs and disappointments. From the beginning, there were clashes between personalities, collaboration and competition, and promises kept and broken.

Part Two of the book, titled "Who Owns Intelligence?," explores how many of the people named above were wooed by the different companies, and moved back and forth between them, sometimes working together and sometimes competing with each other. The companies understood the power of neural networks and deep learning, but they could not develop the technologies without the direction of the leading researchers, who were in limited supply. To woo the best researchers, the companies competed to develop exciting and show-stopping technology, such as self-driving cars and an AI to play (and beat) the best in Chess and Go.

In Part Three, "Turmoil," the author explores how the players began to realize the shortcomings and potentially dangerous effects of the AI systems. AI systems were becoming more and more capable in a variety of tasks. "Deep fakes" of celebrities and the auto-generation of fake news (often on Facebook) led many to question the direction AI was going. Ian Goodfellow said, "There's a lot of other areas where AI is opening doors that we've never opened before. And we don't really know what's on the other side" (p. 211). One surprising figure taking a stand on the side of caution was Elon Musk, giving repeated warnings of the possible rise of superintelligent actors. Further, it was discovered that the Chinese government was already using AI to do facial recognition and track its citizens as they moved about.

Other concerns dampened the community: it was discovered that small and unexpected flaws in training could have significant effects on the ability of an AI system to do its job. For example, "by slapping a few Post-it notes on a stop sign, [researchers] could fool a car into thinking it wasn't there" (p. 212).

Additionally, the biases in training data were being exposed, leading some to believe that AI systems would not equally benefit minority groups, and could even discriminate against them. Furthermore, Google was being approached by the US government to assist in the development of programs which could be used in warfare. Finally, Facebook was struggling to contain fake news and finding that even AIs could not effectively be used to combat it.

In the final sections of the book, the author explores the AI researchers' attitudes toward the future and the big questions. Will AI systems be able to eventually take over all work, even physical labor? Can the AI juggernaut be controlled and directed? Will AGI be fully realized?

This last question is explored in the chapter titled "Religion." "Belief in AGI required a leap of faith. But it drove some researchers forward in a very real way. It was something like a religion," said roboticist Sergey Levine (p. 290). The question of the feasibility of AGI continues to generate much debate, with one camp claiming that it is inevitable, while the other camp insisting that AI systems will excel only in limited tasks and environments.

As a Christian, I found the debates about the proper role of AI to be intriguing. Is the development of AGI inevitable? Should we as Christians petition companies and governments to have debates on the pursuit of AGI? Should we enact laws to limit or prohibit the use of AI in warfare? Should independent evaluators be required to review AI systems regarding discrimination? Should Christians participate in the further development of AGI?

Learning the histories and attitudes of the leading individuals in the development of AI also intrigued me. Many of the individuals seem to have very little concern for the potentially negative impact of their work. Their only motivation seems to be fame and fortune. It makes me wonder if the field of computer science should require all its practitioners to take ethics training like professional engineers are required to do. This book certainly confirms the importance of ethics in the field of computer science and the need for its practitioners to be people of virtue.

In summary, this was a different kind of book from many others in the field of technology. It was fascinating that so much of what I was reading about had

happened in just the last ten years. Hearing the anecdotes of back-office meetings, public outcries, and false claims was intriguing. If you, like me, wonder how we got to where we are today in the area of AI, this is the book for you.

Reviewed by Victor T. Norman, Assistant Professor of Computer Science, Calvin University, Grand Rapids, MI 49546.

TEACHING MACHINES: The History of Personalized Learning by Audrey Watters. Cambridge, MA: The MIT Press, 2021. 313 pages. Hardcover; $34.95. ISBN: 9780262045698.

Teaching Machines, by freelance writer, researcher, and technology commentator Audrey Watters, is a history framed by a critical rallying cry. The main body of the book is a history of the development and demise of "teaching machines" (mechanical devices for self-paced, programmed instruction) from the 1920s to the 1960s. It attends closely to the extent and limits of the influence of B. F. Skinner (and his forerunner Sidney Pressey), the role of commercial interests and processes, the development of a receptive social imaginary through popular media, the inconclusive nature of empirical findings about the learning that resulted, the eclipse of the mid-century teaching machine by programmed learning in book form, and the rise of computers. This account by itself might seem a little arcane. It is, however, given added heft by a framing argument that ties the history of teaching machines to present-day trends, and critiques some common myths regarding the history of educational technologies that are used to sell current technological options. This framing argument contends, on the one hand, that the "Silicon Valley mythology" (p. 249), regarding education's digital future, rests on misinformation about the past, and, on the other hand, that current digital developments have more continuity with the behaviorist and totalitarian impulses of that past than is commonly admitted.

