IMPROVING SCIENCE LITERACY THROUGH SCIENCE FICTION LITERATURE, FILMS, AND DIGITAL GAMES

by

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To my family

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by

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IMPROVING SCIENCE LITERACY THROUGH SCIENCE FICTION LITERATURE,

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This dissertation demonstrates the role of science fiction literature, films and digital games in enhancing scientific literacy at a high school level. While there are many ways of teaching scientific concepts, this project studies how science content may be taught through an analysis of specific science fiction novels, films, and video games. These works include: the book and film versions of Michael Crichton's *The Andromeda Strain* (1969) and *The State of Fear* (2004); *The Andromeda Evolution* by Daniel H. Wilson (2019) and *Change Agent* by Daniel Suarez (2017); the film, *Gattaca*, written and directed by Andrew M. Niccol (1997;) Naomi Oreskes' *The Collapse of The Western Civilization* (2014); and Kim Stanley Robinson's *New York 2140* (2017) and *The Ministry for the Future* (2020). Digital games discussed range from *Geniverse* (2016), In *Other Waters* (2020), *Perfect Strain* (2017), *Microscopya* (2022), *Plague Inc: Evolved* (2015), *The Cure* (2021), *Mission Biotech* (2020) to *Maroon* (2017).

Through an analysis of these SF materials, scientific concepts and issues from bacteriology, biotechnology, climate change and CRISPR are identified and evaluated for their potential use in high school science classroom. Each of the science fiction works provide a

coherent narrative that offers students an engaging way to access and understand science in complex contexts. Whether in the form of novels, films or digital games, high school teachers could use these materials as entry points to explain scientific concepts and societal themes in ways the supplement their existing science curricula and learning goals. Used wisely, science fiction works can develop students' abilities in thinking critically and scientifically through imaginative reading and play which in turn fosters the skill- sets needed to become scientifically literate citizens.

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INTRODUCTION

Science in the twenty-first century made remarkable progress in medical and technological fields. Science continues to reveal new developments and provides new knowledge to better understand the relationship between humans and their environment. Genetic engineering is one of the most powerful discoveries that has made tremendous changes to this understanding. The benefits and drawbacks of genetic advances constitute a pivotal shift in science that has been noticed by science fiction writers. Many authors of science fiction and speculative fiction have written about genetic engineering either to praise such discoveries for improving the future of humanity or to criticize it for manipulating God's creation and changing the natural order of beings. In this dissertation, my goal is to examine the role of science fiction in disseminating scientific knowledge and issues to students and to the general public. The detailed descriptions and analyses of scientific facts discussed in these selected fictional works may function as a resource for students and their teachers who are interested in discovering scientific narratives in forms that extend beyond those available in traditional science textbooks.

Most scholars agree on the need to improve scientific literacy among students and the general public in order to instill an interest in science and to engage society in making valuable decisions when controversial issues arise. Journalist and author Steve Miller and fictional writer Jane Gregory argue "that the public must understand science if they are to be useful citizens, capable of functioning correctly as workers, consumers, and voters in a modern technological world."[1] It is crucial to spread scientific awareness to help communities make better choices

[1] Jane Gregory and Steve Miller, *Science in Public: Communication, Culture, and Credibility* (Plenum Press, London, 1998), 1.

under given circumstances, to enable citizens to evaluate factual evidence, compare their findings, analyze them, and finally be able to draw accurate and valuable conclusions that contribute to problem-solving. This idea is supported by the U.S. educator, John Dewey, who "claimed that young people should be inculcated with a 'scientific attitude' that would help them approach the issues and problems of everyday life in a rational and logical fashion."[2] To expand the boundaries of science topics and appeal to students at the high school level, I will study factual science content and themes as depicted in works of twentieth and twenty-first-century science fiction (SF) to evaluate how they contribute to science literacy among secondary students and the general public. The goal of this project is to show that factual science can be presented in narrative fictional works that are easy to understand. Specifically, I will assess the possible effectiveness of SF narratives, SF films, and SF digital games in presenting genetic editing, biotechnology, and global warming science concepts to non-science majors and I will analyze the valuable potential of these science fiction materials for improving the public's understanding of science. In addition, I will examine how science fiction narratives in various forms may play a role in enhancing critical thinking about ethical problems and social issues raised by scientific development and their applications. I will base my analysis on a combination of scholarship from the areas of science fiction criticism and science education.

Many creative writers have used science fiction as a medium to share their ideas, their novel and creative imagination of the future of science and technology in their works. Mary Shelley, the "mother" of the science fiction genre, influenced many authors with her novel,

[2] John Dewey, "The Supreme Intellectual Obligation," *Science Education* 18 (1934): 1-4, quoted in Gregory and Miller, *Science in Public: Communication, Culture, and Credibility* (Plenum Press, London, 1998), 3.

Frankenstein (1818). Jules Verne, Isaac Asimov, Ursula Le Guin, David Brian, and Neal Stephenson, to name a few, have all made science fiction a pervasive genre that examines problems faced by humanity. Science fiction does not only deal with space science, astrophysics, or nuclear wars but often discusses real current developments that will shape the future world and directly impact human life. Almost three decades ago, Erica Van Dommelen, former assistant editor of *BioScience* and former president of the Washington Science Fiction Association, acknowledged the shift in science fiction topics: "Today science fiction, although never abandoning its time-honored themes of travel between stars, times, and alternate universes, often focuses on the biological sciences. Genetic manipulation from the cellular level to the species level is a hot topic."[3] She also addressed the topic of Global Warming and the Greenhouse Effect on sea level and how they affect the geography of the fauna and flora and contribute to the problems of deforestation, relocation of people living on the coastal areas, and larger demographic changes that will perturb the socio-economic status of a given area and create social disorder. Today, *Ethical Futures and Global Science Fiction* (2020) focuses on possible technological tools that may mitigate climate change, create adaptable environments to reverse or slow down global warming and reduce the effects of anthropogenic activities. Applying biomimicry architecture, using renewable energy and devising creative and innovative technologies might help decrease the effects of green gases diffusion and save the environment from further warming.

Helen Klus, a science communicator and astronomer with a special interest in physics and philosophy, argues that twenty-first century science fiction often describes future worlds that

[3] Erica Van Dommelen, "Biology in Science Fiction," *Bioscience* 39, no.10 (November 1989): 729.

reimagine new technological and scientific discoveries and raise questions related to political and ethical views. Klus considers three main reasons why such science fiction is important. First, she argues that:

> By considering worlds that are logically possible, science fiction can be used to explore our place in the universe and consider fundamental philosophical questions about the nature of reality and the mind. […]. Secondly, science fiction can inspire more people to become scientists […]. Thirdly, and perhaps most importantly, science fiction is the only genre that depicts how society could function differently. This is the first step towards progress as it allows us to imagine the future we want and consider ways to work towards it. It also makes us aware of futures we wish to avoid and helps us prevent them.[4]

Discussing science fiction works allows students to learn about real world topics such as bioengineering, bioweapons, and anthropogenic activities in an informal way, providing them opportunities to inquire about the consequences of using these technological advancements on society in an imaginary context. Genetic engineering, biological weapons and global warming are all influential topics and themes in science fiction narratives where their authors emphasize the issues and problems they present to humanity today, with emphasis on the search for effective solutions.

The purpose of integrating science fiction into the educational curriculum as Jack Williamson explains in *Teaching Science Fiction: Education for Tomorrow* is to engage students in reading materials that promote scientific explanation. Williamson argues that "science fiction

[4] Helen Klus, "Imagining the Future: Why Societies Needs Science Fiction," *The Star Garden*, http://www.thestargarden.co.uk/Why-society-needs-science-fiction.html#google_vignette (accessed March 18, 2020).

should be used with high school students to develop comprehension of subsurface levels of meaning, awaken a sense of world concept, and introduce the study of a literary genre in an informal way."[5] The reading of science fiction may also help students develop their imaginations and experience scientific facts related to the real world. Science fiction is a popular form of literature that projects the future: "it has immense value as a mind stretching force for the creation of the habit of anticipation."[6] Science fiction narratives combine imagined technological advancements with real science to reflect the political, social, and ethical conflicts that might arise from the application of such innovations.

The process of discovering scientific facts through science fiction materials could be included in elective courses where high school students discuss scientific topics from political, sociological, philosophical and ethical points of view. The topics that science fiction addresses "can present, contemplate and answer issues and problems that do affect students now and might affect them in the future."[7] Since most science fiction stories are based on scientific facts, they have the potential to create greater engagement with science by students and the general public. Scenarios of "what if," as imagined in science fictional works, can describe the impact of science on social life and allow the audience to ponder thoroughly the beneficial influence of science as well as the detrimental effects of its misuse.

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[5] Jack Williamson, *Teaching Science Fiction: Education for Tomorrow* (Philadelphia: Owlswick Press, 1980), 85.

[6] Richard Vernon, "What Is Science Fiction and Why Is It Popular?" (Dissertation thesis, Pacific Lutheran University, 1979), 23.

[7] "What Is Science Fiction and Why Is It Popular?" (Dissertation thesis, Pacific Lutheran University, 1979), 23.

To provide background for this discussion, I will survey science fiction novels, films, and digital games that engage their audience in thinking about scientific concepts. Valerie Ontell, in *Science Fiction: Popular Culture as Reading and Learning Motivation* (1997), describes the use of science fiction as a tool to stimulate the imagination and to motivate students to learn. Ontell argues that science fiction stories can provide a platform for discussions in psychology, history, anthropology, English, and science. Ontell's approach emphasizes the role of science fiction novels and movies in increasing students' engagement in science. She argues that science fiction has the "ability to prompt a reader's imagination to soar to other worlds and other (alien) life forms."[8] She acknowledges that science fiction can cover a wide variety of cross-disciplinary teaching concepts that shape the teaching process and mold students' perception of the present and the future.

Other scholars who consider science fiction as a platform to extend science literacy include science pedagogy professor, Fardad Firooznia. In his article "Giant Ants and Walking Plants: Using Science Fiction to Teach a Writing-Intensive Lab-Based Biology Class for Nonmajors," Firooznia explains how science fiction stories allow students to visualize scientific concepts and enhance their interest in science. Firooznia's goal "is to tap into [science fiction's] popularity with young people and use it as an educational tool to build interest and awareness of real science, especially biology."[9] Other scholars such as Aquiles Negrete, Cecilia Lartigue, and Rudolph John argue that scientific knowledge communicated through stories creates emotional

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[8] Valerie Ontell, *Science fiction Popular Culture as Reading and Learning Motivation* (Washington, D.C: Distributed by Eric Clearinghouse, 1997), 13.

[9] Fardad Firooznia, "Giant Ants and Walking Plants: Using Science Fiction to Teach a Writing-Intensive, Lab-Based Biology Class for Nonmajors," *Journal of College Science Teaching* 35, no. 5 (March 2006): 26.

and cognitive connections with students and the public that can enable them to relate and to associate fictional events with real world situations. Despite Gregory and Miller's warning that science fiction narratives may possibly spread "pseudoscience" and misconceptions that might lead the public into confusion, John Rudolph highlights the seriousness of the "decline in the public's science literacy [that] may be more injurious to the nation in the long run. [The] future citizenry as a whole will be even less well prepared to understand and support scientific development."[10] Keeping students interested in science and encouraging them to choose science as a career can help a country flourish economically and technologically. In this dissertation, the promising role of science fiction in helping to motivate the learning of science in non-traditional science-content courses will be investigated through multiple science fiction works and materials.

For example, Julie E. Czerneda confirms that reading science fiction gives readers the opportunity to explore scientific concepts. She asserts: "By bringing science into the realm of individual lives as well as entire cultures, these stories are thought experiments about anything we can imagine, from global warming to evolution."[11] She claims, based on her own experience as a teacher of science fiction, that science fiction is not only for entertainment, but it helps students delve into scientific concepts coated with imagination and creative thinking. Science fiction, according to Czerneda, develops students' critical reading skills. Christine V. McDonald argues that science literacy is crucial for students to acquire the knowledge necessary to improve

[10] John Rudolph, *How We Teach Science: What's Changed, and Why It Matters* (Harvard University Press, 2019), 189.

[11] Julie E. Czerneda, "Science Fiction and Scientific Literacy: Incorporating Science Fiction Reading in the Science Classroom," *The Science Teacher* 73, no. 2 (February 2006):39.

their scientific background and be ready for the twenty-first century. McDonald believes that students' lack of interest in science may be "largely attributed to transmissive, teacher-centered pedagogies; perceived irrelevancy of school science to the real world; heavy, difficult and content-driven curriculum; curriculum focused on preparing the academic elite; and a lack of attention to the human aspects of contemporary science."[12] The best way of learning science, according to McDonald, is to engage students in pedagogical practice of argumentation, to provide the opportunity for students to participate in discussions where they need to provide evidence for their argumentation, to create an environment where students can debate ideas, evaluate their claims, and learn from each other. These elements are considered "best practices" for science learning. "Encouraging students to engage in critical thinking, discussion and debate has many benefits, including participating in scientific discourse, improved learning of scientific concepts, generating questions, formulating informed positions, and engaging in socioscientific decision-making."[13] This is what Stephen P. Norris and Linda M. Philips acknowledge when they discuss scientific literacy in their article, "How Literacy in Its Fundamental Sense is Central to Scientific Literacy" (2003). They both admit that to achieve scientific literacy, students should be required not only to read science textbooks and to decode the words and locate the information but should also be taught to read them from a theoretical perspective. However, even if students are able to read, identify, locate, and recall information found in the text, Norris and Philips noticed that the same students "paraphrase when asked to analyze, summarize when

[12] Christine V. McDonald, "Stem Education: A Review of the Contribution of the Disciplines of Science, Technology, Engineering and Mathematics," *Science Education International* 27*,* no.4 (2016): 536.

[13] "Stem Education: A Review of the Contribution of the Disciplines of Science, Technology, Engineering and Mathematics," *Science Education International* 27*,* no.4 (2016): 542.

asked to criticize, and retell when asked to interpret."[14] They conclude that students should be taught to read the texts as substantive scientific content, but to use metacognitive skills to interpret critically information and evidence, evaluate factual knowledge and investigate the accuracy of scientific facts. To master scientific concepts, students must master literate thought that enables them to think metacognitively in order to interpret the text, adjudicate the meaning based on the validity of the evidence and to record one's stance towards the texts that are being studied. Scientific literacy has long been included as part of the general knowledge taught at schools, so additionally, training students to investigate science as presented in different kinds of materials will allow them to build their factual knowledge beyond the high school level, so they will become more scientifically educated citizens able to solve future problems as informed decision-makers.

To better communicate science to the public, some science fiction scholars claim that science literacy is better achieved by the public if it is represented through storytelling in novels, films, and video games. For instance, Gary Graham argues that: "Story comes naturally to us. Somewhere in the 2% difference in DNA between human beings and chimps lie the secrets of language and grammar; the secrets of stringing sounds together in such a way that [they] can convey action, intent, and emotion, not only in the present, but also in the past and the future."[15] This fact actually makes us more vulnerable and susceptible to learn through storytelling; human nature is predisposed to share ideas and stories about common and relevant topics which render

[14] Stephen P. Norris and Linda M. Philips, "How Literacy in Its Fundamental Sense Is Central to Scientific Literacy," *Science Education* 87, no. 2 (March 2003): 227.

