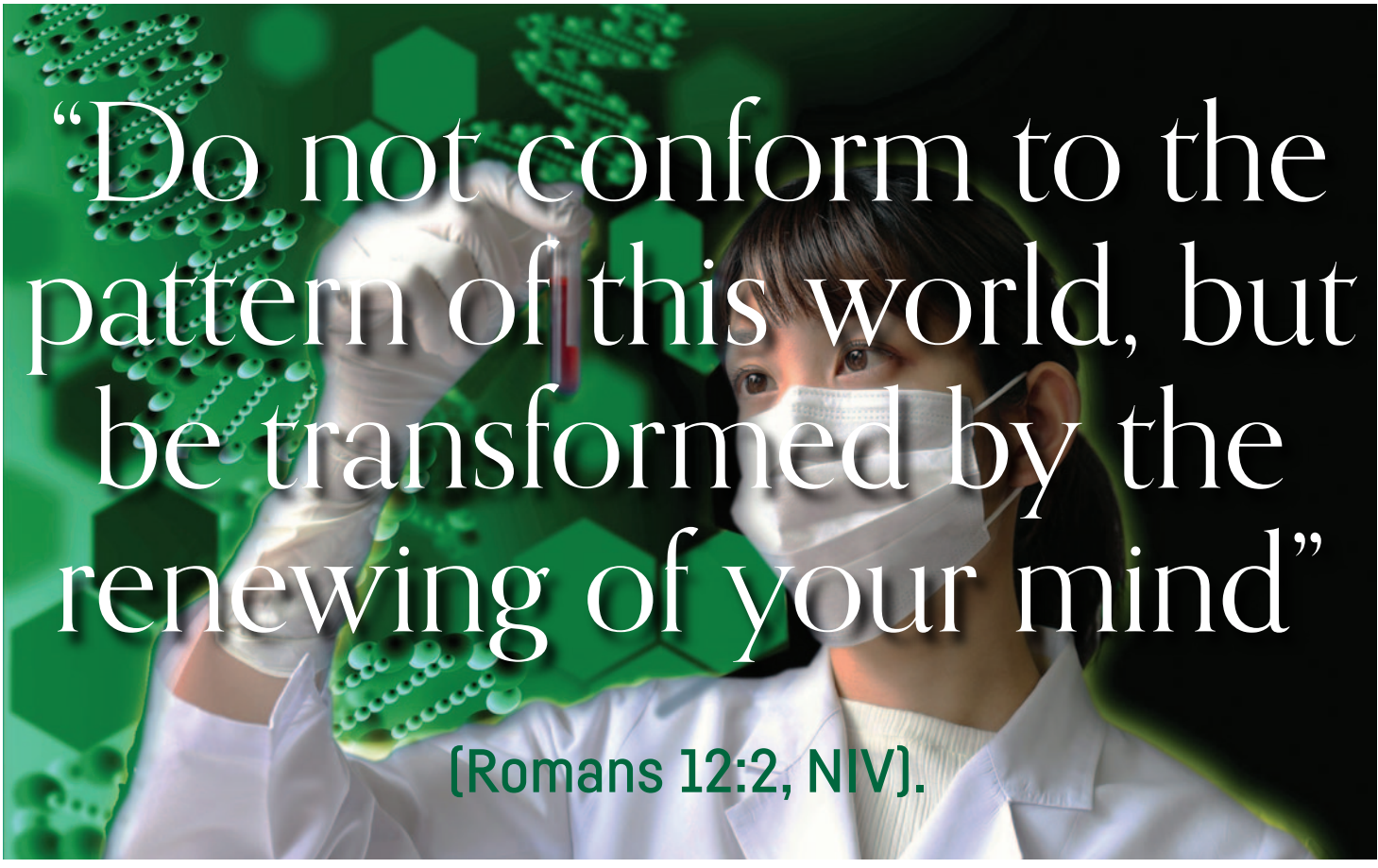
Peter Lyons



Editing Life: Modern Biology and Biblical Principles

Recent years have seen incredible growth in our understanding of the molecular underpinnings of life. Technology now enables us to look deep within the cell to view the activities of individual molecules, enzymes, even individual atoms.[1] The sequencing of the human genome is old news, and we are now sequencing the genetic code of untold numbers of other biological organisms. We are nearly reaching the point at which a trip to the doctor's office will be accompanied by an analysis of our genetic code.[2] It seems that we will soon know the secret of life . . . at least,

that is what some might say.

More astonishing is the rapid pace at which techniques are being developed to manipulate life as we know it. Scientists are actively pursuing the ability to replace failing organs with new organs grown directly from the person's own stem cells. The scientific world has been abuzz in recent years about a technology that will soon enable fine edits of human DNA code to correct disease-causing mutations. We are now able to make designer genes, and researchers are working on making designer organisms—for example, mosquitoes that are unable to transmit malaria.

These developing technologies—stem-cell therapeutics, gene editing, and synthetic biology—have great implications for health care and for the stewardship of our planet. They also have great potential for abuse. Because of this, the scientific community has invested considerable effort to consider the ethical implications of these technologies, including a 2015 summit in Washington, D.C. on the emerging area of gene editing,[3] which was organized by scientific organizations from the U.S., England, and China, with nearly 500 scientists, ethicists, and other interested groups from around the world participating. The meeting concluded with a recommendation to refrain from any gene editing research on viable human embryos intended for implantation and pregnancy until ethical and safety concerns have been resolved.