Concerning the former point, Watters points to a common narrative purveyed by figures such as Sal Khan and Bill Gates that presents education as beset by a static factory model rooted in the nineteenth century and buttressed by resistance to change on the part of Luddite educators. The solution then comes in the form of commercially sourced digital tools that now offer revolutionary degrees of individualization and access to learning. Watters's account undermines both halves of this story. She marshals a substantial body of evidence to show that education has been far from static over the past century, that technological innovations designed by educators regularly stalled due to inertia and disorganization on the part of the business world, and that the rhetoric of revolutionary individualization and personalization of learning has been the stock-in-trade of purveyors of a long string of new educational technologies but has also consistently fallen short in practice. A generous amount of space is devoted to B. F. Skinner's bouts of epistolary fury directed at his business partners who stalled development of his teaching machines until their moment had passed. More significantly, Watters makes clear that the recurring claim of individualization came within a recurring and expanding envelope of standardization. Proponents of teaching machines made much of the potential for individualized instruction, understood as the capacity for learners to proceed at their own pace. Those same learners were expected to follow programmed sequences, assemble predetermined atoms of knowledge, prepare for standardized tests, and submit to a rather deterministic process of behavioral manipulation. The talk of individualization may perhaps have been sincere, but it amounted in the end to something comparable to today's processes of "personalizing" your smartphone by choosing the same device as millions of others in one of a handful of colors, or perhaps clicking on the same online instructional video, framed by the same perspective, as everyone else. In the meantime, the appeal to individualization helped to shift product.

The suggestion of contemporary parallels points to the second part of the book's framing agenda, which claims that teaching machines were not just a curious episode that met its demise with the rise of computing. Watters points out that claims to revolutionary breakthroughs in education through technology commonly end up looking oddly conservative. Dreams of technocratic learning and robot teachers in the 1950s and 1960s still placed the robots in front of classrooms with rows of chairs in which students answered multiple-choice questions. Watters suggests that contrary to some tellings of the story, the teaching machines of the day did not give way to computers so much as help to establish assumptions about programmed learning rooted in behavioral manipulation, atomization of content, and linear progress that continue to inform today's digital educational technologies. The commercial involvement in all of this is, moreover, far from disinterested, with considerable research and design acumen going into the creation of digital products that reinforce behaviors favorable to those who make their living from eyeballs remaining on webpages and apps. After a

chapter starkly comparing the Skinnerian vision of education based on control through behavioral engineering to protests from figures such as Freire and Chomsky in the name of freedom, Watters wonders aloud in the concluding chapter whether the quaint teaching machines of yore were just setting us up for a larger-scale loss of freedom in the name of surveillance capitalism, a loss sold under the aegis of the latest reiteration of educational utopia based on individualization.

The book is engaging, well written, and highly readable. Its deconstruction of the popular narratives about technology and education that it targets is persuasive, patient, and useful. For a book that ultimately has some larger points to make, it narrates the history carefully and in a measured tone. The concluding argument about the continuities between Skinnerian teaching machines and the mechanisms of surveillance capitalism rings true, but comes as a bigger leap given that all of the detail is focused on the decades between 1920 and 1970, after which we race somewhat headlong to the present in a welter of telling one-liners from various authors. That there are family resemblances between now and then seems undeniable based on the evidence presented, but detailed lines of descent are less clearly established. One also wonders whether the key opposition of totalitarian control versus radical individual freedom is quite adequate to do justice to the landscape. The closing sections are a little broad-brush, but certainly well worth pondering. The book is recommended reading for anyone interested in technology's relationship to society and education, and for anyone who imagines that educational technologies are just tools for making schools better.

Reviewed by David I. Smith, Professor, Director, Kuyers Institute for Christian Teaching and Learning, Calvin University, Grand Rapids, MI 49546.

SCIENCE FICTION by Sherryl Vint. Cambridge, MA: The MIT Press, 2021. 224 pages. Paperback; $15.95. ISBN: 9780262539999.

Science Fiction is the story of the romance between fiction and science. The goal of the book is not to define the history or essence of science fiction, but rather to explore what it "can do" (p. 3). How does fiction affect scientific progress? How does it influence which innovations we care about? In the opposite direction, what bearing does science have on the stories that are interesting to writers at a point in time? *Science Fiction* references hundreds of books to paint a cultural narrative surrounding science fiction. Throughout the book, Vint refers to the fiction as 'sf' in order to avoid distinctions between science fiction and speculative fiction. The dynamic between science and fiction is a relationship defined by both scientific progress and by forming judgments of the direction of development through a lens of fiction. Fiction is cause and effect; we use fiction to reflect upon changes in the world, and we use fiction to explore making change.

Vint, Professor of Media and Cultural Studies and of English at the University of California, Riverside, gives overviews of different areas of sf. These include some of the most common sf elements, such as utopias and dystopias (chap. 2), as well as relatively recent concerns, such as climate change (chap. 7). Through these questions, she is navigating one question: how does sf engage with the world? It is more complex than the commonly reflected-upon narrative that sf is an inspiration to inventors—it is a relationship moving in both directions and involves value judgments as well as speculation about scientific possibilities.