[15] Gary Raham, *Teaching Science Facts with Science Fiction* (Portsmouth, NH: Teachers Ideas Press, 2004), 3.

the process of retaining information easier to remember. However, some difficulties emerge when students read fiction to learn about scientific concepts. As Helene C. Boswell and Tasha Seegmiller reveal in their research article "Reading Fiction in Biology Class to Enhance Scientific Literacy" (2016), students often struggle in science reading comprehension in undergraduate college classes. Boswell and Seegmiller attribute this struggle to the lack of minimal scientific literacy that students are supposed to have at the university level. Boswell and Seegmiller support the use of Czerneda's approach of using science fiction novels and films to teach scientific literacy. They specifically suggest using science fiction materials as a tool to encourage scientific literacy in biology classrooms to directly promote science learning. They argue that scientific literacy can enable students to discuss the possibilities and limits of science through the comparison of science-based academic readings with creative literature and they implemented this process among both undergraduate majors and nonmajors in a General Biology course. In this study, they found that the integration of fiction into the science curriculum did enhance students' critical thinking and helped them to develop cognitive skills by "nurturing creative elements that lead to scientific discovery."[16] To measure the efficacy of this approach, students who were enrolled in the program were required to read science fictional excerpts and were asked to address in their final paper the relationship between a science theme in fiction and their science topic. Students also were given online open-ended questions to discuss as part of their graded assignments. The final class assessment was a written paper that assessed students' analytical discovery of the story's main idea and their ability to make connections with scientific

[16] Helen C. Boswell and Tasha Seegmiller, "Reading Fiction in Biology Class to Enhance Scientific Literacy," The American Biology Teacher 78, no. 8 (October 2016): 645.

articles or textbooks of their choice. After analyzing students' final written responses, Boswell and Seegmiller found that "56 out of 59 (94.9%)" students learned more about science concepts from science fiction than they would typically learn from reading only scientific textbooks.

Other approaches that emphasize SF as "speculative fiction" offer additional useful perspectives. In her book, *Creating Life from Life: Biotechnology and Science Fiction* (2015), Rosalyn W. Berne argues that science fiction works can predict future possibilities of biotechnology and its influence on society. Her philosophical approach demonstrates that biotechnology is not only a scientific endeavor; it is interrelated to economics, religion, culture, and politics. According to Berne, science fiction increases awareness of biotechnological advancements and helps the general public to be more conscientious about innovative endeavors in science. Similarly, my analysis will focus on how fiction can "smuggle scientific facts into the consciousness of a scientifically illiterate public"[17] and how it may help the public assess the effects of innovative scientific advancements on society and human culture.

Ralph Martin also notes the importance of literature in promoting science as he argues that literature provides a plethora of various resources and "it captures student interests and compels them to confront and explore real-life issues."[18] He invites teachers to use science fiction in science classrooms so their students can benefit from the additional advantages that include "stimulation of higher-order thinking and increasing the levels of student reading,

[17] Thomas C. Erren and Puran Falaturi, "Research Insights and Insides: Science-in-Fiction as a Contribution to the Third Culture Concepts," Medical Hypotheses 72, no.5 (May 2009): 487.

[18] Ralph E. Martin, Using Literature to Teach Science (Washington, D.C: Distributed by Eric Clearinghouse, 1979), 3.

writing, talking and independent learning."[19] Usually science fiction stories investigate real-life issues as they describe the near future portrayed in light of science and technological advancements and their repercussions on society. For example, Mary Shelley's *Frankenstein* could be a starting point for discussion about creating life as Dr. Frankenstein did in his laboratory as compared to current-day technologies of in-vitro reproduction or the test-tube baby controversy. Students could discuss the topic from ethical and moral points of view and discuss the consequences of this creation. Exposing students to debatable dilemmas promotes the development of critical thinking skills, allows them to shape their personal opinions and encourages them to research more about topics relevant to them. Accessing a variety of materials to learn about science broadens students' opportunities to integrate science in real life events; it will help them in their decision making, their valued principles formation, and finally enable them to see the relationship between science and real life.

Even though many scholars advocate for the use of science fiction materials in academic settings, other scholars, such as Valerie Smith, raise concerns and consider this approach potentially deceptive and misleading. Smith addresses some potential classroom issues such as unsuitable subject matter or sexual and racial stereotyping that may reinforce student biases and inequity, not to mention the difficulties raised in trying to overcome a conceptual misconception once inaccurately represented.[20] For example, Michael Crichton pretends that "Kalocin" developed by Jensen Pharmaceuticals (fictional company) is a drug that stops cancer and is

[19] Using Literature to Teach Science (Washington, D.C: Distributed by Eric Clearinghouse, 1979), 2.

[20] Valerie Smith, *Teaching the Science in Science Fiction* (Washington, D.C: Distributed by Eric Clearinghouse, 1990), 10-11.

considered "a broad-spectrum antiviral agent. He described it as killing the virus polio, rabies, leukemia, and the common wart."[21] This fictional description of a multi-purpose drug is only an aspiration that Crichton's characters may ambitiously wish to be true, but it could create a misconception if it were considered true by undiscerning readers.

More recently, Charalambos Vrasidas and Lucy Avraamidou discuss the integration of science fiction into education in a research study that they conducted. They found that narrative is one of the vehicles that helped students to understand science within the context of a social environment. According to Charalambos and Avraamidou, "narratives offer an empowering tool for communicating science and making science more accessible to the public."[22] They also note that teachers and educators value the benefits of narrative in education and specifically in learning about science. They state that "narratives enable students to develop research skills, critical and creative thinking, debating, and decision-making skills, which are related to managing and utilizing scientific knowledge in everyday life as well as skills that are needed to deal with science-related social and environmental problems."[23] Although Vrasidas and Avraamidou point to huge benefits from implementing science fiction into the high school curriculum, they note other problematic issues that teachers and educators encounter in their classrooms. They argue that teachers lack necessary experience in the domain of science fiction and some of them are not proficient in explaining scientific concepts. Both assert that teachers

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[21] *The Andromeda Strain*, 265.

[22] Charalambos Vrasidas, Lucy Avraamidou and al., "Science Fiction in Education: Case Studies from Classroom Implementations," *Educational Media International* 52, no. 3 (July 2015): 202.

[23] Charalambos Vrasidas, Lucy Avraamidou and al., 203.

need to receive professional development related to science fiction teaching and that teachers need to redesign and reconfigure their courses to integrate science fiction in an effective and relevant way to students. Many challenges complicate the process of integrating science fiction into teaching practices due to lack of educational materials and teachers' lack of experience with science fiction works. Other issues may reside in teachers' attitudes towards integrating science fiction narratives into their classrooms. Some of them are not too enthusiastic about the idea and find it very difficult to "explain adequately to the students the connection between science and science fiction.[24]

In this dissertation, I will specifically address the valuable potential of science fiction in promoting scientific literacy in three specific areas: biology, biotechnology and anthropogenic global warming. Each of these three fields raises controversial issues that are currently under debate within civic, religious and political contexts in current global society. As described below, specific popular works of Science Fiction novels, films and games directly engage these debates through their use of imaginative scenarios that consider the pros and cons of emerging science and technological developments and their likely impact on human life, other life forms and our planetary environment. Through the materials studied here, I will analyze the details of scientific facts described in the literary works that focus respectively on genetic engineering, biological warfare and global warming to highlight how such factual information can be shared through fictional narration to educate readers about genetic interference, the importance of limiting the development of mass destructive weapons and devising solutions for global warming.

[24] Charalambos Vrasidas, Lucy Avraamidou and al., 205.

Chapter One offers a case study in which two works of science fiction describe an outbreak of infectious disease and the use of biological weapons, *The Andromeda Strain* (1969) and *The Andromeda Evolution* (2019). Similar to the methods of Firooznia and Czerneda, I will analyze both works to evaluate the accuracy of the scientific concepts represented in the stories and I will employ Negrete and Lartigue's approach to argue that speculative fiction could enhance students' cognitive and critical skills and expand their scientific knowledge. Negrete and Lartigue evaluate the outcome of communicating science through narratives by applying the (RIRC) method which measures students' "ability to Retell, Identify, Remember and Contextualize information."[25] My approach will analyze in detail the scientific content in each science fiction narrative or will provide specific references and analyses that may be of use to future teachers. I will show that the narrative evokes scientific facts and explains how the details of the descriptive events are meticulously represented to stimulate readers' thinking and invite them to ponder the consequences of biological weapons on societies. I will also draw upon Fuller Torrey's *Beasts of the Earth* (2005) to discuss how deadly bacteria are the most likely organism to be used as bioterrorist weapons. Clay Farris Naff's *Biological Weapons* (2005) and Helena Costa's article "Bioterrorism in the Literature of the Nineteenth Century" (2017) will provide current real-world information about how bacteria and viruses can be transformed into biological weapons that can threaten humankind.

In Chapter One, I will shed light on the origins of bioterrorism and how the idea of creating bioweapons was inspired by infections discovered and transmitted to humans from

[25] Aquiles Negrete and Cecilia Lartigue, "The Science of Telling Stories: Evaluating Science Communication via Narratives," *Journal Media and Communication Studies* 2, no. 4 (April 2014): 100.

animals either by accidental exposure or ignorance of the transmissibility. *Beasts of the Earth* lists twelve microbes that can be used in bioterrorism attacks. Some of these microbes have the potential to infect while floating in the air and cause infectious diseases in a variety of animals in addition to humans. For example, Q fever and Tularemia are "of special interests to bioterrorists"[26] as they can be easily spread and consequently infect by inhalation. Identifying different sorts of bacteria and studying each one of them and its specific effects on human bodies will help students better understand how our nervous and respiratory systems react to such deadly diseases. Learning about the impact of these weapons on human health can give students some insights into what to expect in the case of biological weapon deployment.

In Chapter Two, I will focus on Daniel Suarez's novel *Change Agent* (2017) and the film, *Gattaca* (1997) to discuss gene editing for the therapeutic elimination of hereditary diseases and to examine the societal repercussions of genetic manipulation that may lead to discrimination and social eugenics. Through the study of these two works, I will analyze factual scientific elements such as DNA mapping (*Gattaca*) and CRISPR technology (*Change Agent*) to critique the human aspiration to "design" people with specific characteristics or to erase their identities. To demonstrate the effectiveness of such science fiction films on science literacy, I will base my discussion on Cavanaugh and Dubeck who argue that films allow students to visualize and encounter a variety of science concepts and provide a new and entertaining pathway for learning.

[26] Fuller E. Torrey and Robert H. Yolken, *Beasts of the Earth: Animals, Humans, and Diseases* (Rutgers University Press, 2005), 30.

> Viewing science fiction films improves learning science in various ways. The films allow direct visualization of abstract topics. High interest in science fiction facilitates learning related concepts. Terence Cavanaugh and Catherine Cavanaugh explain in *Learning Science with Science Fiction Films* that "science fiction film focuses on the action involved in solving a problem […]. Science Fiction films often explore modern world problems and issues and provide the opportunity to consider the future and the changes that may occur. Science fiction films can be much more than just special effects; they can be the promoters of ideas and change.[27]

In this section, I will study gene editing from cultural and theological points of view as presented in Ted Peters' *Playing God? Genetic Determinism and Human Freedom* (2003), Henk Belt's "Playing God in Frankenstein's Footsteps" (2009) and David A. Kirby's "The New Eugenics in Cinema" (2000). Peters proposes two assumptions in his book that explain the myth of genetic determinism. He states that if humans are totally programmed by their DNA, then human freedom is in fact a delusion but if our DNA can be fully engineered then "we can gain control over nature and guide our own evolutionary future."[28] In such a scenario, it is reasonable to ask if humans are defined by their genetic sequences or by the reflection of their environment and cultures. In this chapter, I will also discuss the cloning process as it is also addressed frequently by science fiction and causes profound disputes among scientists and various world religions. I will discuss cloning from a medical perspective for therapeutic purposes to cure

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[27] Terence Cavanaugh and Catherine Cavanaugh, *Learning Science with Science Fiction Films* (Washington, D.C: Distributed by Eric Clearinghouse, 1996), 3-4.

[28] Ted Peters, *Playing God? Genetic Determinism and Human Freedom* (Routledge, 2003), xiii.

patients from diseases such as diabetes and Alzheimer. In *The Cambridge Companion to Science Fiction* (2003), Edward James and Farah Mendlesohn discuss Mary Shelley's *Frankenstein* (1818) as the title character creates a monster from dead body parts and the resulting "monster" was rejected for not fitting the norm of what the surrounding culture considered "natural." Today, cloning humans is still viewed as a monstruous act that denies the clone individual identity and birth rights. James and Mendlesohn raise important questions about whether "a cloned child [is] 'bad', or simply different? Or, ironically, not 'different enough?"[29] The book sheds light on the challenges that humanity faces as biological entities, the need to deal with biological weapons threats, genetic engineering and most currently the rise of anthropogenic issues. The most relevant challenge resides in altering humans' genes to reach posthuman levels where humans can resist diseases, overcome aging and acquire unlimited control over desires, emotions and mental abilities. Such concerns may also relate to ethical and social dilemmas that might widen the gap between society's members. To provide multiple educational resources, science fiction films may provide teachable moments that can guide us in ethical decision-making and enable us to better imagine the future consequences of our actions.

In Chapter Three, I will address representations of climate change in science fiction works. I will analyze Michael Crichton's *The State of Fear* (2004), Naomi Oreskes' *The Collapse of The Western Civilization* (2014), Kim Stanley Robinson's *New York 2140* (2017) and *The Ministry for the Future* (2020) to assess the scientific information in these SF novels, explore the causes of global warming and present an optimistic view to train students' thinking

[29] Edward James and Farah Mendlesohn, *The Cambridge Companion to Science Fiction* (Cambridge: Cambridge University Press, 2003), 147.

to reflect potential solutions for the climate change problem. I will discuss the non-fiction documentaries of former Vice President Al Gore: *An Inconvenient Truth* (2006) and *An Inconvenient Sequel: Truth to Power* (2017) to present a point of view that considers global warming as an anthropogenic activity. By contrast, the work of Roy W. Spencer, a former senior NASA climatologist, *The Great Global Warming Blunder* (2010) argues that global warming is the result of a natural cycle and it is not man-made. His work contradicts science author Brian Clegg's *Ten Billion Tomorrows* (2015) who warns of devastating outcomes due to the melting of the Arctic ice cap, rising oceanic water and inhabitants' dislocations. He believes "the biggest threat that we face as a race at the moment is climate change."[30] To elucidate the conflicts among climate change views, I will draw on recent publications such as "Between Fact and Fiction: Climate Change Fiction" (2016), "Sunken Cities: Climate Change, Urban Futures and the Imagination of Submergence" (2017), "Science Fiction and the Time Scales of the Anthropocene" (2019) and *Biomimicry in Architecture* (2019). Using science fiction scenarios and fictional speculations may help students gain better understanding and clearer visualization of our potential futures. I will also discuss *Adaptation of Climate Change: From Resilience to Transformation* (2011) and *Stages of Transmutations: Science Fiction, Biology, and Environmental Posthumanism* (2019) to highlight innovative and creative ways of imagining better futures where climate change is not a threat and it is under control.

In Chapter Four, I will discuss case studies where digital games and technology can be used to advance scientific literacy. Games are cultural tools that not only convey information but

[30] Brian Clegg, *Ten Billion Tomorrows: How Science Fiction Technology Became Reality and Shapes the Future* (New York, N.Y: St. Martin's Press, 2015), 140.

also engage players in interactive learning. Based on Margaret Honey and Margaret L. Hilton's book *Learning Science through Computer Games and Simulations* (2011) students in the U.S. lack scientific knowledge. More recently, students lost interest in learning science due to the recent pandemic and to the economic struggle that left many in dire situations. "More than a third of high school students […] will not be able to complete their STEM courses. […] 72 percent of low-income students didn't complete their AP physics courses and 63 percent missed AP calculus."[31] Honey and Hilton attribute this lack of interest in science to educational approaches that "focus on improving student performance on high-stakes accountability tests, [and] provide students with few opportunities to conduct investigations, directly observe natural phenomena, or work to formulate scientific explanations for these phenomena."[32] In addition, they point out that "Games and simulations have the potential to advance multiple science learning goals, including motivation to learn science, conceptual understanding of science topics [and] science process skills"[33] through simulations that can reproduce actual events, provide a safe and efficient model for problem-solving issues by testing ideas and make predictions.