In this article, I would like to consider some of these developing technologies that are now enabling us to modify life as we know it. What exactly are these biological technologies? How do they work? Will they be beneficial to us and our planet, or result in negative repercussions? Most importantly, are there biblical principles that might guide Christian communities' approach to these issues? Finally, I will discuss how to best approach these subjects in the classroom. How can we teach about these rapidly changing aspects of science while getting the science and the Bible correct and encouraging students' practical involvement in the issues?

Embryonic Stem Cells

Stem cells are unique because they are capable of both regenerating themselves and becoming, or differentiating into, new types of cells. Scientists originally thought that stem cells were found only in embryonic tissues or bone marrow, but we now know that stem cells are found in a wide variety of normal adult tissues, even in certain regions of the brain,[4] to enable continued growth and regeneration of tissues. Stem cells that grow in bone marrow, for example, are capable of regenerating the many cell types that circulate throughout the bloodstream: red blood cells, platelets, macrophages, and several types of immune cells. Stem cells found within the small intestine continually regenerate its lining as old cells age and slough off. The discovery of these cells and their ability to regenerate tissue, is thought to be a major advancement toward treating and curing disease.

While adult stem cells hold much potential, a great deal of the publicity about stem cells has centered on *embryonic* stem cells, which exhibit special properties not found in adult stem cells. It is embryonic stem cells that differentiate to form each human being, which means that they can ultimately become all the cell types of the body, a capability that is referred to as *pluripotent*. The blood stem cells mentioned above are only able to form other types of blood cells, so they are referred to as *multipotent*. The advantage of a pluripotent stem cell and the core of the hype that surrounds stem cells is that pluripotent stem cells do not limit themselves to creating a particular repertoire of cell types. Scientists may be able to use these stem cells to grow any type of cell or organ humans need. Whereas patients now must wait for an appropriate organ donor, doctors of the future might simply place an order for a replacement organ that was grown in the lab.

While the potential of these cells is exciting, embryonic stem cells are typically derived from five- to six-day-old human embryos that have been banked at fertility clinics but not used for their intended purpose. The origin of embryonic stem cells raises the concern of those who believe that life begins at conception, as the embryos from which the stem cells are harvested do not survive. Although some might argue that this concern has been "holding back the progress of science," the response of the public against embryonic stem cell use was at least partially responsible for a push within the scientific community to develop an alternative type of stem cell.

In 2006, Shinya Yamanaka's lab in Kyoto, Japan, showed that pluripotent stem cells could be derived from normal adult cells through some genetic manipulation.[5] Recent research has enabled the differentiation of many types of cells from these induced pluripotent stem cells (iPSCs), reducing the need to work with embryo-derived stem cells.[6] iPSCs, in fact, could enable the production of replacement organs from a person's own cells, thus eliminating the rejection issues when donor tissues are used in transplants. While embryonic stem cells have many unique and useful characteristics, some alternatives now exist.

Currently, few treatments using any type of stem cell have been approved by regulatory agencies, illustrating the complexity of this form of therapy and the many hurdles scientists must overcome to successfully use stem cells in transplantation ther-

apies.[7] However, hundreds of studies are currently underway investigating the possibilities. Scientists have made some progress in using embryonic stem cells to treat macular degeneration by transplanting stem cell-derived retinal cells.[8] Similar transplant methods have been attempted in the treatment of spinal-cord injury. A stem-cell treatment has recently been approved in Europe that uses a patient's own unaltered adult stem cells to repair the cornea after injuries such as burns.[9] But perhaps the best-known stem-cell treatment has been around for more than 60 years—bone-marrow transplants, in which a donor's adult stem cells are transplanted into a recipient, often a leukemia patient, as a replacement for his or her own malfunctioning (cancerous) stem cells, all of which have first been destroyed by radiation or chemotherapy.

Three-parent Embryos

While neither embryonic stem cells nor iPSCs have made it to market as an approved therapy, the manipulation of embryonic tissue has been approved in at least some countries in the form of three-parent embryos.[10] In this case, scientists are not using embryonic cells for potential therapeutic use in an adult patient, but rather manipulating the embryo itself so that the developing individual does not inherit severe mitochondrial disease. Mitochondria are the powerhouses of the cell—small organelles that are largely responsible for converting food into usable energy. Some of the instructions for running these powerhouses come prepackaged with each mitochondrion in the form of mitochondrial DNA. Mutations in the mitochondrial DNA can sometimes result in incurable and often fatal diseases. While most of our genetic material comes from both our parents, the bulk of our mitochondria and other organelles come only from our mother through the large cytoplasm of the egg. To produce a three-parent embryo, the nucleus of an egg with faulty mitochondrial DNA is transplanted into a de-nucleated donor egg with normal mitochondria. This manipulated egg is then fertilized by sperm in the lab and implanted into the mother's uterus. The individual resulting from this process would have genetic information from three parents—two mothers and a father. This mitochondrial replacement therapy has been approved for use in fertility clinics in Britain.[11] Although it has not yet been approved in the Unites States, experts are urging the United States Food and Drug Administration (FDA) to approve its use in clinical trials. There are, of course, some unknowns: Might there be some detrimental effect of having third-party genetic material in cells? Could there be a psychological impact on the child of having a