The book also navigates the attitudes at the root of sf. Vint presents sf as a fundamentally hopeful, perhaps even an optimistic, genre. She describes sf as "equally about frightening nightmares and wondrous dreams" (p. 13). Yet even dystopian stories require hope for a future. Showing the world gone wrong still requires "the seeds of believing that with better choices we might avoid these nightmares" (p. 32). This is certainly true in the discussion of climate change sf. Where nonfiction writing often focuses on the impartial mitigation of disasters, the heart of fiction offers "the possibility to direct continuous change toward an open future that we (re) make" (p. 136).

The most surprising chapter is the penultimate one, focusing on economics (chap. 8). Vint discusses the recent idea of money as a "social technology" (p. 143) and the ways our current economy is increasingly tied to science, including through AI market trading and the rise of Bitcoin. The chapter also focuses on fiction looking at alternative economic systems—how will the presence or absence of scarcity, altered by technology, change the economic system? Answers to this and similar questions have major implications on the stories we tell and the way we seek to structure society.

As Christians, we have stories to help us deal with our experiences in life and our hope for the future. *Science Fiction* discusses sf as the way that our

communities, including the scientific community, process life's challenges and form expectations for the future. We must not only repeat the stories from scripture, but also participate in the formation of the cultural narratives as ambassadors of Christ. While *Science Fiction* does not discuss the role of religion in storytelling, the discussion of our ambitions and expectations for the future is ripe for a Christian discussion.

Vint describes sf as a navigational tool for the rapid changes occurring in the world. *Science Fiction* references many titles that illustrate the different roles sf has played at historical points and that continue to form culture narratives. While some pages can feel like a dense list of titles, it is largely a book expressing excitement about the power and indispensability of sf. I would recommend this book for those who want to think about interactions between fiction, science, and culture, or learn about major themes of sf, as well as those interested in broadening the horizons of their sf reading.

Reviewed by Elizabeth Koning, graduate student in the Department of Computer Science, University of Illinois at Urbana-Champaign, Urbana, IL 61801. ▼

Letter

"Unformed" and "Formed"

In the June 2022 issue of *PSCF*, the editor James C. Peterson noted, in his helpful survey of different views of personhood ("Recognizing the Presence of a Person," *PSCF* 74, no. 2: 106–11), a list of Church Fathers culminating in Aquinas who made the distinction between "unformed" and "formed" (p. 108). One of the reasons these Church Fathers sometimes gave for this distinction was the Septuagint's translation of Exodus 21:22–23.

Exodus 21:22–23 speaks of two cases involving a fight which injures a pregnant mother. The Hebrew text is difficult to interpret. One interpretation (for example, the RSV and NRSV) holds that in the first case, if a miscarriage occurs with no harm to the mother, then monetary compensation is required. In the second case, if the woman is harmed the rule of *lex talionis* is invoked. Some argue that this stereotyped phrase was not to be taken literally, but that the one who hurt the woman had to compensate her husband for the death of either his wife or his baby.

The Hebrew text can also be interpreted, as in the NIV, to mean that in the first case a premature birth of a healthy child occurs with no harm to the mother or child, and that in the second case one of them is harmed.

The Greek translation (the Septuagint) reads quite differently from the Hebrew:

> When men strive together and hurt a woman with child so that the woman miscarries an unformed child (*mē exeikonismenon*), he shall pay according to the husband's account. If the child is formed (*exeikonismenon*), he shall give life for life. (Exod. 21:22–23)

The distinction between an "unformed" and a "formed" child may have been influenced by the views of Aristotle.

Aristotle held that the fetus receives a "vegetative or nutritive soul" at the moment of conception, an "animal or sensitive soul" at a later stage, and a "rational soul" as the moment of birth draws near. In his *History of Animals* 7.3, he expressed the belief that the first movement occurred on the 40th day for males and on the 90th day for females.

Stoics, in general, held that the fetus was merely part of the mother's body, and that its life began with its first breath. Though Augustus passed legislation to promote marriages and procreation, Roman law adopted the Stoic view that the fetus was not yet a person. The emperors Septimius Severus (193–211) and Caracalla (211–217) prescribed banishment for a divorced woman who had an abortion contrary to the will of her former husband, and the death penalty for those who provided an abortion drug which caused the death of the woman.

Augustine, following the Septuagint of Exodus 21:22–23, held that the destruction of an "unformed" fetus, though immoral, was not murder. The codification of the laws under Justinian simply listed abortion as grounds for divorce.

Edwin M. Yamauchi
ASA Fellow ▼

American Scientific Affiliation

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Canadian Scientific and Christian Affiliation, PO Box 63082, University Plaza, Dundas, ON L9H 4H0. Website: www.csca.ca.

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