Amy Green's *Storytelling in Video Games: The Art of the Digital Narrative* (2018) and James Paul Gee's *Good Video Games + Good Learning: Collected Essays on Video Games, Learning, and Literacy* (2007) all contribute to the discussion of the potential educational impact

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[31] Sarah D. Sparks, "Science Teaching and Learning Found to Fall Off in Pandemic," *Education Week* (April 12, 2021), https://www.edweek.org/teaching-learning/science-teaching-and-learning-found-to-fall-off-in-pandemic/2021/04 (accessed October 2021).

[32] Margaret Honey and Margaret L. Hilton, *Learning Science through Computer Games and Simulations* (Washington, D. C: National Academies Press, 2011), 6.

[33] *Learning Science through Computer Games and Simulations* (Washington, D. C: National Academies Press, 2011), 15.

of science games on players' science literacy. Leonard A. Annetta's "article investigating the Impact of Video Games on High School Students' Engagement and Learning about Genetics" (2008) provides insights about how genetic concepts may be explained to students through digital games. I will also survey more recent games such as *Mission Biotech* (2010) and *Perfect Strain* (2017) which immerse students in virtual worlds and help them practice scientific experiments. Using SF video games to introduce scientific concepts increases players' engagement and may provide an additional resource that can enhance science education.

Games and simulations can help science teachers provide visual content for students to practice their learning and to expand their experiences. Virtual worlds provide a sort of laboratory environment where students can explore and experiment with different outcomes of their hypotheses. Games that combine fun engagement with learning have great potential to create the necessary motivation to learn about science. Learning through games may enable instructors to conduct ongoing assessments and offer individualized instruction as feedback that can further help students practice and repeat tasks until proficiency goals are met. Honey and Hilton note that "blue-ribbon panels have recently called for increased use of games to boost U.S. students' science learning"[34] and encourage schools to create academic clubs, elective courses, or match lessons with available educational games to foster engagement with learning.

If successful, my research may help non-science majors and educators appreciate science and get involved in learning about relevant science topics. Previous SF scholars have primarily discussed space science, physics, aliens, and time travel, etc. My project deals with current topics

[34] *Learning Science through Computer Games and Simulations* (Washington, D. C: National Academies Press, 2011), 20-21.

in biology and climate science that directly affect ongoing real-world problems. My analysis will contribute useful suggestions that can aid educators in choosing SF materials wisely for classroom use and help them implement science fiction into the curriculum and make it an effective learning tool.

Through a close examination of SF works, I hope to bring greater awareness about the "real" science in science fiction and provide an analysis of scientific content that science educators and students can use to engage science learning in non-traditional ways. This project will establish a potential foundation for a high school curriculum of elective courses that introduce scientific concepts, biomedical ethics and technological advancements in ways that impact people's thoughts and lives. My project will contribute to the learning and analysis of science fiction from an interdisciplinary perspective and promote the relationship between science and literature by serving as a reference guide for educators who wish to try something new in their classrooms. Hopefully, this project will inspire further studies of other science fiction works that could also be integrated into secondary education and public education, and help us make informed decisions that improve the health and well-being of our global environment.

CHAPTER 1

SCIENCE EDUCATION INSPIRED BY SCIENCE FICTION

Frederick Pohl, the winner of six Hugo Awards, discusses in "Science Fiction: Stepchild of Science" (1994) the work of famous science fiction authors who try "to reconcile their imaginations with current scientific doctrine."[35] These authors write fiction about science but in reality, their topics are inspired by events surrounding us. Pohl considers every science fiction story to be written according to the "scientific method" which defines the steps of scientific inquiry. He states that such a storyline develops according to "the orderly system of information gathering and theory formulation that distinguishes science from random anecdote."[36] To clarify his theory, Pohl claims that science fiction authors have been applying this method all along either consciously or unconsciously. Their stories take parts of the world around us and add invented and imagined elements showing how science and technology change many aspects of our lives. In other scholars' views, science fiction promotes critical literacy and fosters social, political, and cultural understandings that enable students to develop critical responses for issues with social and ethical relevance. According to Diane Zigo and Michael T. Moore, both former high school teachers, readers of science fiction engage in a variety of reading strategies: they "make intertextual connections, reread challenging sections of text, reply on contextual clues to

[35] Frederick Pohl, "Science Fiction: Stepchild of Science," *Technology Review* 97, no.7 (1994): 57.

[36] Ibid., 58.

explain unfamiliar terminology or initially puzzling narrative structures, and synthesize content across numerous passages to make meaning."[37]

However, part of the real challenge in education is connecting school knowledge with real life issues and experiences. This goal could be achieved by introducing students to critical thinking through science fiction readings. Ira Shor, professor of composition and rhetoric at College of Staten Island, City University of New York, argues that "critical literacy has the potential to connect the political and the personal, the public and the private, the global and the local, the economic and the pedagogical life"[38] through analysis of interdisciplinary subjects that science fiction introduces in the narrative plot. Other researchers, such as Julie E. Czerneda, have used science fiction to help students extend their scientific knowledge on the one hand and to extrapolate meaningful experiences from imagined scenarios, on the other. Czerneda suggests asking students to identify the science described in fictional work and evaluate its role in solving problems to engage students in learning about science. Students are invited to examine the accuracy of scientific evidence in the text. "Most science fiction authors ask: "What if?" and speculate about what could happen if a certain aspect of science or technology existed-or did not exist."[39] Through an analysis of speculative scenarios, students are exposed to scientific facts.

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[37] Diane Zigo and Michael T. Moore, "Science Fiction: Serious Reading, Critical Reading," *English Journal* 94, no.2 (November 2004): 87.

[38] Ira Shor, "What Is Critical Literacy?" *Critical Literacy in Action: Writing Words, Changing Worlds* (1999): 1, quoted in Zigo and Moore, "Science Fiction: Serious Reading, Critical Reading" *English Journal* 94, no.2 (November 2004): 88.

[39] Julie E. Czerneda, "Science Fiction & Scientific Literacy: Incorporating Science Fiction Reading in Science Classroom," *The Science Teacher* 73, no 2 (February 2006): 39.

Good science fiction narratives "do not violate scientific principles, but rely on them to guide thought experiments through to possible consequence."[40]

This line of thought continues with "Manipulating Our Futures: The Role of Science Fiction in Education" (1979) in which Walt Michalsky argues that reading science fiction novels allows students to expose their curious minds to unexpected storylines in which they are emotionally and intellectually engaged. For Michalsky, science fiction creates an appealing interest to students who "can further [their] skills and techniques in reading, writing, talking, and exploring independently."[41] He claims some teachers are stuck with canonical reading materials long considered the ultimate reading material for literature. But these materials are so dated, according to Michalsky, that students cannot feel an emotional connection with the content. On the other hand, science fiction novels offer readers stories that deal with humanity's position in the world and its responsibility to solve social issues. Science fiction allows students to intellectually "[experiment] with entirely new concepts and their various effects on man and his world."[42]

Using science fiction to improve comprehension of scientific concepts has several benefits for students. First, science fiction engages students and introduces abstract concepts with compelling narratives and illustrations. Fictional examples in exciting scenarios propel students to delve deeply and discover the science in fictional works. Since the nature of science fiction is

[40] Ibid., 41.

[41] Walt Michalsky, "Manipulating Our Futures: The Role of Science Fiction in Education," *The Clearinghouse* 52, no.6 (1997): 247.

[42] Ibid., 248.

interdisciplinary, students can have a wide variety of class discussions related to literature, science, sociology, ethics, and other topics. In this context, students are exposed to various forms of information that help them "solidify their knowledge and comprehension of the material."[43] In the biology class of Professor Andrea Bixler, students are required to read science fiction novels and focus on an excerpt of their choice to discuss science facts or misconception.

Studying science fiction in the classroom supports interdisciplinary approaches to learning that allow students to experience the relationship of science and technology. To support science learning, Kevin Grazier, a planetary physicist, claims "real progress in science is made when the techniques of multiple disciplines are brought to bear on a problem."[44] This overall picture helps expand students' knowledge and introduces them to real-world challenges.

Other teachers have also introduced science fiction to their students in their biology courses. For instance, Fardad Firooznia taught biology courses that explore real science through science fiction works. Firooznia claims "science fiction allows [students] to study biology in a setting different than a standard introductory course. It provides students with an opportunity to explore aspects of biology that are relevant to their lives through critical analysis of works of science fiction."[45] By introducing science to students through narratives, students have the opportunity to build factual knowledge or at least question the scientific facts provided in the

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[43] Andrea Bixler, "Teaching Evolution with the Aid of Science Fiction," *The American Biology Teacher* 69, no. 6 (August 2007): 337.

[44] Kevin R. Grazier, ed., *The Science of Michael Crichton: An Unauthorized Exploration into Real Science Behind the Fiction Worlds of Michael Crichton* (BenBella Books Inc., Dallas, Texas, 2008), VIII.

[45] Fardad Firooznia, "Giant Ants and Walking Plants: Using Science Fiction to Teach a Writing-Intensive, Lab-Based Biology Class for Nonmajors," *Journal of College Science Teaching* 35, no. 5 (March 2006): 27.

narration to inquire about their scientific accuracy. According to Firooznia, the main goal of introducing science fiction to non-biology majors is to help students practice scientific reasoning, evaluate and analyze data and record their findings. In Firooznia's class, the students' final research papers are designed to help them develop some expertise in the topic of their choice so students learn to appreciate the interconnectedness of science. According to Firooznia, science fiction allows students to imagine the future and allows them to engage with biology learning to become effective citizens.[46]

There are several other ways to use science fiction in science education. Ralph Martin, author of *Using Literature to Teach Science* (1979) emphasizes the role of science fiction in providing more appealing materials that deal with real issues. He claims that "Literature presents the human side of science and provides opportunities for students to experience issues which frequently confront scientists in real life."[47] In their research, Christopher Benjamin Menadue and Karen Diane Cheer highlight the multidisciplinary relationships between science fiction and human culture. The influence of science fiction on science and science on science fiction is reciprocal, according to Menadue and Cheer. Their research finds significant value for science fiction used for educational purposes: "Science fiction is employed as a lens through which human culture may be viewed to discover new interpretations. These may be relevant to cultural, social, scientific, and literary studies, and support efforts at improving science communication,

[46] Ibid., 30.

[47] Ralph E. Martin, *Using Literature to Teach Science* (Washington, D.C: Distributed by Eric Clearinghouse, 1979), 1-2.

and especially science education."[48] Moreover, teachers who used science fiction literature in their classroom assert that "additional benefits includ[ing] the stimulations of higher-order thinking and an increase in levels of students' reading, writing, [speaking] and independent learning"[49] are noted through students' performance through the academic progress.

More academic teachers such as Helen C. Boswell and Tasha Seegmiller advocate the use of fiction in biology class as "fiction provides a creative framework in which 'what ifs' are played out to reach a hypothetical resolution […]. If guided with the right sorts of questions, these 'what ifs' provide a theoretical context within which students can evaluate information to form value judgments and propose solutions to problems."[50] Using science fiction novels such as *The Andromeda Strain* (1969) written by Michael Crichton and *The Andromeda Evolution* (2019) written by Daniel H. Wilson expose students to a variety of scientific topics including infectious disease, genetic engineering, and bioweapons. In addition, students can explore the authors' use of the scientific method to solve issues and problems. More importantly, students could investigate the science and examine a range of hypotheses to formulate their own theories based on their research.

The Andromeda Evolution could be studied as a sequel to *The Andromeda Strain* as it continues the plot by showing the evolution of the strain as a result of the viruses' mutation. This narration highlights biological advancements in learning about the mutation and adaptation of

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[48] Christopher Benjamin Menadue and Karen Diane Cheer, "Human Culture and Science Fiction: A Review of the Literature, 1980-2016," *Sage Open* 7, no. 3 (August 2017): 13.

[49] *Using Literature to Teach Science* (Washington, D.C: Distributed by Eric Clearinghouse, 1979), 1-2.

[50] Helen C. Boswell and Tasha Seegmiller, "Reading Fiction in Biology Class to enhance Scientific Literacy," *The American Biology teacher* 78, no. 8 (October 2016): 645.

viruses. Through the narration of *The Andromeda Evolution,* the student-reader realizes that the virus can expand, acquire new forms and replicate. Although *The Andromeda Evolution* is longer than *The Andromeda Strain,* the storyline recounts fewer scientific events. In the latter, Crichton ensured that factual and scientific events carried the plot while his characters made assumptions, conducted experiments and provided explanations. However, *The Andromeda Evolution* represents the evolution of the virus as a living organism that multiplies and duplicates and the plotline stresses the virus's ability to propagate and instigate a pandemic.

DEADLY INFECTIOUS DISEASE

The Andromeda Strain (1969) helped define the science fiction genre in contemporary world literature and is a good example of a science fiction work that conveys factual science through fictional narrative. This novel can be used as a way of teaching students about several science-related topics such as space exploration, bacteria, viruses, biological weapons and infectious diseases. The evidence that Crichton evokes in his narration has the potential to build interest in real science. For example, engaging interest in fictional space science, bioengineering, and infectious diseases feeds readers' imagination and allows them to formulate hypotheses about given scenarios that might help them in their futures. This is one great quality of science fiction: it gives readers a story about a current or prospective problem guided with questions and theories that is akin to a detective search with clues to solve the puzzle.

The novel's beginning provides readers with fictional background about a military project intended to explore space and develop biological weapons to defend the United States. The plot opens with the arrival of an extraterrestrial organism on a crashed military probe. The organism is a deadly bacterium that kills most of the habitants of a small desert town, Piedmont,

Nevada. Only two survive: an old addicted man and a newborn baby. The story continues to evolve when a secret governmental emergency response protocol for attacks on the United States, Project Wildfire, is mobilized to investigate the incident at Piedmont. This detail is crucial as it prepares for the rest of the scientific evidence that Crichton evokes throughout the narration. Crichton describes in detail the launch and the return of different probes such as Scoop VI which was recovered containing "a previously unknown form of unicellular organism, cocobacillary in shape, gram-negative, coagulase, and triokinase-positive"[51] to give his narrative more convincing scientific foundation. Such detail provides readers with information about military activities related to biological weapons' development. Describing the germ recuperated from space with specific technical terms helps students visualize microbes' biological structure and learn about their anatomy.

All of Crichton's characters are doctors specializing in different fields: Dr. Jeremy Stone is a bacteriologist in the bacteriology department at Stanford University; Dr. Charles Burton is a pathologist at the Baylor College of Medicine; Dr. Peter Levitt is a clinical microbiologist, experienced in the treatment of infectious diseases and suffers from epilepsy; and Dr. Mark Hall, is a surgeon who was added to the team under great pressure from the Defense Department according to the "Odd Man Hypothesis."[52] This fictional hypothesis states that an unmarried man should be in charge of executing decisive measures in case of life-threatening events since he would be more likely to initiate the facility's self-destruction process in case of contamination.

[51] Ibid., 53.

[52] Ibid., 55.

The Andromeda Strain focuses upon bacteria and viruses since they are the main causes of illness and death due to their rapid transmissibility. After reading the novel, students can be asked to research the different types of diseases that might have the same effects described in the novel, learn about their structure, understand how they attack the human body and identify their respective symptoms. The death of Piedmont residents is described as if the residents were killed by an asphyxiant gas similar to sarin, a biologically engineered gas. However, in *The Andromeda Strain*, the investigation carried out by bacteriologist Dr. Stone and pathologist Dr. Burton eliminated this hypothesis after they examine the corpses. For instance, Burton suggested it was a trauma to the head or possibly a nerve gas. Stone says: "If it was an enzymatic block of some kind —like arsenic or strychnine— we'd expect fifteen to thirty seconds, perhaps longer. But a block of nervous transmission, or a block of the neuromuscular junction, or cortical poisoning— that could be very swift."[53] Burton and Stone's explanation that toxicant gases block the nervous and muscular systems when they are highly diffusible and cause death by asphyxiation helps students conceptualize the effect of gas on human neurological systems. Teachers could use this scene to ask students to check whether the description of death by asphyxiation in the novel conforms to real scientific evidence.