Beginning a Discussion: Some Ideas for Teachers

While many of the topics in this article deal with complicated biological and ethical issues, they are rooted in basic biology and biblical study and provide an opportunity to demonstrate the relationship between the two. Here are some ideas for considering these topics in a variety of classrooms:

• ***In the upper elementary/junior high classroom (grades 6-8):*** This is the age at which students are beginning to develop their independence and are becoming aware of current issues. They may not be prepared to deal with ambiguous questions, but are certainly interested in issues such as fairness, the value of life, and the unique talents of each individual. These topics can be addressed from both biblical and biological points of view through the lens of current issues and family relationships. For example, a discussion of the value of each human being might begin with the story of the widow's mite, followed by consideration of how we all have value—even, and especially—those who may be disabled in some way. This might lead to consideration of the accomplishments of handicapped people throughout history, gene editing, and the value we place on specific traits. A consideration of talents immediately brings to mind the parable of the talents, as well as Paul's description of the variety of spiritual gifts in the church. This naturally leads to the biological basis of many differences we see in other people and the issue of who is "normal." Elementary teachers who feel unprepared to discuss the topics discussed here could invite a guest speaker who has considered these topics in more detail; for example, a local medical doctor or academy science teacher.

• ***At the secondary/high school level (grades 9-12):*** Secondary students have increased abilities to think in abstract ways and to reason through complex problems. In addition, many are rapidly approaching (maybe even reaching) the age at which they can drive and vote, and thus are likely to be interested in current events. They may be reticent to express their opinions for fear of being embarrassed. To break the ice, use a short game to introduce the subject and get them talking. UNESCO's online book, *Moral Games for Teaching Bioethics*[1] has a number of useful ideas for stimulating student discussion. These games might be used to introduce a subject or to follow up a science presentation to encourage students to grapple with principles in areas

third parent? What if the procedure doesn't work? What if the defective mitochondria are somehow transferred over and retained? This possibility has been demonstrated, suggesting that we must be very careful as we approach these kinds of manipulations.[12] Questions aside, it is likely that this therapy will be approved in other countries in the near future. Recently, news has arrived that a three-parent baby was born in April of 2016 in Mexico.[13] We have arrived at this point, whether we like it or not.

Gene Editing

Mitochondrial replacement therapy has a relatively small market—people with defects in their mitochondrial DNA. However, nearly all disease has a genetic basis. That is, most diseases are caused by either an inherited or an acquired change in the DNA code, so a technology that could reverse those changes would have a huge impact in curing and preventing disease. Just such a gene-editing technology has emerged in recent years. The technology is called CRISPR/Cas9, an acronym that describes a bacterial immune system.[14] Just as humans have to fight off viral infections, so do bacteria. Bacteria do this by incorporating a piece of the viral genetic material into their own DNA, then using this as a template to recognize other invading viruses, which are then chopped up by the Cas9 bacterial enzyme. Scientists have now adapted this system for use in mammalian cells such as our own. In fact, you might say that scientists have made this system even "better" by making subtle changes that improve the precision of the cutting mechanism, and by manipulating the mechanism to be used in many ways that include not just cutting, but also subtle editing of the genetic material.[15]

Will this technology be used in therapeutic ways to solve human disease? Companies are already lining up with great expectations for CRISPR technology. Two companies in particular have garnered substantial funds for the effort. Editas, based in Cambridge, Massachusetts, and backed by Bill Gates and others to the tune of US$120 million, has the goal of using this technology in at least five human clinical trials by 2022, hoping to eventually cure diseases such as Duchenne muscular dystrophy and cystic fibrosis. CRISPR Therapeutics, also based in Cambridge, Massachusetts, has brokered deals with Bayer (US$335 million) and Vertex Pharmaceuticals (US$105 million) to develop the technology to treat conditions such as blood disorders, blindness, and congenital heart disease.[16]

There is every likelihood that this technology will produce results in the near future. Its effectiveness has already been shown in animal models. In 2014, a mouse with a mutation in the dystrophin gene, which typically leads to the development of muscular dystrophy in mice, was

where there are often no black-and-white answers. Current events in the news, such as the idea of three-parent embryos, are sure to engage secondary students. Since these issues often come with very personal and/or political opinions, students need to be taught how to identify reliable sources online in the course of doing research. A homework assignment might ask students to engage their parents on these issues, using some specific and directed questions.

• ***For college/university courses:*** The above ideas can be adapted for college-level classes as well. However, college students need to deal with ambiguous situations as they prepare for the "real world" and will benefit from being required to think through and research a variety of situations. Case studies involving real medical dilemmas are widely available and are great resources for stimulating the thinking of college students.[2] These can be followed up by a debate in which students are required to argue the merits of one side of an issue and/or create a reflection in writing. Students in the bioethics class at Andrews University (Berrien Springs, Michigan, U.S.A.) have sometimes commented on how useful such activities are in preparation for things such as medical school admissions interviews. Developing the ability to think through such issues is sure to be useful for many students; a course at the general-studies level will likely take a similar approach, but delve into the scientific details to a lesser extent than a capstone or majors course. Further, for students enrolled in health care or genetics-related programs, seminars and workshops by experts in these topics would provide opportunities for them to understand and learn to navigate these topics.

REFERENCES

1. Darryl R. J. Macer, *Moral Games for Teaching Bioethics* (Haifa, Israel: The UNESCO Chair in Bioethics, 2008): http://www.unesco-chair-bioethics.org/wp-content/uploads/2015/09/Moral-Games-for-Teaching-Bioethics.pdf.

2. Case studies are widely available online. Here are a few to get started: The Center for Bioethics and Human Dignity: https://cbhd.org/resources/case-studies; Center for Practical Bioethics: https://www.practicalbioethics.org/resources/case-studies; McGraw Hill Case Studies: http://www.mhhe.com/biosci/genbio/olc_linkedcontent/bioethics_cases/index.html; Bioethics at Iowa State University: http://www.bioethics.iastate.edu/classroom/case_studies.html

treated with CRISPR technology, which halted the development of the disease.[17] Its use in humans was initiated in the summer of 2015, to a loud outcry from the international scientific and bioethics communities, as scientists in China revealed the possibility of using this technology in nonviable human embryos.[18] More recently, the technique was used to modify immune cells from a patient with lung cancer, with the hope of stimulating the immune system to attack the cancer, and in viable human embryos that were not implanted, to successfully correct a defect leading to hypertrophic cardiomyopathy.[19]

Gene editing has gone past the editing of humans to achieve better health to the editing of mosquitos to try to accomplish their demise (and to improve our health). Mosquitoes were targeted because they transmit many serious diseases, including dengue fever, malaria, and zika virus. Scientists have developed a method to manipulate the mosquito's genetic material in order to block pathogen transmission.[20] In addition, a method of rapidly disseminating this trait throughout the entire wild population has been developed using a "gene drive." The most dramatic version of this approach eliminates all male mosquitos, effectively causing a crash in mosquito populations (no males, no reproduction). While this technology is currently locked up in secure labs, it may eventually be used.

Synthetic Biology

Related to the idea of gene editing is the concept of synthetic biology making new organisms and species that can do what we want them to do. This is not a new concept. In fact, the biotechnology industry began with this revolutionary idea, that we can manipulate organisms (initially just bacteria) to produce things useful to humanity. Genentech was a pioneer in this area, using genetically engineered bacteria to produce insulin for the treatment of diabetes.[21] Many diabetics are currently the beneficiaries of this bacterially produced human insulin, or Humulin®.

Today, however, we can not only engineer bacteria to do simple tasks, but are also able to dramatically alter the makeup of organisms. The implications of this kind of manipulation of nature are wide-ranging. For example, a group of scientists recently inserted more than 20 foreign genes into a strain of yeast to enable it to produce opioids.[22] Currently, the production of drugs like morphine relies on the volatile international supply of poppies; a reliable supply of these crucial pain drugs would be beneficial. However, the apparent ease of opioid production from yeast has led some to speculate on the potential for abuse if the technology falls into the wrong hands.

Some years ago, a team of scientists at the J. Craig Venter Institute artificially synthesized an entire bacterial genome, describing the feat as the "Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome."[23] Although the scientists didn't actually create a cell, but rather just inserted a chemically synthesized version of a bacterial genome into a cell in which the DNA had been removed, this still raised a controversial question: Might humans be able to synthesize life? Another research team led by Craig Venter has recently created a new species of bacterium with a genetic code smaller than anything known in nature.[24]

The future will surely hold many new feats of biological prowess, from the engineering of cells with new chemical production capabilities to the development of entirely new synthetic organisms with completely unique genetic circuits to do what is currently unimaginable. Many of these technologies and products will certainly be beneficial and lead to future improvements in our quality of life. Some of these products will challenge us to probe more deeply the ethical and moral principles guiding our lives.

Biblical Principles

Each of these technologies for gene and cell editing holds great promise for the control of disease and the correction of previously incurable genetic diseases. Each also presents many ethical issues and potential for misuse, and forces us to consider carefully a number of questions, such as: (1) Is it ethical to use human embryos in research? (2) Is it appropriate to genetically modify human cells to treat disease? (3) How do we define "disease"? (4) Do we have the right to genetically modify the germ line (reproductive cells) of species, particularly our own species?

While the Bible doesn't say much about modern molecular biology and genetics, it certainly has plenty to say about life and health and about the Creator and the creation. Let's consider what the Bible has to say.

1. *Is it ethical to use human embryos in research?* This could be a situation in which God brings good out of the less than ideal. God is an expert in this. We might think of Paul in prison in Philippi, where a bad situation for Paul turned into good for the jailer, who became a believer (Acts 16:1-40). Or what about Solomon, considered the wisest man who ever lived, who was the product of a relationship that began with murder and adultery (2 Samuel 12:1-31)?

It is unlikely that God intended embryos to be stored in fertility clinics. It is, however, likely that He can bring good out of the situation. There are several options for dealing with the more than 600,000 embryos estimated to be in cryogenic storage in the United States alone[25]: (a) leave them in the freezer; (b) implant them in the owner or donate them to other hopeful parents; (c) donate them to

Jesus, the Great Physician, commanded His disciples to go out and heal every disease (Matthew 10:1). The apostles were agents of healing and miracles in the early days of the church (Acts 5:16), and God has given His people through the ages many gifts, including the gift of healing (1 Corinthians 12:28), which has been considered the "right arm" of the Seventh-day Adventist Church since its early days.

research; or (d) destroy them. There seems to be little difference between leaving them frozen or destroying them, as those left frozen are bound to be destroyed or deteriorate eventually. Donating them to other parents seems noble and a way for these embryos to fulfill their potential, although there would seem to be a greater need in our world for parents to adopt the born rather than the unborn.