Throughout the novel, Crichton portrays Burton as an expert on staphylococcus bacteria who shares factual information about these fields with readers. He describes Dr. Burton as having "shown that this organism produced two enzymes that altered blood. One was the so-called exotoxin, which destroyed skin and dissolved red cells. Another was a coagulase, which

[53] *The Andromeda Strain*, 67.

coated the bacteria with protein to inhibit destruction by white cells."[54] Such factual explanations provide readers with accurate information about blood clotting and how viruses can destroy blood cells. Student-readers, then, are exposed to scientific facts that help them understand the process of blood clotting as well as other medical terminology that can help increase their scientific literacy.

As both characters continue examining bodies and evaluating the scene around them, Dr. Stone presents a new hypothesis. He says the cause of death may be coronary or pulmonary embolus, although he quickly eliminates these options as none of the dead people show signs of grimace or pain on their faces. However, since the victims died with their hands clutching their chests, Dr. Stone reasons they could not breathe and died by asphyxiation. This guess is also eliminated because people tend to loosen their clothing in such situations, but that did not happen as they observed a man wearing a tie and he did not touch it and a woman wearing a tightly buttoned collar with no sign of pulling the collar down (*The Andromeda Strain* 71-72). The investigation carried out by both doctors follows a logical and scientific process that Crichton relates in an exciting and easy to-understand style that invites readers to speculate about evidence and clues. Such imaginary scenarios can facilitate science understanding as readers can visualize the situation and gain concrete ideas about bioweapons' effects on people. Describing the corpses' positions provides crucial observation to think of potential causes of death. Students could be asked to research coronary or pulmonary embolus symptoms to validate Crichton's fictional narration.

[54] Ibid., 119.

To introduce the reader to other diseases, Crichton describes the work of Dr. Burton, the bacteriologist in *The Andromeda Strain*, who early in his life was interested in studying diplococcus pneumoniae, a gram-positive bacterium responsible for pneumonia. Later, Dr. Burton's interests shifted to the study of staphylococcus aureus, a round-shaped gram-positive bacterium found in the upper respiratory tract and on the skin. Both bacteria are susceptible to penicillin. However, Crichton continues his narration by introducing a new strain of staph that can resist penicillin: "The new strains were virulent and produced bizarre deaths, often by brain abscess."[55] All the crew members investigating this incident are required to go through decontamination procedures to enter the Wildfire facility to eliminate and remove any traces of potential contaminants and reduce any cross contamination with the virus in question. They are required to have all vaccinations up to date. For instance, the scientists' team needs to be free of smallpox, diphtheria, typhoid, paratyphoid, tetanus toxoids, yellow fever, plague, cholera, and tuberculosis. The team had to have "gamma-globulin shots for viral infection"[56] and must be free from any of the following diseases: syphilis, spirochetal disease, streptococcus, staphylococcus, pneumococcus, gonococcus, meningococcus, proteus, pseudomonas, salmonella, and shigella. Students could be asked to research each of these diseases to check their infectious impact on humans and provide a list of each disease's symptoms.

Crichton does not miss an opportunity to complicate the successions of events in the narration with more scientific facts and information that enrich readers' understanding and expand their knowledge. Amid the culminating Wildfire self-destruct moment, Dr. Hall

[55] *The Andromeda Strain*, 62.

[56] Ibid., 103.

discovers that Levitt is epileptic as he has a seizure due to the blinking light of the alarm. Crichton gives a full description of the epileptic episode which informs readers about what to expect when such seizures happen. Dr. Hall recommends injecting him with a hundred milligrams of phenobarbital (barbiturate anticonvulsants) until he gets him Dilantin which is an antiepileptic drug that controls seizures. "Hall waited until Leavitt relaxed, until his body stopped its seizures, and then he injected the barbiturate."[57] To understand this scene, students could research why epileptic people suffer from blinking lights and how could this issue be solved. They might also discover the new updated medication that are used nowadays to treat seizures such as Keppra, Levetiracetam, diazepam, and Vimpat to name a few. Students could have a research project to compare these medications and explain to their peers the specificity of each medication in treatment.

Examples of other realistic scientific facts in *The Andromeda Strain* include when Private Lewis Crane, the electronics technician and Lieutenant Roger Shawn discovered buzzards hovering above the village. Crane was nervous and he asks Shawn "why should there be buzzards here? They only come when something is dead."[58] Crichton's narrative suggests the fact that dead bodies emit a distinct odor caused by the body's decomposition and gases' release such as skatole, indole, hydrogen, methanethiol, and dimethyl. The common element is the bad smell and precisely the rotten fish smell of the corpses diffused in the air which explains the buzzards lingering the sky.

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[57] *The Andromeda Strain*, 262.

[58] Ibid., 12.

One more scene reveals additional factual details about the dead bodies examined by the team of scientists:

> The bodies appear to be different temperatures. Forty-seven are rather cold, indicating death some time ago. […] The third is puzzling. You see him here, apparently standing or lying curled in the street. Observe that he is quite white, and therefore quite warm. Our temperature scans indicate that he is about ninety-five degrees, which is little on the cool side, but probably attributable to peripheral vasoconstriction in the night desert air.[59]

In this passage, Comroe, one of the pilots who took pictures of Piedmont village after the incident, gives new scientific information to readers explaining that vasoconstriction is caused by constriction of the blood vessels and therefore, restricting the flow of blood. Vasoconstriction also retains body heat which explains the ninety-five temperature of the last body comparing to the others. This puzzling scene engages readers in pondering unanswered questions about the discrepancies in victims' body temperatures. Such engagement is a well-known technique for increasing readers' motivation to research scientific information.

Crichton adds more surprising and exciting elements to his plot to show the progress of the team's findings and present more factual scientific details. For example, Crichton describes the confusion of Dr. Stone and Dr. Burton as they examine the corpse of Dr. Benedict, the village doctor. His body shows no trace of bleeding. Burton decides to check the lividity (the discoloration of the skin due to settling of the blood after death) of Dr. Benedict to find the reason for the absence of bleeding. Crichton explains that:

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[59] Ibid., 26-27.

> Normally, after a person died, blood seeped to the lowest points, drawn down by gravity. This information is scientifically accurate as gravity pull the blood down and depending on the [body's] position the blood will cumulate at the bottom. A person who died in bed had a purple back from accumulated blood. But Benedict, who had died sitting up, had no blood in the tissue of his buttocks or thighs.[60]

This novel can also support the study of coagulation. In the story, Dr. Burton tried to make an incision in the inner wrist, and to his shocked surprise "crumbling red-black material fell out into the floor. […]. Clotted solid."[61] He continues with the same procedure and cut the medial thigh, the chest, the heart but in vain, no bleeding occurred. The incision to the heart revealed an interior "filled with red, spongy material. There was no liquid blood at all."[62] Dr. Burton, an expert in pathology and infectious diseases, explains the case as disseminated intravascular coagulation, a condition in which the body responds to infection by forming blood clots throughout the body in response to infection such as sepsis. The informative description of Dr. Burton is scientifically correct and would be very useful in the learning process since not everyone knows that the blood forms clots to fight diseases.

The plot keeps evolving with complicated details to describe how the team is using scientific methods to define the object of study: the extraterrestrial germ. The scientists in the novel conduct some experiments similar to real scientists to identify the germ. They placed

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[60] *The Andromeda Strain*, 75.

[61] Ibid., 76.

[62] Ibid., 76.

specimens of the germ in jelly compounds of sheep and horse blood agar (blood mixture), chocolate agar (growth medium), and in forty-three specialized culture media to evaluate the growth and evolution of the germ. Some of these petri dishes were placed at room temperature, others were placed under heat or cold temperature, and under high or low oxygen. This process illustrates real scientists' jobs in laboratories where experiments are conducted depending on variables (*The Andromeda Strain* 167) showing how scientists proceed in their experiments, formulate their hypotheses according to the reaction of the germ with the variable and define its characteristics.

To show his readers the steps taken by the scientists as they proceed in their experiments, Crichton depicts how Burton identifies the transmissibility of the disease. Burton placed a dead rat exposed to the disease alongside a living rat, and he placed a millipore filter with perforations equal in size to 100 angstroms in diameter between the dead rat and the living one. He claims that the germ is larger than a virus since it did not trespass the filter, so he kept replacing it with larger perforations until the rat died (*The Andromeda Strain* 165-166). This experiment permits Burton to conclude that the agent is roughly the size of a cell, one micron in diameter, which excludes the previous theory that a gas was used at Piedmont village. Crichton recounts the experiments conducted in the laboratory to show the steps taken to define the structure of the virus and educate his readers. Although the narration identifies the size of the germ and the way the virus is spread, it does not yet explain how the germ is transmitted into the body. Is it by inhalation or by contact with the skin? Burton, the pathologist in the novel, needs to trace the clotting blood location to determine the cause of death. Depending on the clotting location, Burton would confirm if the virus is inhaled or absorbed through the skin. Pointing out the fact

that blood clotting would be a piece of evidence in detecting the path of the virus could be part of students' learning by investigating blood clot formation and discovering whether Burton's hypothesis is accurate and correct.

In a deeper analysis of the germ track, Crichton mentions how blood can significantly convey valuable information to determine the status of virus contamination. According to Dr. Hall, the pathogen survives in a normal pH (potential of hydrogen): "The Andromeda Strain grew within a narrow range. If the medium for growth was too acid, the organism would not multiply. Only within the range of pH 7.39 to 7.42 would it grow well."[63] True scientific information would propel students to search the chemical composition of the virus and define its components. The "aha" moment was achieved by Dr. Hall, when he discovered the acid-base level in the old man. The amount of acid in the old man blood was too high due to aspirin and alcohol that he consumed to relief his stomach pain (ulcer) but instead it worsened his situation and made him cough blood. Since aspirin and alcohol produce metabolic acidosis, the acid level in the old man's blood protected him from the infectious disease. On the other hand, the baby is not anemic or alcoholic, but survived. What is common between these two survivors was the answer to finding a cure. The baby's pH level was too alkaline because he was crying continuously (hyperventilation) rendering his blood level too low on acid. Students, in this case, could then learn about neutrophilic and acidophilic heterotrophs. As their name suggests, neutrophilic heterotrophs grow in a neutral pH level whereas acidophilic heterotrophs grow at lower pH levels. In addition to this conclusion, Burton comes to the assumption that the germ

[63] *The Andromeda Strain*, 272.

kills by coagulation that takes place in the lungs. Still, if coagulation is prevented for pH level considerations, "then the organism erodes through the vessels of the brain, and hemorrhage occurs."[64] Students would be directed to research and learn about bacteria that fall into this category such as staphylococcus aureus, clostridium botulinum, salmonella enteritidis, escherichia coli and vibrio cholera, etc. and learn how these bacteria deteriorate body cells in case of infection.

After Dr. Hall's discovery, Crichton's explanation seems convincing and logical since the survival of two people unfolds and connects the events of the storytelling. Moreover, Crichton uses an isolated environment as one of the most important steps to avoid contamination of other individuals with the microbe. The scientists conduct many experiments on the Andromeda Strain, and it has a crystalline structure that contains no proteins, DNA or any other nucleic acids, which makes it a unique life-form with no comparison on Earth. Related to studying this work, students should know that every virus contains a nucleic acid either DNA or RNA, learn about their structure and ways they transmit infections.

GENETIC ENGINEERING BACTERIA AND VIRUSES

Due to technological advancements in biotechnology, scientists could replicate the viruses' genetic materials into powerful weapons of mass destruction. The replication of pathogens and toxins by terrorists is considered one of the most dangerous threats to humanity as these pathogens can be used to sicken or kill people or even to annihilate vegetation.

[64] Ibid., 241.

Exposing students to the bioterrorism topic in high school and sharing scientific information help reduce potential panic, expand understanding of pandemic's consequences, help effectively manage an outbreak and decrease the likelihood of social breakdown. Bioterrorism may also trigger students' panic and anxiety, therefore, approaching this topic requires careful management by showing students how scientific advancements need ethical and critical legitimization before getting approved. The advances in bioengineering and the potential to expand bioweapons demand stricter biodefense strategies that require "extraordinary scientific talent and investments of financial and political capital on a scale far beyond that now committed or consecrated."[65] As mentioned earlier, the fear that diseases can be transformed into biological weapons primarily concerns pathogens such as anthrax, plague, tularemia, botulism, smallpox, and the viral hemorrhagic fever.

One approach to studying *The Andromeda Strain* could focus on introducing students to the potential for the genetic engineering of viruses as Crichton refers to an organism engineered secretly for military purposes. Genetic engineering can be applied for lethal or malicious intents. For example, scientists developed strains of the bacterium anthrax to resist antibiotics, but viruses can also be genetically enhanced to kill infected cells and resist vaccination. Biological weapons using viruses and bacteria could be genetically modified to survive in stressful environments and to be easily disseminated through the air. Promoting scientific awareness to high school students by explaining the potential harm of bioweapons encourages them to research how bioweapons are made, when was the first time they were used and their impact on

[65] Ibid., 104.

humans and the environment. This might increase high school students' interest in advancing their learning in bioengineering at the college level.

To give his readers a sense of how the virus is structured and the way it is formed, Crichton describes the intriguing Andromeda organism and analyzes its constituents: the organism is alive, although it has nothing in common with the forms of life that are commonly found on Earth. The organism has no proteins, no DNA and it has the form of a crystal, scientifically defined as an inorganic object associated with minerals. However, Crichton also complicates the mystery when he adds a twist to the Andromeda's development: he represents it as a living organism that replicates, multiplies in the shape of a hexagon, changes its color from green to purple and vice-versa, with the ability to mutate into an innocuous organism, adapted to its environment. Although the crystal form is not organic, in the biology or chemistry classroom, students could be encouraged to compare the structure of living organisms with non-living and investigate the problem of "what is life?" The virus in *The Andromeda Strain* does not meet the minimum requirements of living organisms. It misses the basic chemical compounds known as proteins responsible for body growth and biochemical reactions needed for living organisms. Biologists define life as an organism formed "of genomic capsules made of proteins and containing a payload of DNA or RNA."[66] In the novel, Stone and Burton define a living organism as anything that contains carbon, hydrogen, oxygen, and nitrogen. Levitt, the clinical microbiologist in the novel, gives more information about amino acids, considered the building blocks of proteins. He compares proteins to a freight train where amino acids are aligned

[66] *The Science of Michael Crichton: An Unauthorized Exploration into Real Science Behind the Fiction Worlds of Michael Crichton*, 4.

together to form a protein. He states that the different combination defines which protein is formed, whether insulin, hemoglobin, or growth hormone. Here, Crichton inserts easy-to-understand scientific explanations. To define the protein controlled by amino acids' combinations, scientists "turned to the DNA, the genetic-coding substance, which acted like a switching manager in a freight yard."[67] Grazier confirms that "In cells, carbon atoms are combined with the other elements to form organic molecules such as amino acids, sugars, fats, and nucleotides, which [form] the building blocks of bigger molecules such as proteins, DNA, or cellular membranes."[68] However, according to Grazier, scientists such as Alexander Cairns-Smith, the author of *Seven Clues to the Origins of Life* (1985), strongly defended the hypothesis "that crystals would have been good candidates as primitive forms of '"-life-"' that could have later evolved into more complex organism."[69] Maya Wei-Haas, in her *National Geographic* article, "4-Billion-Year-Old Crystals Offer Clues to the Origins of Life,"[70] supports the claim of Cairns-Smith and suggests that the origin of life could be decoded, based on biochemical reactions of water with rocks, through the zircon crystals that survived 4.4 billion years of Earth's transformation.

It is not surprising that Crichton chose the crystalline form to be the alien organism that invaded the Earth as other authors such as the organic chemist and molecular biologist Cairns-

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[67] *The Andromeda Strain*, 199.

[68] *The Science of Michael Crichton: An Unauthorized Exploration into Real Science Behind the Fiction Worlds of Michael Crichton*, 4.

[69] Ibid., 5.

[70] Maya Wei-Haas, "4-Billion-Year-Old Crystals Offer Clues to the Origins of Life," Science (September 2018), https://www.nationalgeographic.com/science/article/news-earth-rocks-sediment-first-life-zircon (accessed February 20, 2021).

Smith, the Scottish scientist, and the French astronomer Jean Schneider also believed that the primitive form of life on earth could have been originated from non-chemical life. Schneider wrote in 1976 about his crystalline theory claiming that "dislocations in crystal propagate and interact, producing new dislocations with mathematically predictable patterns, mimicking a simple [chemical] reaction."[71] Philosophers such as Leonardo Bich and Sara Green argue that defining the origins of life is crucial because it helps configure other scientific concepts such as genes, diseases, or organisms. They argue that "definitions of life — despite their diversity — reflect ongoing attempts to understand the complexity of the central properties of life form from different perspectives."[72] All the information that Crichton draws upon in his novel could trigger class discussion about how a crystalline form could contribute interesting explanations about the origin of life. Students could be encouraged to research key texts and develop strong evidence for, or against this hypothesis. In both cases, they need to defend their choices with factual and convincing arguments. One goal of teaching science through science fiction is to train students to think actively of science, search for objective knowledge, analyze, compare and produce solutions for real-life problems.

The following example shows how teacher Janice Lamb incorporates *The Andromeda Strain* in her classroom. She uses the novel to introduce her 10-12th grade students to space biology. One of Lamb's topics in her discussion is chemical evolution and the origin of life that

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[71] *The Science of Michael Crichton: An Unauthorized Exploration into Real Science Behind the Fiction Worlds of Michael Crichton*, 6.

[72] Leonardo Bich and Sara Green, "Is Defining Life Pointless? Operational Definitions at the Frontiers of Biology," Synthese (Dordrecht) 195, no. 9 (Springer Netherlands, 2018): 3925. doi:10.1007/s11229-017-1397-9 (accessed July 7, 2021).

still stir deep conversations and controversy. She includes questions such as: "What is the origin of life? Which came first heterotrophs or autotrophs? [And] when did life first come about and what form was it?"[73] These questions help students formulate hypotheses, evaluate their findings and build their critical thinking skills.

When her students read *The Andromeda Strain* they are assigned additional readings about gene-editing to build their scientific knowledge and help them understand the concept of gene modification. In addition, Lamb claims that teachers, like scientists, have the responsibility to promote scientific knowledge among the general public and their students who will be our future politicians, legislators, and responsible for making vital decisions on behalf of humanity. She acknowledges the necessity of educating lay people to produce knowledgeable citizens who can help solve future problems and convince them of the need to support scientific research financially.

More topics such as bacteria mutation could also be studied through *The Andromeda Strain*. In the novel, the special team of scientists discovers that the organism is capable of mutating and eating rubber as it is described in the following passage: "… My rubber air hose is dissolving. It must be the vibration. It's just disintegrating to dust. […]. Everything made of rubber in the cockpit is dissolving."[74] More to the readers' surprise, Crichton states that the airline's cockpit had no rubber. "It was all a synthetic plastic compound. […]. It's a polymer that

[73] Janice Lamb, *Ways to Bring a "Far Out" Subject Space Biology into the Classroom* (Washington, D.C: Distributed by Eric Clearinghouse, 1975), 7.

[74] *The Andromeda Strain*, 194.

has some of the same characteristics as human tissue. Very flexible, lots of applications."[75] The alien organism was able to depolymerize the plastic in the airplane.

Crichton was a pioneer in introducing the idea of plastic-eating bacteria. Scottie Andrew, a reporter on CNN, published a report in 2020 about plastic-eating bacteria discovered by scientists to fight the world's plastic pollution crisis. The new strain of bacteria, identified as Pseudomonas putidia, was found in the soil where plastic waste was dumped and it was found to be able to "degrade the harmful compounds in polyurethane products."[76] The bacteria feed on polyurethane diol, a chemical compound used to protect materials from corrosion. Although Crichton does not explain the process of how bacteria can dissolve rubber and plastic, he presents crucial information for readers to learn about potential applications of bacteriology. By adding this event to the dramatic narrative, Crichton encourages readers to question whether bacteria can really "eat plastic." Students may be inspired to investigate and learn about bacteria, discover their advantages and inconveniences, and inspect effective ways of reducing plastic accumulation in the environment by using bacteria or genetically engineering similar ones.

By incorporating such exciting factual details through fictional narration, *The Andromeda Strain* explores scientific dilemmas complicated by both social and military consequences. Step by step, the story recounts how the mysterious and deadly unidentified green-colored form is analyzed by the investigative team of the "Wildfire" facility. The elite group of biophysicists must understand the structure of the germ to control it before it duplicates and mutates. During

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[75] Ibid., 196.

[76] Scottie Andrew, "Plastic Eating Bacteria Could Be Small Step toward Tackling World's Pollution Crisis-CNN.com," CNN Cable News Network, (July 7, 2020). https://www.cnn.com/2020/03/30/world/bacteria-degrades-plastic-scn-trnd/index.html (accessed October 5, 2020).

the analysis of the object at the top-secret laboratory, the scientists discover that the organism is mutating and became harmless to humans, but it can destroy rubber by transforming to an airborne mass and escaping captivity. The mutated form of the germ attacks the synthetic rubber of the Wildfire facility spreading the contamination to all levels and provoking the launch of the atomic self-destruct system. Through this story, students learn about inherited mutations called germ-line mutations as well as mutations caused by environmental factors. Some mutations are beneficial since they create genetic diversity, others are detrimental since they cause disease and can be genetically engineered as weapons.

DISCOVERING BIOLOGICAL WEAPONS USING SCIENCE FICTION

Many critics consider *The Andromeda Strain* to be the perfect novel to discuss bacteriology and germ warfare. For example, Clinton Mathias, an assistant professor at the Department of Pharmaceutical and Administrative Science in Western New England University, introduces students to *The Andromeda Strain* novel "to investigate a deadly outbreak a novel extraterrestrial organism."[77] The learning of the novel focuses on infectious diseases with an emphasis "on microbiology, pathophysiology, immunology, and therapeutics."[78] David Baltimore, a biologist and former president of the California Institute of Technology argues that *The Andromeda Strain* raises the specter of germ warfare by creating hazardous organisms with recombinant DNA. "Much of the discussion about recombinant DNA research has centered on whether the work is likely to create hazardous organisms [including] speculation about the

[77] Clinton Mathias, "A Learner-Led, Discussion-Based Elective on Emerging Infectious Disease," *American Journal of Pharmaceutical Education* 79, no.6 (August 2015): 4.

[78] Ibid., 6.

possibility of inadvertent development of destructive organism like the fictious Andromeda Strain."[79] This novel would be also a great enticement for students to introduce the topic of the bioengineered weapons and to research bio-warfare's impact on all forms of life in general and human life in particular. In *The Andromeda Strain,* Crichton represents humanity's fight against extraterrestrial germs introduced to Earth by space exploration. People who encounter the extraterrestrial organism die instantly of blood clots or become fanatically crazy and commit suicide. Crichton's novel was published several months before the launch of Apollo 11. Influenced by NASA's Lunar Receiving Laboratory, Crichton based his fictional Wildfire plant on NASA's real-life decontamination center. He depicts NASA's strict regulations to prevent contamination of outer space and to eliminate any confusion when "probes were being sent to Mars or Venus to search for new life forms, [or] defeat the purpose of the experiment for the probe to carry earth bacteria with it."[80]

For instance, Streptococcus bacteria were discovered on Surveyor 3 probe after it returned to Earth. Scientists concluded that the bacteria were carried from Earth and could survive 31 months in extremely harsh conditions on the moon.[81] This is a fact scientists were concerned about during space exploration. While *The Andromeda Strain* deals with an alien microbe that invades the fictional village of Piedmont, scientists at NASA were raising real-life concerns about contaminating other planetary bodies with bacteria transferred from the earth to

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[79] David Baltimore, "Limiting Science: A Biologist's Perspective," *Daedalus* (Cambridge, Mass.), 134, no. 4, The MIT Press, 2005): 9 https://doi.org/10.1162/001152605774431446 (accessed October 2020).

[80] Michael Crichton, *The Andromeda Strain,* 1st ed. (New York: Knopf, 1969), 45.

[81] *Analysis of Surveyor 3 Material and Photographs Returned by Apollo 12* (Washington: Scientific and Technical Information Office, National Aeronautics and Space Administration), 1972.

space. In a recent article in *The Scientist,* Ashley Yeager explains how microbiologists are still trying to reduce the amount of the bacteria load on spacecraft to enable researchers to "distinguish potential alien life from something brought back home."[82]

Through the lead character of the novel, Jeremy Stone, Crichton reveals the true purpose of the project after the incident of Piedmont village: to find new life forms that might be transformed into biological weapons that benefit the Fort Detrick program (*The Andromeda Strain* 50). Detrick is a fictional biological defense program named after the real-world facility Fort Detrick due to its renowned biological weapons program that was active between 1943 and 1969, operated by the United States Army Medical Command. Crichton also brings to the readers' attention other programs that aim to study the impact of biological warfare to broaden readers' knowledge about some drawbacks of science. Crichton recounts that one of these programs "was devised to evaluate studies of actual or potential injuries and illnesses, studies of diseases of potential biological-warfare significance, and evaluation of certain chemical and immunological responses to certain toxoids and vaccines."[83]

Another example of real science in this work of fiction is depicted through the character of Lieutenant Edgar Comroe, a cardiovascular physiologist, who is interested in the stress levels that high-G accelerations cause to the human body. In real life, astronauts and military personnel receive extensive training of high-G acceleration to expose their bodies to the pressure of acceleration before heading to space. In this scenario, students learn that the typical human body

[82] Ashley Yeager, "Bacterial Genetics Could Help Researchers Block Interplanetary Contamination," *The Scientist* 32, no. 8 (August 2018): 3.

[83] *The Andromeda Strain*, 51.

tolerates up to 5 Gs (the amount experienced on a roller coaster) while astronauts and military pilots withstand up to 9 Gs. The increase of G forces impacts the human cardiovascular system since blood flows away from the brain, the heart rate accelerates to supply the brain with the blood. Anything above this level, loss of consciousness, blindness, brain damages, and even death may occur. In figuring out how the Andromeda kills its victims, Burton shares with the rest of the team that the germ has a predilection for cerebral vasculature. No one reason seemed obvious, but he realistically forms this hypothesis: "For instance, under circumstances in which normal body vessels dilate or contract —such as extreme cold, or exercise— the brain vasculature does not change, but maintains a steady, constant blood supply to the brain."[84] Burton shares this information to help the team narrow its hypotheses and identify the cause of death in Piedmont. He eliminates the possibility of collective brain stroke of the villagers since symptoms vary among the residents.

Based on this information, other recorded observations by Dr. Hall helps clarify the cause of death among the villagers. Dr. Hall recalls from his conversation with the old man that headache was one of his symptoms before becoming insane. Hall theorizes that the disease produces mental aberrations and might lead to suicide or hemorrhage inside the brain if clotting is prevented. "I'm wondering, […], if our organism attacks vessel walls. If so, it would initiate clotting. But if clotting were prevented in certain persons, then the organism might eat away and cause hemorrhage in those persons."[85] The way Crichton recounts subsequent events and the discoveries made by the team can create suspense and curiosity in students to keep reading and

[84] Ibid., 240.

[85] Ibid., 240.

feel further involved in scientific puzzle-solving. He explains further that during demanding physical activities, the blood supply increases to support muscles activities with oxygen and maintain the metabolic system. However, "the brain receives the same amount of blood every minute, hour, day."[86] The novel invites students to question this claim to confirm the necessity of blood supply to the brain. Students might research and learn that a lack of blood supply to the brain may cause vertebrobasilar circulatory disorders with common symptoms such as dizziness, slurred speech, nausea, numbness of the face, and uncoordinated movements. Students will learn that diseases affect many vital activities such as vision, consciousness, and movements coordination. Students could also research the causes and symptoms of these diseases to better understand the crucial role of blood circulation in the human body.

Crichton adds other key scientific details to his narrative regarding the physical condition of Major Arthur Manchek to whom Lieutenant Comroe needs to report the incident at Piedmont. Manchek, according to Crichton is "plagued by labile hypertension, which threatened to end further promotions as an Army officer."[87] Labile hypertension, in medical definition, is high blood pressure caused by anxious or stressed situations, for example, dangerous or high-pressure situations. Sometimes eating food with high sodium levels or consuming a lot of caffeine can also increase blood pressure above normal levels. Some symptoms such as migraine, severe headache, heart palpitation and tinnitus (ringing in the ears) are signs of elevated blood pressure. While researching how the blood plays a major role in regulating pH, defending against viruses and maintaining body temperature, students might also find the relation between blood issues

[86] Ibid., 241.

[87] Ibid., 20.

and different types of hypertensions (primary and secondary). For example, they will learn that primary hypertension is related to obesity, smoking, diet and hereditary conditions. But secondary hypertension is caused by an abnormality in the arteries, tumors of the adrenal glands and hormone abnormalities. Learning new medical terms, investigating causes and consequences of medical issues, finding treatments and cure would broaden students' factual learning and help them lead a healthy life.

While scientists are working day and night to cure diseases with the help of bioengineering tools, others were using this technology to develop genetically engineered viruses and bacteria. In his book, *The Biotech Century: Harnessing the Gene and Remaking the World* (1998), Jeremy Rifkin discusses genetically engineered viruses and bacteria. He acknowledges the devastating threat of genetically engineered bacteria on the environment and human species if they were accidently or deliberately released. He states that "Biological agents can mutate, reproduce, multiply, and spread over a large geographic terrain by wind, water, insect, animal, and human transmission. Once released, many biological pathogens are capable of developing viable niches and maintaining themselves in the environment indefinitely."[88] Any accident during the genetic engineering of a virus or bacteria could be costly for humans and could cause a serious pandemic if deliberately released. Through technology, scientists can "insert lethal genes into organisms that affect regulatory functions that control mood, behavior, and body temperature."[89] These biological weapons, according to Rifkin, have never been used widely, but if they are, they will be deadly and could cripple the economy of a country.

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[88] Jeremy Rifkin, *The Biotech Century: Harnessing the Gene and Remaking the World* (Jeremy P. Tarcher: Putnam, 1998), 91.

[89] Ibid., 93.

Moreover, P.R. Chari, a member of the Indian Administrative Service who was in charge of the Institute of Defense Studies and Analysis and Arpit Rajain, a senior policy analyst at the New Delhi office of the center for Global Studies, admit that "advances in the biotechnology sector, including progress in the sphere of recombinant DNA technology, has brought numerous benefits and much growth; however, it has also created the ability to misuse this development by enhancing the threat of biological and chemical warfare."[90] They also consider that biological warfare is an emerging threat in two important ways: first, the advancements in genetic engineering that created new viruses and bacteria have made them more efficient in causing mass deaths. Secondly, these lethal weapons can target humans, agriculture, and livestock, devastating all sources of nutrition and contaminating water, food, and air. The development of biological warfare is under scrutiny by the Chemical Weapons Convention (CWC), which limits their expansion and keeps them under control as the "genuine overlap between legitimate research and commercial biotechnology and offensive warfare programs"[91] is so blurry and hard to track.

The deadly potential of biological agents is unlimited as scientists can manipulate micro-organisms, duplicate certain toxic strains, and enhance the virulence and viciousness of diseases. Scientists classify these genetically enhanced virulent strains in two categories: chemical agents and biological agents. The former can be delivered as a liquid mist, fine powder, or as aerosol. On the other hand, biological weapons can be inhaled, ingested, or injected. Both agents can severely damage living things and cause death. In addition, biological agents are hard to detect since microbial toxins are genetically constructed. However, some toxic agents are naturally

[90] P.R. Chari and Arpit Rajain, *Biological Weapons: Issues and Threats* (India Research Press, 2003), 27.