2. *Is it appropriate to genetically modify human cells to treat disease?* Jesus, the Great Physician, commanded His disciples to go out and heal every disease (Matthew 10:1). The apostles were agents of healing and miracles in the early days of the church (Acts 5:16), and God has given His people through the ages many gifts, including the gift of healing (1 Corinthians 12:28), which has been considered the "right arm" of the Seventh-day Adventist Church[26] since its early days. James wrote in James 2:16: "If one of you says to them, 'Go in peace; keep warm and well fed,' but does nothing about their physical needs, what good is it?"[27] In like manner, if one has the means to fix a genetic disease, or to replace a degenerated organ, but does nothing about it, what good is it? Who among us would be willing to tell a parent of a child with Tay-Sachs disease, for example, that we are able to cure your child's disease, but sorry, we will not, because that would be "playing God"? That is exactly the kind of "playing God" that God asked of us, when He sent out the disciples, apostles, and each of us as ministers to the world to heal hurting people both spiritually and physically.[28]

3. *How do we define "disease"?* This may be the most difficult question to discuss, and can get us into some sticky territory. For example, while Tay-Sachs disease and cystic fibrosis are genetic diseases that cause untold suffering and would benefit immensely from a cure, most personality traits and superficial characteristics also have a genetic basis, although often more complex, and so also have the potential to be modified through developing genetic techniques. There are many cases where a characteristic might be considered abnormal by some, but normal by others. Most of us would consider deafness to be a problem. However, members of the deaf community have their own language and culture and consider their deafness to be a difference rather than a disease to be cured.[29]

This issue of differentiating normal from abnormal is maybe the greatest challenge of a gene editing age. The Bible may help us in some areas, although certainly not in all. Paul suggests in Romans 12:2 that normal in this world is not to be desired: "Do not conform to the pattern of this world, but be transformed by the renewing of your mind." Many verses in Scripture declare that our normal inclination is not what God desires, but with God's help we can become a "peculiar people" (1 Peter 2:9, KJV) abnormal in the eyes of the world.

In another context, Paul presents a list of those individuals who we might consider abnormal, who will not inherit the kingdom of God (1 Corinthians 6:9-11). It rapidly becomes apparent that normal or abnormal is based on one's point of view. The Bible gives us some indication of what is good; what, in the context of the kingdom of God, should be considered normal. However, our understanding is at best imperfect, and the parable of the wheat and the tares indicates that it is not our role to separate the good from the bad.

History provides examples of what has happened when humans tried to separate normal from abnormal, the wheat from the tares, so to speak. In the early 20th century, the eugenics movement[30] tried to weed out the bad genes from the good. This resulted in the forced sterilization of individuals diagnosed as being "feeble-minded" or "insane." Many of these individuals, if they were alive today, would likely be productive members of society, if not

"normal" in the typical sense of the word. In his book, *The Gene: An Intimate History*, Siddhartha Mukherjee concludes that abnormal is whatever doesn't match the current environment, and that as the environment changes, different characteristics are considered abnormal.[31] For example, Attention Deficit Hyperactivity Disorder (ADHD) is considered abnormal in most contexts of our current far-too-sedentary world. However, distraction and hyperactivity in the context of a hunter-gatherer society might be considered a strength. It is clear that we must tread softly where clarity is lacking, but heal quickly where diseases are clearly debilitating.

4. *Is it our right to genetically modify the germ line of species, particularly our own species?* Heritable changes have the potential to fundamentally change who we are as a species and the makeup of ecological communities on our planet. Is it appropriate to be involved in creation to this extent, and if so, who gets to make the decisions? Are we stepping outside of our bounds when we involve ourselves in this kind of "playing God"?

The Bible is clear that humanity has a certain level of responsibility for what happens on this planet. God created the heavens and the earth, and commanded human beings to "'rule over the fish in the sea and the birds in the sky . . . and over all the creatures that move along the ground'" (Genesis 1:26). God wished for the prosperity of the earth and wanted humankind to be central to that prosperity. David reiterated this sentiment: "'You made them rulers over the works of your hands; you put everything under their feet'" (Psalm 8:6). These texts suggest that God intended human beings to have mastery over all of creation as an extension of God's authority, to care for the earth, to serve as stewards of the planet.

As stewards of this planet, our actions must show both care for humanity and care for the entire web of life on the Earth. For just as our bodies are temples of the Holy Spirit (1 Corinthians 6:19), so also is the Earth "the Lord's, and everything in it" (Psalm 24:1). God cares for even the sparrow (Luke 12:6), and provided a means for the land to have a Sabbath year of rest (Leviticus 25:2-5; Exodus 23:10, 11). He even commanded humans not to pollute the Earth, because it is His home, too! "'"Do not pollute the land where you are . . . . Do not defile the land where you live, and where I dwell, for I, the LORD, dwell among the Israelites"'" (Numbers 35:33, 34).[32] Clearly, our stewardship of this planet comes with great responsibility.

We care for our planet because it is God's creation. But it is certainly not the perfect Earth that God made in the beginning, having undergone

many mutations due to the ravages of sin. We await the time when we will be made new, according to God's original plan. While we assume that this will fully occur at the Second Coming, Jesus suggested that the kingdom of God was both yet to come and in the present: "'The kingdom of God is in the midst of you,'" He said in Luke 17:21. Could it be that our ability to fix the effects of sin to a degree, through medical advances including those described here, can in a small way bring "the kingdom of God" to us in the here and now?[33]

Could it be that God has given us the opportunity to relieve some of the groans of creation (Romans 8:22) through our abilities to prevent disease, impart pest resistance, increase food production, and replace degenerated organs? Jesus relieved suffering and healed people throughout His ministry, and with each healing proclaimed the good news of the kingdom (Matthew 4:23; Luke 10:9). One might imagine that as Jesus healed the blind and the paralyzed, that He was performing some divine genetic engineering, just a small taste of the change that will occur "in the twinkling of an eye" at His second coming (1 Corinthians 15:52).

The challenges that we face as a human race that can do so much damage scientifically are largely based on our greed and arrogance. While we work to improve human life, we must ensure that we are not responsible for the demise of the species with which we share our planet. This is our responsibility as stewards (Revelation 11:18). Currently we are doing a poor job of this, mostly because we do such a good job of exploiting the resources of the planet for our own benefit. Since we are witnessing the extinction of species at an unprecedented rate, I have strong concerns regarding the elimination, for example, of mosquitos for the benefit of humanity. How many more species will we choose to eliminate for our benefit? What might be the repercussions to the food web or the entire ecosystem? Is it possible to manage our resources using all the technologies at our disposal in ways that benefit humanity as well as the whole of Planet Earth?

A Classroom Approach

The discussion above makes it clear that our understanding of the fundamentals of life is growing by leaps and bounds. Biology, specifically genetics, affects each one of us personally in our health and family histories. It also impacts our communities and countries by improving our quality of life and driving large segments of the economy, and affects our relationships with our world and our Creator as we understand the effects we have on the environment. While these topics are clearly relevant to life today, the dramatic changes in biology make it difficult to stay abreast of the latest developments, let alone understand how they fit into a biblical worldview.

The Scriptures present general principles that may help us to navigate through difficult issues. For example, one of these principles is *love*, the central commandment found in the Bible (Matthew 22:37-40). Our relationship with God should encompass a compassion for our fellow human beings and the beasts of the field. This concern for the well-being of all of life, not just humanity, should inform our decisions in difficult areas of biology.

Another principle that should guide our thoughts in these areas is *humility* (2 Chronicles 7:14). When we understand our place in the world from a biblical perspective, we cannot help but be humble. Additionally, the Bible commands us to focus on truth (or the Truth), and states that we can understand some parts of truth through the various faculties provided us, including our human reason (Isaiah 1:18).

Certainly our young people are interested in the truth. Moreover, they are interested in being involved in the issues being debated as we search for truth. Discoveries in biology and genetics will be a central part of the world in which they grow up. It is important that we become involved in the world as it exists today, and we need to encourage our young people (and older ones as well) to be involved in the issues that will affect them, their descendants, and the environment. Many of our students will become leaders in science and technology, so we have a responsibility to engage with them to discuss how our faith and the principles of the Bible intersect with their interests, with the progression of science for the benefit of humankind, and the implications of scientific discoveries that have the potential to harm the Earth and its inhabitants. As they do so, they may discover new truths in God's Word and new examples of God's leading in all aspects of life.

Some resources exist to help us in this search for understanding. The Christian View of Human Life Committee, commissioned by the Seventh-day Adventist Church, produced two excellent documents in an attempt to clarify our relationship to genetic engineering technologies. Although the first was produced in 1995, more than 20 years ago, the principles outlined therein remain pertinent to the issues at stake today. The second, produced in 2000, focused on human gene therapy, with similar principles presented.[34] In addition to these documents, Adventist higher education institutions address bioethics at a number of levels. For example, some of our undergraduate institutions offer classes dealing with many bioethical issues, and Loma Linda University (Loma Linda, California, U.S.A.) supports a Center for Christian Bioethics with a focus on biomedical ethics, a Master's degree in bioethics, and a recently initiated annual conference on Adventist

Bioethics in Healthcare.

For teachers who may not have access to these university resources, it is important to engage with these topics and teach our young people the best information that is available. This can be done through in-service education, online courses, and research. When we don't know the answer, and in some cases we never will, the best way to approach these issues in the classroom is to present what we do know, and then encourage discussion. We can clarify areas where we have information, both biblical and scientific. We can guide students toward using Christian perspective to think critically, identify bias and hidden agendas, and analyze the quality of various sources they will encounter.

And, ultimately, we remain humbled by what we don't know. In recent years, I have come to know an organization called The Colossian Forum,[35] whose goal is to facilitate difficult discussions, often in areas where there are many opinions and no clear consensus. While there may never be a clear consensus on some issues, the central idea is that it is beneficial to travel the road together as a community with differing opinions, that it offers an opportunity to practice Christian grace, and that ultimately all things hold together in Christ (Colossians 1:17). We can have confidence that God can see the end and will guide us along the way. ✐

This article has been peer reviewed.

Peter Lyons, PhD, *is Associate Professor in the Department of Biology at Andrews University, Berrien Springs, Michigan, U.S.A. Dr. Lyons received his PhD in Biochemistry from Dalhousie University in Halifax, Nova Scotia, Canada, after which he was awarded a postdoctoral fellowship at Albert Einstein College of Medicine in New York. His current research and teaching interests lie in cell and molecular biology. He is a regular contributor to a course on bioethics at Andrews University.*

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NOTES AND REFERENCES

1. Jannik C. Meyer et al., "Imaging and Dynamics of Light Atoms and Molecules on Graphene," *Nature* 454:7202 (July 2008): 319-322.