[91] Ibid., 3.

present in the environment in small doses such as anthrax, so bacterium Bacillus anthracis causes an infection which can occur in four different ways: through the skin, lungs, intestines, or by injection. This disease is easily spread among people especially those working with animals or animal products. Some of anthrax's symptoms are high fever, abdominal pain, diarrhea, vomiting, small blisters on the skin, and shortness of breath. This is a very vicious bacterium that has been developed in certain countries as a weapon. Arms control experts warn against the development of such biological weapons. When anthrax was delivered by mail in 2001 to members of Congress and journalists, investigations revealed that the virus was the same one developed by the U.S Army Medical Research Institute for Infectious Diseases. This incident raised many concerns about how malicious groups could access bioweapons. The number of genetic engineering scientists is also growing rapidly so the fear of losing control over genetically engineered pathogens is growing as well.

Observers fear that manipulating DNA may become an easy task akin to computer hacking. Currently, biotechnologists can hack bacteria, viruses, fungi, etc., to reprogram the DNA for experimental purposes or create deadly viruses that are easily spread across communities. The accessibility of biotechnology also raises the possibility of terrorists' access to bioweapons and even their ability to create one. In the modern world, global transportation is another key vector for contagious diseases to spread. We have seen the severe acute respiratory syndrome (SARS) that appeared in China in 2002 and spread worldwide within couple of months and we are now witnessing the spread of the uncontrolled global pandemic COVID-19. The origin of COVID-19 is still unknown and it could be a genetically modified virus used as a bioweapon. "In March 2020, the U.S. Department of State summoned the Chinese ambassador to

protest statements of a Chinese spokesperson, who suggested that the virus was brought to Wuhan by the US military, allegedly as a bioweapon."[92] Controversially, the State Department and Treasury in both the Democratic and Republican administrations assigned David Asher, a senior fellow at the Hudson Institute at Washington, D.C. to conduct classified intelligence investigations about this issue. Asher states that "this [Covid-19] might have been a weapon vector gone awry, not deliberately released, but in development and then somehow leaked, this has turned out to be the greatest weapon in history. […]. We have entered into an area of Chinese biowarfare, and including using things like viruses."[93] In addition, the refusal of the Chinese authorities to allow international inspectors to inquire about the virus raised suspicions and aggravated the accusations against China.

Chari and Rajain claim "that the biotechnological revolution will engender a profound change in our understanding of how the human nervous system and associated endocrine and immune systems work, in which chemical messengers play a very important role. Misuse of this new neuroscience could provide a novel means of manipulating human behavior by chemical means".[94] These toxic agents affect the physiological functioning of the body. They can cause broncho-constriction, change in blood pressure and heart rate; they can also cause muscle-contraction, disorders in the immune system, psychological disturbances, and paralysis.

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[92] Dacre Knight, "COVID-19 Pandemic Origins: Bioweapons and the History of Laboratory Leaks," *Southern Medical Journal* 114, no. 8 (August 2021): 465 (accessed November 2021).

[93] Jennifer Griffin, "Former Top State department Investigator Says COVID-19 Outbreak May Have Resulted from Bioweapons Research Accident," *Fox News* (March 12, 2021), https://www.foxnews.com/world/top-state-official-coronavirus-bioweapon-accident (accessed January 2022).

[94] *Biological Weapons: Issues and Threats* (India Research Press, 2003), 69.

Biological weapons' development appears to grow by leaps and bounds. Their use seems inevitable with the rise of international terrorism and the conflictual policies between powerful countries, including the United States, China, Iran, and Russia. The race to find advanced and effective biodefenses focuses on discovering novel antibiotics and new vaccines to target and destroy viruses. Biological weapons are hard to detect and identify. Even if a few vaccines are available as antidotes, identifying the biological weapon takes a long time and it is difficult to find which agents have been used to generate the weapon. According to Chari and Rajain, biological weapons' spread is enabled by three factors: the spread of technology and specifically biotechnology and gene editing; the exchange of food and services facilitated by global communications and technological advances; and improper use of antibiotics that leads to resistance against the deadliest diseases such as tuberculosis, malaria, and hepatitis.

Concerns about viruses and bacteria attack, bioweapons, and bioengineering are found in Crichton's novel and can be used in classroom discussion. To provide credibility to his representation of the scientific team in the novel, Crichton portrays individual scientists according to their professional fields and their methods of collecting data about the organism: "They use scientific knowledge and intuition to formulate hypothesis about its nature."[95] For example, Dr. Hall wonders "if [the] organism attacks vessel walls. If so, it would initiate clotting. But if clotting were prevented in certain persons, then the organism might eat away and cause hemorrhage in those persons."[96] The way Crichton lays out the investigation of the deadly "alien" organism and the examination of corpses at Piedmont suggest that bioengineered viruses

[95] *The Science of Michael Crichton: An Unauthorized Exploration into Real Science Behind the Fiction Worlds of Michael Crichton*, 2.

[96] *The Andromeda Strain*, 240.

or bacteria were the cause of death. To understand Crichton's reasoning about deadly engineered viruses that are used as biological weapons, teachers could ask students to research the types of diseases that bacteria and viruses could cause and study their shapes, forms and their impact on human health to engage them in the novel's investigation and try to determine the disease that caused Piedmont people's death.

TREATMENT OF DISEASES SIMILAR TO THE ANDROMEDA STRAIN

Knowing the symptoms of each bacteria or virus would help students compare and eliminate potential diseases to reach their final verdict while investigating scenarios similar to Piedmont village. They can learn about virus incubation timing, disease spread, and ways to prevent and eliminate the viruses. Several diseases might be considered in students' research as they show some similarities with the infection of Piedmont villagers. For example, pneumonic plague is initiated by a bacterium called yersinia pestis that infects the lungs and accompanied by fever and headache. This kind of disease is treated with streptomycin, tetracycline, and chloramphenicol. Genetic engineering of this bacterium results in a resistant mutating drug that leaves the population at greater risk of death. Another potent and lethal threat that could be used as biological weapon is the botulism bacterium, a toxin produced by clostridium botulinum that can be inhaled or digested. This disease is treated with an equine antitoxin that treats specifically A, B, and E toxin types. Tularemia is a respiratory infection triggered by Francisella tularensis causing respiratory complications and fever, and weight loss. To treat Tularemia, antibiotics such as streptomycin, gentamicin, tetracycline, and chloramphenicol have a great impact on eliminating the disease.

Another disease in this category is Viral Hemorrhagic Fever (VHF), which includes four families of the virus-producing the same symptoms: arenaviruses, filoviruses, bunya viruses, and flaviviruses. Symptoms of these viruses are exhaustion, fever, and systematic bleeding at the mucus membranes. The VHF viruses are cured by an anti-viral drug Ribavirin that fights the infection and help with recovery. Other infectious diseases such as the Q fever caused by Coxiella bumetti infects generally animals but it can also have an effect on humans. Symptoms are almost the same as often viruses and bacteria shown in the previous passage with additional night sweats, cough and pneumonia. Some people might be asymptomatic, but it can transform into chronic disease and manifest as endocarditis. Students' task would be learning about the "invisible enemy" by searching, analyzing, and finding matching cases to the Piedmont incident and thus learn about infectious diseases. Students can present their hypotheses and compare them with those of other students to evaluate their evidence and find the most appropriate diagnostic for the death of Piedmont villagers.

More biomedical investigations are carried out in the plot of *The Andromeda Evolution* (2019) that depicts more scientific facts as it relates fictional events related to the evolution of the strain. Daniel Wilson, the author of *The Andromeda Evolution* gives readers insights into a deadly disease that causes progressive loss of motor neurons that control muscles. This disease known as Amyotrophic Lateral Sclerosis (ALS) deteriorates the neuromuscular system, weakens muscles' functions and leads to death. Sophie Kline, a character in the novel who suffers from the consequences of the disease, enjoys being an astronaut because the muscle pain caused by her ALS disappears in zero gravity, and her physical capabilities are effectively equal to any other astronauts'. Her disability seems to vanish as she floats on board of the spacecraft. Kline's

condition is an actual medical condition categorized as a hereditary disease that leads to neurodegeneration. However, new research has shown that while such neurodegeneration may be hereditary, it can also be caused by toxic gas. The research conducted on veterans who participated in the Gulf War in 1991 and who suffered from ALS after being exposed to sarin nerve gas suggested that environmental toxicants can cause ALS. "Exposure to sarin nerve gas, particularly deadly organophosphate, may explain the high rates of ALS in troops who served in the Gulf War."[97] Fictionalized descriptions of the effects of toxic gases on the human nervous system can educate readers and students about the real-world danger of biological weapons.

As students research the variety of toxic gases, they gain a broader prospective about how biological engineering advancements could be used. For example, the highly toxic gas sarin was developed in Germany in 1938 as a pesticide. This gas has no color or odor, and can dissolve easily in water. Exposure to sarin has several effects on the body including convulsions, loss of consciousness, paralysis and breathing failure. Another toxic gas is the VX agent, a chemical weapon that blocks the biological activity of the enzyme Acetyl Cholinesterase (AChE). The gas paralyzes the brain, intercepts all messages down the spinal cord in few seconds, and contracts all muscles until the diaphragm muscle contracts and causes death by asphyxiation. Ricin is a deadly biological cytotoxic agent extracted from the castor bean plant. Ricin is a protein formed of two polypeptides chains that enter the cell and inactivate the ribosomes responsible for proteins production within the cell. Unlike anthrax, ricin is not a living organism and therefore, it cannot reproduce and multiply, but it is also considered a chemical agent because it is composed

[97] "Pesticides Raise Risks of ALS and Potentially Alzheimer's Disease," *Alzforum Networking for A Cure* (May 2016), under "News," https://www.alzforum.org/news/research-news/pesticides-raise-risk-als-and-potentially-alzheimers-disease (accessed September 2, 2020).

of protein. Ricin is best defined as a biochemical agent, and it "is listed as Category B Bioterrorism Agent," and a "Schedule 1 Chemical warfare Agent."[98] Chemical nerve agents can immediately cause death and serious injuries to people exposed to them. By contrats, biological, and biochemical agents' effects are experienced after several hours or even several days after exposure. Investigating the various causes of actual ALS cases may help students deepen their knowledge about the effects of toxicants such as sarin gas and ricin on the human body and inspire them to pursue careers in medical field.

The analysis of scientific elements in *The Andromeda Evolution* functions as the final stage of the experiment initiated in the narrative of Crichton's *The Andromeda Strain*. In *The Andromeda Evolution,* a "real-life" scientific event is discovered by the scientist Nidhi Vedala working on quantum mechanics in her laboratory. Under the microscopic lens, she finds that the Andromeda, a nanomaterial-based anomaly structure "underwent a form of… mitosis […]. Each microparticle split and produced a copy of itself"[99] similar to the cell division process. The scientists and bacteriology experts continue to investigate Andromeda. They examine several elements that are available in nature, which might have impacted the evolution of the strain. For example, nitrogen, carbon dioxide and phosphorus all play roles in cell division. *The Andromeda Evolution* narrative relates the similarity between the Andromeda cell division and other cells found in nature. Although the novel does not elaborate on the five phases (prophase, prometaphase, metaphase, anaphase, and telophase) of cell division, it highlights the impact of the environment on living organisms and elaborates its consequences upon the human body.

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[98] Clay Farris Naff, *Biological Weapons* (Cengage Gale, 2005), 2.

[99] Daniel H. Wilson and Michael Crichton, *The Andromeda Evolution*, 1st ed. (New York: NY: Harper, 2019), 175.

Even though *The Andromeda Strain*'s story eliminates the possibility of a nerve agent's attack on the village of Piedmont, Wilson's novel discusses the gas as a self-defense weapon in case the team falls prey to their enemies. The toxic substance is called OMEGA, an amber-colored liquid in a vial identified by Stone (the baby who survived the disease in *The Andromeda Strain* was adopted by Dr. Jeremy Stone and named James Stone) as a nerve agent that kills immediately. Wilson picks the term "Omega" (the genetically engineered fluid) for its meaningful interpretation in different fields. The symbolism behind Omega, the 24th letter of the Greek alphabet, denotes the end of something, the final phase. In the novel, it denotes death, an easy way to end one's own life. "Omega," as described in the novel, is apparently a nerve agent "produced by a state-sponsored program run by very smart and well-equipped chemists. Placed on any surface or in food or drink, this substance would kill us all quickly and without struggle."[100] This nerve agent is totally imaginary and does not exist, but it is similar to the cyanide pill called the "suicide pill," a fatally poisonous substance that kills immediately. Agents from military and espionage organizations are provided with these pills to end their lives if they get captured by the enemy. If these toxic gases were released, they would spread quickly and have the same effect as a pandemic.

VIRUSES AND PANDEMIC IN SCIENCE FICTION

Humanity today is already struggling with powerful diseases that impose constraints on our health, our social life, economic exchange and political agreement. The current pandemic that humanity is struggling with is the deadly COVID-19 virus, known as the Corona virus. It

[100] *The Andromeda Strain*, 185.

attacks the respiratory system causing many health complications. Is it a virus or an engineered toxin akin to the Andromeda Strain? Crichton seems to have predicted the future with his fictional virus that coagulates blood and causes death by blood clots. Crichton's novel deals with many medical-scientific issues and directly reflects the methods that scientists use to diagnose. For example, the deaths of all the fictional villagers at Piedmont are caused by chemical elements emitted by an imaginary extraterrestrial microbe and their deaths are caused by blood clotting. According to Levitt, the clinical microbiologist in the novel "the example of cholera [comes] to mind. For centuries, men had known that cholera was a fatal disease and that it caused severe diarrhea, sometimes producing as much as thirty quarts of fluid a day."[101] For many years, scientists searched for an antidote to escape the lethal effect, and they missed the cure: treat the symptoms of dehydration. "Cure the symptoms, cure the disease" [102] is an expression that leads Levitt to wonder about the death of Piedmont residents. He pondered whether curing blood clotting is the main issue caused by the virus or a post-pathological consequence. Burton also tried to cure the symptoms of blood clotting by injecting the rats with heparin, an anticoagulating drug when exposed to the organism. But the rat "died of intravascular coagulation; the arteries, the heart, lungs, kidneys, liver and spleen-all blood-containing organs-were rock-hard, solid."[103] In the classroom, teachers can ask students to research the reasons of a heart or brain stroke, lists the symptoms and causes, and find how these conditions can be treated. Students can also work in separate groups to search for different types of blood clotting

[101] Ibid., 121.

[102] Ibid.,121.

[103] Ibid., 174.

and explains the difference between them (VTE, or venous thromboembolism, DVT, or blood clots in deep veins of the legs or arms, and Pe, or blood clots traveling through the bloodstream to the lungs). Another group can research the causes of blood clots (birth control pills, obesity, immobility, Factor V Leiden disease or polycythemia vera, and coronavirus) and share their findings with the rest of the class. A third group can search for treatments available and ways to prevent blood clotting.

Some researchers found that the Covid-19 virus manifests as cold or flu symptoms masquerading as respiratory illnesses. Once infected with this virus, the respiratory system disintegrates and infects the lungs. Oxygen in the blood drops significantly, and coagulopathy and vascular inflammation appear. The new viral pneumonia COVID-19 infects the blood vessels associated with cough and high fever. Findings in early cases in China and New York City emphasized the "association between elevation in D-dimer (protein fragment that is made when a blood clot dissolves in the body) and fibrinogen (glycoprotein complex that converts enzymatically by thrombin to fibrin and to fibrin-based blood clot), degradation products (FDPs) and increasing COVID-19 severity and mortality."[104]

Recent research about the newly discovered virus states that it uses the respiratory system to enter the blood stream and causes cerebral blood clots known as ischemia clots. After entering the blood-stream, the severe acute respiratory syndrome corona virus 2 (SARS-CoV-2) may cause strokes "associated with clots in large vessels supplying the brain [and] requiring vacuum

[104] Meaghan E. Colling and Yogendra Kanthi, "COVID-19- Associated Coagulopathy: An Exploration of Mechanisms," *Vascular Medicine* vol.25, no.5 (2020): 471.

aspiration devices or clot retrieval devices and blood-thinning medications"[105] to save the patients. The similarity between fictional events created by Crichton in *The Andromeda Strain* and factual incidents in real-life gives more credibility to Crichton's account, especially as he recounts symptoms of a real virus activates infection by respiratory viruses, heart and brain strokes caused by blood clotting and death. With some patients of COVID-19, the virus was contained in the upper or lower respiratory tract, and symptoms of mild flu or pneumonia appeared inconsistent depending on patients' immune systems. However, when the virus penetrates the alveolar membrane and infects the cells, critical illness and inflammatory response occur at the alveolus level or the tiny air sacs in the lungs. In the case of Covid-19, the virus is "150 nm (≤ .15 microns) in diameter so it can easily pass through the lung capillaries that are 5,000-8000 nm (5-8 microns) in diameter and enter the left side of the heart to be pumped all over the body including the brain."[106] The similarities between the deaths of Piedmont people and those who are now dying from COVID-19 are uncanny. As Crichton produces in his narration, the respiratory illness starts to develop mainly the first couple of days with Covid-19 and escalates to cause blood clotting. Many cities in 2019 during the first surge of the virus, including Wuhan, New York, and London recorded high death tolls for hospitalized COVID-19 patients who had died of stroke. "In New York city […], nearly 9 out of 10 (88%) patients who were on ventilators died. […]. In a report from Wuhan, 90% of hospitalized Covid-19 patients

[105] Vallabh Janardhan and al., "COVID-19 as a Blood Clotting Disorder Masquerading as a Respiratory Illness: A Cerebrovascular Perspective and Therapeutic Implications for Stroke Thrombectomy," *Journal of Neuroimaging* 30, no.5 (2020): 555.

[106] "COVID-19 as a Blood Clotting Disorder Masquerading as a Respiratory Illness: A Cerebrovascular Perspective and Therapeutic Implications for Stroke Thrombectomy, 556.

had coagulopathy (without bleeding) with an 18-fold increase in mortality […]. In a report from London, 91% of Covid-19 patients with a prolonged activated partial-thromboplastin time had positive lupus anticoagulant assays."[107] The strokes increased mortality, and they were varied; some strokes were "clots in the brain, heart (heart attacks), lungs (pulmonary emboli), gut (mesenteric ischemia), and legs (limb ischemia) …"[108] but out of all these strokes, the most frequent blood clotting with Covid-19 patients was the pulmonary embolism (PE).

Through the reading of science fiction, high school students can be exposed to multidisciplinary topics that provide them access to global knowledge about science. Science fiction narratives bring forward powerful stories about potential futures that might become a reality and present scientific facts in an appealing way that stirs students' curiosity to learn about scientific concepts. In a recent paper, Georgeta and Dumitru Chirlesan recognize the impact of science fiction on scientists. They argue that science fiction helps scientists "see into the future"[109] and think of how to make possible what is impossible. Science fiction literature, as we have seen with *The Andromeda Strain* and *The Andromeda Evolution*, can investigate a variety of potential futuristic events that give readers an unusual and challenging way to learn about real science. Furthermore, Czerneda acknowledges that "science fiction is all about thinking beyond, about stretching the limits of what is known in science to what might be. The speculation of

[107] Ibid., 557.

[108] Ibid., 557.

[109] Georgeta Chirlesan and Dumitru Chirlesan, "Incorporating Science fiction literature in Teaching Science," (March 2014), https://www.researchgate.net (accessed December 10, 2019).

science fiction allows students to explore concepts, relationships, and potential societal impacts within their imaginations."[110] Science fiction provides an opportunity for students to think creatively about solving present and future problems and develop their critical thinking skills to imagine a better future.

Sun Kwok argues in "Astrobiology as a Medium of Science Education" (2019) that "most science courses inform students on our current interpretations on how things are, with little attention paid to how scientists came to the present point of view."[111] Science learning is not only about memorizing facts but it is about understanding the process of why and how things happen. It "is about the process of rational thinking and creativity. […]. The essence of science is not so much about the current view of our world but how we changed from one set of views to another."[112] Therefore, science fiction can be considered a medium to convey scientific information inspired by everyday life.

Discussing infectious diseases, bacteria engineering, bioweapons, viruses and pandemic allow students to experience the beneficial role of science in investigating, experimenting and exploring the dangerous potential of science. Promoting scientific literacy among student-readers through science fiction might encourage reluctant ones to pursue future studies in science and medicine.

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[110] Julie Czerneda, *No Limits: Developing Scientific Literacy Using Science Fiction* (Toronto, Canada, Trifolium Books Inc, 1999), 6.

[111] Sun Kwok, "Astrobiology as a Medium of Science Education," in *Handbook of Astrobiology*, ed. Vera M. Kolb, 1st ed. (Boca Raton: CRC Press, 2019), 47.

[112] Ibid., 47.

In the next chapter, we will examine the role of science fiction in *Gattaca* and (1997) *Change Agent* (2017) to highlight the impact genetic engineering can have on education and society. My analysis will investigate the potential role of bioengineering as a curative method to eliminate debilitating diseases to enhance humanity.

CHAPTER 2

EXPLORING THE ETHICS OF GENETIC ENGINEERING THROUGH SF NOVELS AND FILMS

One powerful aspect of science fiction is its ability to explore an imaginary yet plausible world while uncovering fundamental philosophical questions about humans' interconnection with the actual universe. As discussed by Tom Shippey, "the great body of science fiction is an interest in cultures, in the ways in which intelligent beings could live and think, as dictated by circumstances, their technical ability, [and] their systems of thought."[113] Most of the science fiction novels adapted into movies discuss real science and try to depict its perils and benefits on society. Movies can be a medium of teaching science as well as novels. Science fiction movies represent science accomplishments and pitfalls in narrative settings relevant to viewers. Films can help viewers visualize the abstract concepts of science by using special visual effects to portray factual events while they keep the narration moving.

While communicating science through science fiction novels can effectively expose students to scientific knowledge, films provide additional opportunities to explain scientific concepts that are either impossible or not practical to demonstrate in a classroom setting. Taking the advantage of science fiction films to introduce more complicated science concepts can provide an opportunity to better understand science in societal context and promote students' critical thinking. Many great topics such as the nature of science, the origin of life, and ethical

[113] Tom Shippey, *Hard Reading: Learning from Science Fiction* (Liverpool University Press, 2016), 101.

use of new technology on humans could be discussed after watching science fiction films. Students can be exposed to such information while watching the film and then be asked to formulate their own opinions about the topic.

Based on their teaching of science through movies, Terence W. Cavanaugh and Cathy Cavanaugh argue that abstract concepts are easier to visualize with science fiction films. Students are more likely to engage and understand the film than traditional science textbooks. The Cavanaughs argue that science fiction films allow "students to experience a wide variety of science topics or encounter concepts in a new context. Students are more likely to remember information they have been involved with in an entertaining or enjoyable way."[114] For Terence and Cathy Cavanaugh, "science is a vehicle for comprehension. It allows us to better understand ourselves and our surroundings. It teaches us how to make decisions and consider the future consequences of our actions."[115]

In *Companion to Science Fiction* (2005), David Seed argues that science fiction film is "visual by nature […] less contemplative and analytic and more spectacular and kinetic than its literary counterparts."[116] He considers science fiction films as shaping and forming the American historical imagination of technology's impact on the meaning of being human in an ever-

[114] Terence Cavanaugh and Cathy Cavanaugh, "Connecting the Media Center and the Science Classroom Using Films," *Library Media Connection* 23, no.6 (March 2005): 52.

[115] Terence W. Cavanaugh and Catherine Cavanaugh, *Learning Science with Science Fiction Films* (Washington, D.C: Distributed by Eric Clearinghouse, 1996), 3.

[116] David Seed, *A Companion to Science Fiction* (Malden, MA: Blackwell Pub., 2005), 261.

advancing technological world. He states that science fiction film is "symbolic not only of the terrain of our possible futures, but always also of our grounding in the realities of the present."[117]

Seed's arguments are echoed by academic scholars Leroy W. Dubeck and Suzanne E. Moshier's work. They point out the importance of scientific concepts embedded in an exciting plot that students can follow in an entertaining and enjoyable format. Discussing a film helps students to learn about scientific topics and discover the process of scientific inquiry. In addition, "placing science in a dramatic setting and relating it to socially significant issues, makes science more relevant to the students."[118] Often films discuss a topic from the perspective of many disciplines and consequently, offer students an interdisciplinary view. Science does not exist in a void; it is impacted by other disciplines. For instance, *Gattaca,* which premiered in 1997, discusses using genetic engineering of reproductive technology to produce enhanced human beings. At that time in real life, many doctors were using in vitro fertilization (IVF) to help women and men overcome infertility. In the novel *Change Agent*, an Interpol agent Kenneth Durand is injected mysteriously with a fictional genetic serum at a train station in circumstances similar to the real assassination of Georgi Markov, a Bulgarian dissident who was killed in 1978 with a micro-engineered pellet that might have ricin and was delivered by an umbrella puncture in Markov's thigh. Through such fictional accounts, ethical, religious, political, and medical topics could be discussed. Engaging students in appealing ways may spark their interest in

[117] *A Companion to Science Fiction* (Malden, MA: Blackwell Pub., 2005), 273.

[118] Leroy W. Dubeck, Suzanne E. Moshier, and al., "Finding the Fact in Science Fiction Films: Two Thumbs Up for this Activity," *The Science Teacher* 60, no. 4 (April 1993): 47.

science, teach them ways to solve future problems, understand scientific disciplines and explore the impact of effective scientific discoveries.

Shari Laprise and Chuck Winrich also support the use of science fiction films in the teaching of science. They incorporate films in their classes "to excite the interest of students in [their] courses, specifically, and to get students thinking about the broader implications of science information and misinformation depicted through the films."[119] They also state that using films as pedagogical tools enhances students' curiosity and fosters a sense of analysis of science facts depicted in science fiction films. Laprise and Winrich note that "the use of science fiction films can be a useful tool for motivating nonscience majors, with a greater effect noticed for specific course material than for science in general."[120]

Experiencing scientific topics through "science fiction films engage students and encourage greater enthusiasm and interest in science."[121] Besides the entertaining features, "science fiction films often explore modern world problems and issues and provide the opportunity to consider the future and the changes that may occur. Science fiction films can be much more than just special effects, they can be the promoters of ideas and change."[122] Introducing a film into a classroom, according to the Cavanaughs, helps students share a common reference point for discussion, reinforces factual debate, and provide contexts for

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[119] Shari Laprise and Chuck Winrich, "The Impact of Science Fiction Films on Student Interest in Science," *Journal of College Science Teaching* 40, no.2 (November 2010): 46.

[120] "The Impact of Science Fiction Films on Student Interest in Science," *Journal of College Science Teaching* 40, no.2 (November 2010): 49.

[121] *Learning Science with Science Fiction Films*, 1.

[122] Ibid., 2.

scientific topics. Cinematic representations of scientific facts also provide concrete conceptualizations for viewers that effective spread scientific knowledge.

Today, science fiction engages topics connected to real science such as bioengineering, genetic manipulation, and gene editing. In the mid-twentieth-century, gene editing and DNA (deoxyribonucleic acid) studies became widely available in the undergraduate college curriculum. In this chapter, I will explore how using *Gattaca* and *Change Agent* could help expand knowledge about gene-editing for medical reasons and emphasize genetic enhancement for esthetic purposes as well as highlighting issues of social discrimination. The concepts portrayed in these selected materials may help prepare students to think critically and globally if genetic editing becomes a reality as depicted in the films. The value of these materials resides in stimulating students' imagination to think beyond current norms and discover new potential scenarios where they need to invest their inductive and deductive reasoning.

According to Dubeck and colleagues, "creating a positive attitude toward science is perhaps the single most important outcome of the use of science fiction films in the introductory-level college science classroom."[123] As Dubeck argues, students who experience scientific concepts through science fiction films express an interest in science courses and improve their attitude toward science in general. "In short, films make the abstract concrete."[124] Scientific principles are better understood when describing relevant problems and societal issues that cause

[123] Leroy W. Dubeck, Suzanne E. Moshier, and Judith E. Boss, "Using Science Fiction Films to Teach Science at College Level: Improving Student's Attitudes Toward Science through the Magic of the Movies," Journal of College Science Teaching 25, no. 1 (September 1995): 47.

[124] "Using Science Fiction Films to Teach Science at College Level: Improving Student's Attitudes Toward Science through the Magic of the Movies,"47.

a public opinion divide: "…Science fiction films can be an effective science teaching tool. Students can gain a better understanding of science as a discovery process, and their attitudes towards science can improve after watching and analyzing concepts presented in sci-fi films."[125] Students may also be able to recognize pseudoscientific themes while watching science fiction films. "Using science fiction films as a pedagogical tool […] allows the students' imagination and 'thought experiments' to create a virtual learning environment that is safe and practical, yet still engaging and reasonably authentic, even though it is entirely fictional."[126] The genre is considered "as a vehicle to communicate content knowledge in ways that connect scientific concepts to events within fictional narratives."[127] The two works discussed next may serve as jumping off points for the discussion of gene editing therapeutic approaches, and genetic discrimination issues.

UNDERSTANDING THE SCIENCE IN SCIENCE FICTION FILMS AND NOVELS

Novels and films can convey scientific concepts to engage students. They allow students to understand the scientific concepts while watching the plot, driven by a succession of scientific elements. In fact, "images of science and scientific phenomena in movies are designed to be both credible and plausible. Further, given that film and television images are visually appealing, easily understood, and appear to be supported by scientific authorities (e.g. NASA) through the use of science consultants they have a high potential to achieve high status in the minds of

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[125] Leroy W. Dubeck and al., "Finding the Facts in Science Fiction Films: Two Thumbs Up for This Activity," *The Science Teacher* 60, no. 4 (April 1993): 47.

[126] Sevinc Ongel-Erdal, Duygu Sonmez, and Rob Day, *Science Fiction Movies as a Tool for Revealing Students' Knowledge and Alternative Conceptions* (Washington, D.C: Distributed by Eric Clearinghouse, 2004), 3.

[127] Ibid., 3.

students."[128] For instance, an image or dialogue about a scientific concept in the film might meet students' intuitive mental model and become plausible. In addition to this, films can provide convincing arguments to explain scientific processes. As Barnett argues, students find that the fictional depictions in science fiction movies are more understandable than those in non-fictional forms. Furthermore, using science fiction films to introduce scientific concepts "attracts the attention of students more than other classroom activities and thus significantly increases the level of learning."[129]

Undoubtedly, science fiction is considered the literature that most frequently deals with future probabilities and scenarios that impact humans and their interaction with technology. Bioengineering and genetic enhancement topics as discussed in *Gattaca* and *Change Agent* reflect some of the fears that humanity will face in the near future. Through these narratives, students would learn about gene editing and discover therapeutic practices to eliminate hereditary diseases. Gary H. Marks argues that "biological science can anticipate future developments. Past science fiction has accurately predicted social problems such as overpopulation and ecological disasters and technological developments …"[130] The stories evoked by science fiction awake a sense of fascination among students who are encouraged to think and plan for future events. Students are invited to question the social impact of science

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[128] Michael Barnett and al., "The Impact of Science Fiction Film on Student Understanding of Science," *Journal of Science Education and Technology* 15, no.2 (2006): 189.

[129] Fatma Onen Ozturk, "The Impact of Science-Fiction Movies on the Self-Efficacy Perceptions of Their Science Literacy of Science Teacher Candidates," *Educational Sciences: Theory and Practice* 17, no.5 (October 2017): 1576, http://dx.doi.org/10.12738/estp.2017.5.0058 (accessed December 10, 2019).

[130] Gary H. Marks, "Teaching Biology with Science Fiction," *The American Biology Teacher* 40, no. 5 (1978): 275.

fiction films' scientific concepts and technologies as presented in the plot. They are led to question scientific principles, problematic issues and social ethics critically. Some stories evoke conflicts featuring individual rights versus society's values. For instance, enhancing individuals' physical abilities to compete in sports would create conflictual debate among those who support and believe in talent and personal endeavors to achieve success. Students learn about potential problems that gene editing might engender, and they are invited to develop their own opinions.