2. The human genome sequence was completed, at least officially, in 2003. Since then, DNA sequencing capabilities have continued to increase. Scientists are now testing the feasibility and usefulness of whole-genome sequencing at birth; and in 2015, U.S. President Barack Obama announced his Precision Medicine Initiative, a key ingredient of which is obtaining detailed data from genome sequencing.

3. Sara Reardon, "Global Summit Reveals Divergent Views on Human Gene Editing," *Nature* 528:7581 (December 2015): 173.

4. For a scientific review of neural stem-cell growth and function, see Y. Mu et al., "Signaling in Adult Neurogenesis," *Current Opinion in Neurobiology* 20:4 (August 2010): 416-423. The U.S. National Institutes of Health maintains an online primer on stem cells, including adult stem cells, which can be found at https://stemcells.nih.gov/info/basics.htm.

5. Kazutoshi Takahashi and Shinya Yamanaka, "Induction of Pluripotent Stem Cells From Mouse Embryonic and Adult Fibroblast Cultures by Defined Factors," *Cell* 126:4 (August 2006): 663-676.

6. Scientists have produced numerous types of cells from iPSCs, including many types of neurons—for example, **pluripotent stem cells:** Allison D. Ebert et al., "Induced Pluripotent Stem Cells From a Spinal Muscular Atrophy Patient," *Nature* 457:7227 (January 2009): 277-280; **cardiomyocytes:** Lei Yang et al., "Human Cardiovascular Progenitor Cells Develop From a KDR+ Embryonic-Stem-cell-derived Population," *Nature* 453:7194 (May 2008): 524-528; **eggs:** Katsuhiko Hayashi et al., "Offspring From Oocytes Derived From *in vitro* Primordial Germ Cell-like Cells in Mice," *Science* 338:6109 (November 2012): 971-975); **sperm***:* _____, "Reconstitution of the Mouse Germ Cell Specification Pathway in Culture by Pluripotent Stem Cells," *Cell* 146:4 (August 2011): 519-532; and even **vascularized livers***:* Takanori Takebe et al., "Vascularized and Functional Human Liver From an iPSC-derived Organ Bud Transplant," *Nature* 499:7459 (July 2013): 481-484.

7. Josipa Bilic and Juan Carlos Izpisua Belmonte, "Concise Review: Induced Pluripotent Stem Cells Versus Embryonic Stem Cells: Close Enough or Yet Too Far Apart?" *Stem Cells* 30:1 (January 2012): 33-41. The most important difference, which makes approval for human treatment particularly difficult, is the fact that iPSCs are genetically manipulated.

8. While many stem-cell therapies are currently in clinical trials, including the ones reported on by Erin A. Kimbrel and Robert Lanza, "Current Status of Pluripotent Stem Cells: Moving the First Therapies to the Clinic," *Nature Reviews Drug Discovery* 14:10 (September 2015): 681-692, the most promising therapies are for ocular diseases, due to the relative accessibility of the eye. See Mark Fields et al., "Potential of Induced Pluripotent Stem Cells (iPSCs) for Treating Age-Related Macular Degeneration [AMD]," *Cells* 5:4 (December 2016): 44. Recently, one study has shown success in treating macular degeneration with iPSCs: Michiko Mandai et al., "Autologous Induced Stem-Cell-Derived Retinal Cells for Macular Degeneration," *New England Journal of Medicine* 376:11 (March 2017): 1038-1046.

9. Alison Abbott, "Behind the Scenes of the World's First Commercial Stem-cell Therapy," *Nature* (March 2015): https://www.nature.com/news/behind-the-scenes-of-the-world-s-first-commercial-stem-cell-therapy-1.17022. doi: 10.1038/nature.2015.17022.

10. Sara Reardon, "US Panel Greenlights Creation of Male 'Three-person' Embryos," *Nature* 530:7589 (February 2016): 142.

11. Gretchen Vogel, "United Kingdom Gives Green Light for Mitochondrial Replacement Technique," *Science* (December 2016): http://www.sciencemag.org/news/2016/12/united-kingdom-gives-green-light-

mitochondrial-replacement-technique.

12. Mitsutoshi Yamada et al., "Genetic Drift Can Compromise Mitochondrial Replacement by Nuclear Transfer in Human Oocytes," *Cell Stem Cell* 18:6 (June 2016): 749-754.

13. As reported by many news outlets. For example, see http://www.nytimes.com/2016/09/28/health/birth-of-3-parent-baby-a-success-for-controversial-procedure.html.

14. Jennifer A. Doudna and Emmanuelle Charpentier, "Genome Editing. The New Frontier of Genome Engineering With CRISPR-Cas9," *Science* 346:6213 (November 2014): 1258096. Jennifer Doudna and Emmanuelle Charpentier are the scientists who first described this method of genome editing. Chances are good that they will receive a Nobel Prize for this work in the near future. See also Elizabeth Pennisi, "The CRISPR Craze," *Science* 341:6148 (August 2013): 833-836.

15. Increased precision was shown in, for example, Benjamin P. Kleinstiver et al., "High-fidelity CRISPR-Cas9 Nucleases With No Detectable Genome-wide Off-target Effects," *Nature* 529:7587 (January 2016): 490-495. The many ways CRISPR/Cas9 has been used in gene editing are described in Patrick D. Hsu et al., "Development and Applications of CRISPR-Cas9 for Genome Engineering," *Cell* 157:6 (June 2014): 1262-1278.

16. Editas announced this in a press release on January 8, 2018. See their Website at http://www.editasmedicine.com/; Information on CRISPR Therapeutics can be found on their Website at http://crisprtx.com/our-partnerships/partnerships.php.

17. Chengzu Long et al., "Prevention of Muscular Dystrophy in Mice by CRISPR/Cas9-mediated Editing of Germline DNA," *Science* 345:6201 (September 2014): 1184-1188.

18. Puping Liang et al., "CRISPR/Cas9-mediated Gene Editing in Human Tripronuclear Zygotes," *Protein Cell* 6:5 (April 2015): 363-372.

19. David Cyranoski, "CRISPR Gene-editing Tested in a Person for the First Time," *Nature* 539:7630 (November 2016): 479; and Hong Ma et al., "Correction of a Pathogenic Gene Mutation in Human Embryos," *Nature* 548:7668 (August 2017): 413-419.

20. Paolo Gabrieli et al., "Engineering the Control of Mosquito-borne Infectious Diseases," *Genome Biology* 15:11 (November 2014): 535.

21. An excellent description of the role of Genentech in this new field can be found in Sally Smith Hughes, *Genentech: The Beginnings of Biotech* (Chicago: University of Chicago Press, 2011).

22. Stephanie Galanie et al., "Complete Biosynthesis of Opioids in Yeast," *Science* 349:6252 (September 2015): 1095-1100.

23. Daniel Gibson et al., "Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome," *Science* 329:5987 (July 2010): 52-56. doi: 10.1126/science.1190719.

24. Ibid.; Clyde A. Hutchison III et al., "Design and Synthesis of a Minimal Bacterial Genome," *Science* 351:6280 (March 2016): aad6253. doi: 10.1126/science.aad6253.

25. Embryos are usually frozen by fertility clinics by the early blastocyst stage, at which time they contain about 200 to 300 cells. To be clear, I do not think God is in favor of freezing human pre-embryos for the sole purpose of scientific research. However, I believe that this is rarely the motivation for harvesting them. I do think that if there is a moral issue here, it is with the fertility industry, not with the research enterprise; U.S. Department of Health and Human Services, "Embryo Adoption," (August 2017): https://www.hhs.gov/opa/about-opa/embryo-adoption/index.html.

26. Ellen White refers to medical missionary work, which includes health, as the "right arm" of the third angel's message in *Counsels on Health* (Mountain View, Calif.: Pacific Press, 1923), page 331.

27. Unless otherwise indicated, all Bible texts in this article are quoted from the New International Version. Holy Bible, New International Version®, NIV® Copyright © 1973, 1978, 1984, 2011 by Biblica, Inc.® Used by permission. All rights reserved worldwide.

28. Of course, God's healing would be perfect healing, whereas our technologies are likely to contain imperfections. There are always unknown consequences to any treatment, due to our imperfect understanding, which the medical and regulatory communities aim to reduce as much as possible.

29. See M. McKee et al., "Ethical Issues in Conducting Research With Deaf Populations," *American Journal of Public Health* (2013) 103:12: 2174-2178 for comments on deaf culture and the threat of genetic engineering to their culture. A recent issue of *National Geographic* (January 2017) focused on genetic issues relating to gender.

30. The eugenics movement called for mandatory sterilization laws that would prevent people with hereditary diseases from passing traits onto their offspring. Scientists at that time had basic knowledge of the gene unit and its role in inheritance, but did not fully understand how genes worked or could be manipulated. For this reason, they sought to eradicate diseases such as hereditary blindness, insanity, epilepsy, syphilis, alcoholism, and more through sterilization; and, along with sponsored Race Betterment Conferences, promoted the concept of creating and preserving a master race. See Edwin Black, *War Against the Weak: Eugenics and America's Campaign to Create a Master Race* (Washington, D.C.: Dialog Press, 2003), 152, 317.

31. Siddhartha Mukherjee, *The Gene: An Intimate History* (New York: Scribner, 2016).

32. I may be stretching the meaning of this text a little, as the pollution being referred to here is "bloodshed" murder. However, one might argue that pollution leads to much bloodshed, both human and animal, just in a more indirect way.

33. This is not to say that God's kingdom is not yet to come, but that we can experience a little bit of it while still here on earth. We will never cure humanity of its worst condition, that of "heart" disease: greed, jealousy, hatred.

34. "Christian Principles for Genetic Interventions" (June 13, 1995): https://www.adventist.org/en/information/official-statements/documents/article/go/-/christian-principles-for-genetic-interventions/ and "Human Gene Therapy" (April 01, 2000): https://www.adventist.org/en/information/official-statements/documents/article/go/-/human-gene-therapy/, are both found on the official Website of the Seventh-day Adventist Church. These documents present a balanced view of scientific developments at the time they were prepared and appropriate Christian responses to them. The statements assert that relieving human suffering is an important Christian responsibility and consider a number of relevant biblical principles, but leave many questions unanswered. They do recommend that heritable genetic changes should not be made. I suggest that this was easier to say when the technology did not exist, but not as clear now that the technology is becoming available.

35. The Colossian Forum: http://colossianforum.org/.