CRITICAL THINKING AND ETHICAL DECISIONS

Encouraging students to analyze science fiction materials extends their imagination and develops their creativity. Consequently, an increase in creative thinking for future problems might provide better solutions especially in regard to advancing technologies. In addition, students can thoroughly discuss the implications of bioengineering advances on society and investigate whether choosing the sex of a baby or the eye color would have any repercussions on future society. On the other hand, *Change Agent* teaches students the possibilities of switching identities metaphorically using gene editing. Is it possible to transform completely one's genes? And if it is possible, would that affect one's identity and personality? Science fiction plots are replete with such conflicts. "These cultural references can help academic authors make their more philosophical claims understandable and engaging to non- specialists and to the general public."[131] Using the help of science fiction authors' images and narratives to understand the future, students are introduced to an array of scientific topics and hence to a broader societal involvement in the general public's opinions.

[131] Derek So and al., "Science Fiction Authors' Perspectives on Human Genetic Engineering," *Medical Humanities* (2021): 1.

EUGENICS IN *GATTACA*

The science fiction movie *Gattaca* depicts the potential of eugenics to create a flawless community with potential enhancements. According to *Gattaca,* creating the perfect society means improving the societal conditions in which members can thrive and develop. The film focuses on genetically enhanced individuals such as Jerome Eugene Morrow who receives an elite job in the Gattaca space corporation and the naturally born individuals called "invalids" such as Vincent Freeman who is less fortunate and unable to work at the corporation. However, while watching the film, students might consider some bioethical questions regarding the benefits and pitfalls of creating a homogeneous society and examine the efficacity of altering human DNA for therapeutic purposes. The eugenics themes of the film portray a future scenario in which humanity can control biological elements and understand human nature. The film *Gattaca* represents a society that praises superior individuals with genetic enhancements since more sophisticated humans perform better than regular ones. As David A. Kirby argues, "science fiction films almost uniformly support the idea that humanity's fundamental nature lies within its genome and could be improved by technological means."[132] In this movie, students would be exposed to an imagined scenario of biotechnology evolution. They would be able to discuss eugenics concepts and genetic determinism and analyze whether humans are determined by their physical appearance, behavior, or personality. However, although *Gattaca* highlights the importance of gene editing, it simultaneously emphasizes the problems that arise if humans are reduced to mere genes. According to *Gattaca*, a person's genetic makeup determines their

[132] David A. Kirby, "The Devil in Our DNA: A Brief History of Eugenics in Science Fiction Films," *Literature and Medicine* 26, no. 1 (2007): 84.

identity. Therefore, creating a homogenous society similar to *Gattaca*, where individual identity is erased and replaced by a collective one and diversity is rejected to obey new social norms, would result in abolishing the notions of creativity and meritocracy and intensify the consequences of genetic determinism.

The film *Gattaca* constitutes a perfect tool to discuss the impact of gene editing on the public imagination, and it helps examine social and ethical questions about the reproductive genetic technologies used to enhance human capabilities. The film challenges eugenics theory and exposes the lack of credibility in genetic engineering. For example, the genetically enhanced Jerome Eugene Morrow fails to achieve his destiny when he fails to become the next Olympian champion in swimming although he was genetically enhanced to do so. In contrast, Vincent, the "faith birth" conceived without any enhancement whatsoever, deceives the system by impersonating the identity of an enhanced individual, fulfills his dream in becoming one of the Gattaca aerospace members and flies to space.

Since science education encourages the importance of hands-on and inquiry-based approaches in academic settings, teaching science can be challenging in classroom-based learning, due to the lack of materials or the impossibility of performing various activities in classrooms. Science fiction films can be a huge help because they are conceptualized to convey scientific knowledge through a non-traditional medium that can help students learn about scientific concepts through the examples shown in the film's story or through the explanations given by the actors. Dubeck acknowledges in his academic research project the effectiveness of implementing science fiction films as tools to enhance pedagogical methods in teaching science. He states that using science fiction films enables students to discover connections between real-

world phenomena and technologies through the lens of actors solving similar problems that threaten human existence. The learning process occurs when science becomes an essential part of problem-solving situations. Students can experiment and enjoy when realistic contexts in fictional settings create a virtual environment. "Science learning occurs best when content is presented as an intrinsic part of specific problem-solving situation, preferably within a realistic and authentic context."[133] Therefore, using science fiction films as a pedagogical tool allows "students' imagination and 'thought experiments' to create a virtual learning environment that is […] engaging and reasonably authentic, even though it is entirely fictional."[134] The scientific issues exposed in science fiction films can be analyzed and evaluated for their plausibility and reliability in future scenarios.

Learning science through science fiction films refines public understanding of scientific topics and reshapes their concepts about the natural world. Watching the science fiction movie *Gattaca* discussing eugenics and highlighting the potential of human enhancement could broaden the public's understanding of gene editing's potential. The movie revolves around creating the perfect society that can excel in duties. While the movie's concerns are varied, bioethics remain the main problem. Students are exposed to biotechnology and DNA manipulation. Thus, the new eugenics in *Gattaca* reflects humans' anxiety who believe that humans are determined in the first place by their gene's makeup. Genetic determinism or bio-determinism reduces humans' physical appearance, personality and behavior to their genetic code. It is a reductionist ideology

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[133] Sevinc Ongel-Erdal and al., *Science Fiction Movies as a Tool for Revealing Students' Knowledge and Alternative Conceptions* (Washington, D.C: Distributed by Eric Clearinghouse, 1997), 3.

[134] Ibid., 3.

that considers humans are defined by their individual genes. *Gattaca* sheds light on eugenics' goal of creating a "perfect individual" as defined by society. The movie emphasizes the human abilities of those genetically modified and considered elite.

SIMULATING REAL MEDICAL TECHNIQUES IN *GATTACA*

When *Gattaca* premiered in 1997, in vitro fertilization (IVF) was already performed in the United Kingdom to conceive the first "test-tube-baby" — the first baby to be conceived with the new laboratory techniques to help couples overcome infertility. Today, fertility clinics who offer IVF become very popular in the country and a good number of children born in the United States are conceived with IVF. Exploring eugenics in fictional *Gattaca* film became a reality in the twenty-first century. However, unlike in *Gattaca,* in vitro fertilization in real life is performed for medical reasons, not to create a baby to conform to one's wishes.

Another technique available around when *Gattaca* was released is preimplantation genetic diagnosis (PGD) which consists of choosing one cell in an IVF embryo to find genes with potentially fatal or debilitating diseases. The PGD technique can detect embryos that will probably develop conditions such as sickle cell disease, cystic fibrosis, Tay-Sachs and Huntington's disease. The PGD technique is very valuable to people who plan to conceive a child, but suffer from hereditary genetic diseases and risk the potential of transmission. For example, genetic compatibility testing (GCT) helps parents who carry at least one allele of a genetic disease to predict if the conceived child would have the disease. PGD detects and treats genetic diseases, but some people use it to choose some characteristics. For example, a lesbian couple Sharon Duchenseau and Candy McCullough used PGD to procreate a deaf child as they

consider deafness to be a cultural identity and not a medical disability. Depriving a child of one of his basic senses challenges what society considers a normal child.[135]

When used as educational tools and "not just the accumulation of visual technologies, [such films] show social versions of scientific discussions by simply representing the natural world."[136] In *Gattaca*, Marie and Antonio Freeman, the parents of Vincent, are eager to have a child that fits the norms of the Gattaca organization. They decide to customize their future child to guarantee him a secure future. The scene at the beginning of the film recounts the features of the new baby. First, the baby will be "a boy with hazel eyes, dark hair, and fair skin. [Secondly, the doctor states] that he has taken the liberty of eradicating any potentially prejudicial conditions: premature baldness, myopia, alcoholism, and addictive susceptibility, propensity for violence and obesity."[137]

By representing such choices, the movie may help students learn about potential diseases caused by genetic disorders or mutations as well as vocabulary related to genetics. Students also learn about the different types of diseases that might affect genes. In addition, students may also develop critical thinking about issues encountered when eugenics fails or falls into the wrong hands. What would the future of humanity be? How would our world look if everyone wanted to

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[135] Ferris Jabr, "Are We Too Close to Making Gattaca a Reality?" *Scientific American Brainwaves* (October 2013), https://blogs.scientificamerican.com/brainwaves/are-we-too-close-to-making-gattaca-a-reality (accessed April 10, 2019).

[136] "The Impact of Science-Fiction Movies on the Self-Efficacy Perceptions of Their Science Literacy of Science Teacher Candidates," 1576.

[137] "Are We Too Close to Making Gattaca a Reality?" *Scientific American Brainwaves* (October 2013), https://blogs.scientificamerican.com/brainwaves/are-we-too-close-to-making-gattaca-a-reality (accessed April 10, 2019).

have only boys or girls? Would a eugenics market exterminate the notion of meritocracy? Would perseverance, adaptability, and self-improvement be framed under innate genetic talent and explained as genetically superior qualities?

IMPROVING CRITICAL THINKING THROUGH SCIENCE FICTION

Discussing gene editing applications in an academic setting develops students' critical thinking, which is another advantage that science fiction films offer students as an alternative to traditional learning methods. Due to the diversity of topics that science fiction films discuss, students are exposed to global issues caused by the pervasiveness of technology that transcends all boundaries. The visual space offers students an effective, engaging tool for comprehending and analyzing scientific concepts that "often involves an imagined future characterized by drastic advances in technology and science…"[138] For example, showing all actors in *Gattaca* in the same color and design of uniforms emphasizes the homogeneity of the individual as if each one of them represents one of the four DNA bases. Reflecting on the real science as presented in fictional films may promote students' thinking about society, culture, and ideology. They will consider perceiving the future with critical minds and an avid desire to discover and experiment with science and technology. They will gain "confidence to engage as future decision-makers in broader sociopolitical issues beyond the classroom,"[139] and they can acquire valuable skills that allow them to participate as global citizens in responsible decision-making.

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[138] Shuyuan Liu, "Using Science Fiction Films to Advance Critical Literacies for EFL Students in China," *International Journal for Education & Literacy Studies* 7, no.3 (July 2019): 3.

[139] "Using Science Fiction Films to Advance Critical Literacies for EFL Students in China," 6.

GENETIC DETERMINATION VERSUS WILLPOWER

In *Gattaca*, parents are able to customize their children's intelligence and personality, which cannot be achieved through today's PGDs which can only determine skin, hair and eye color. However, intelligence and personality are not detected by a predictive genetic test; only basic characteristics could be determined by PGD such as the skin, hair, and eyes color. Giving "the child the best possible start" (*Gattaca*) as the doctor in *Gattaca* says could possibly begin a new eugenics era where children become customized products. *Gattaca* highlights technological advancements in the field of genetic engineering but it also emphasizes the great danger. Genetic discrimination is represented in *Gattaca* through the valids who have customized genes and have the most respected jobs in the organization of *Gattac*a, and the in-valids who have no alteration of their genes have more menial jobs.

The technique of PGD is not only an effective way of eliminating genetic diseases, but it can also be helpful in forensic science to identify DNA and solve crimes. DNA matching, saliva, sperm, hair parts and skin residue at a crime scene are valuable tools in such identification. By isolating genetic materials such as blood, saliva, fingernails, and hair to determine identities, *Gattaca* introduces the DNA identification process. The newest technologies use DNA 'microarrays," small chips of DNA fragments in genetic analysis. In the film, the body materials depicted remind viewers of the invisible genetic identity reflected by visual effects. "This is a world in which the blood test has replaced the police interrogation and the urine test has replaced

the job interview."[140] However, this technique cannot create human feelings such as love, perseverance or strong will. These are notions genetic engineers cannot reproduce.

In *The Human Genome Project in College Curriculum: Ethical Issues and Practical Strategies* (2008), *Gattaca* is discussed from a bioethics point of view, considering the religious symbolism that the film projects. The science fiction story of a futuristic society in *Gattaca* is a reality coming true. The film's character Vincent, the "invalid" child, suffers from a weak heart and is denied access to the *Gattaca* organization's space academy. He became adamant to prove that his birth disorder cannot stop him from achieving his dreams. He insists on showing his father that genetic inheritance or genetic customization cannot define his future. Even his name prepares him for a successful future. "Vincent" derives from the Latin verb "Vincere" which means winning or conquering. Moreover, his last name "Freeman" liberates him from all genetic regulations to confirm once more that human's determination and willpower are important catalysts to attain the impossible. Therefore, Vincent decides to exchange identities with Jerome Eugene Morrow, played by Jude Law. Morrow belongs to the superior category of people. Even his name connotates scientific terms – "Jerome" – brings to the mind "Genome" and "Eugene" symbolizes eugenics supported by the Greek meaning of "*eugenes*" which is "noble, well born" from "eu" well and "genos" race. Additionally, "Morrow" echoes with "tomorrow'' and it is a reinforcement of the title "Gattaca" that suggests that humanity's future resides in its genetic records. Jerome is conceived to become a great swimmer, but a car accident left him paralyzed and unable to pursue his career. Vincent, eager to be employed by Gattaca, conceals his identity

[140] Jackie Stacey, "Masculinity, Masquerade, and Genetic Impersonation: Gattaca's Queer Visions" *Signs: Journal of Women in Culture and Society* 30, no. 3 (2005): 1853.

by using Eugene's hair, skin, blood, and urine samples to enter the facility. In the film, many scenes highlighted parts of the human body to foreshadow "the film's exploration of scientific ideas and the society's obsession with DNA and genetic material."[141] The first scene shows a small fingernail dropped to the ground with the emphasis on the fingernail's size to explain that the smallest part of the body holds the entire DNA sequence of a human being. Another reference to genetic materials is shown while Vincent is shaving his face and cutting his finger nails. The picture focuses on the follicles of hair that dropped into the ground and on the skin cells left behind. More identification is required of Gattaca employees such as a urine sample. When asked to submit a sample, Vincent attaches a tiny bag of Eugene's urine to his thigh to pass the test. He also wipes out neatly his desk to ensure that no skin residue or loose hair is left on his keyboard. All these scenes demonstrate that DNA is an undeniable part of human identity. Each individual has a unique set of DNA sequences. "Our DNA will determine everything about us. A minute drop of blood, saliva, or a single hair determines where you can work, who you should marry, what you're capable of achieving."[142] The individual identity is defined by our genes. The film suggests that "the demarcation of identity [is] no longer anchor[ed] to traditional forms of visual proof, including sight recognition itself."[143]

CRISPR TECHNOLOGY IN *CHANGE AGENT*

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[141] Zara Walters, "Gattaca Symbols, Allegory and Motifs," GradeSaver, https://www.gradesaver.com/gattaca/study-guide/symbols-allegory-motifs#skin-nails-and-hair (accessed March 2021).

[142] *Gattaca*, Movie Clips Trailer, https://www.youtube.com/watch?v=W_KruQhfvW4 (accessed June 2021).

[143] Olivia Banner, "The Postracial Imagination: Gattaca's Imperfect Science," *Discourse (Berkeley, California)* 33, no.2 (2011): 229.

In *Change Agent*, Daniel Suarez sets his novel in 2045 where the CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) technology has advanced to where someone's whole genetic identity could be replaced with a new one. "Initially developed in 2012, CRISPR technology is a search-and-replace tool for modifying DNA — the blueprint of all living things."[144] Suarez raises the issue of identity loss if genetic selection is allowed. He argues that "human embryos may be safely and reliably 'edited' in vitro to correct deadly heritable genetic disorders."[145] But the novel shows the dangerous effects of such technology in the same way as *Gattaca*. Suarez declares that "If we make edits that don't fit the environment — even though we think they are cool — then bad things could happen to future generations that we didn't expect. […]. That's why we only let sick people correct genetic errors − changes that will make them the way humans evolved to be. Any other edits are against the law."[146] Science should be subservient to humanity and not a destructive tool that threatens human life.

In *Change Agent*, Suarez brings the CRISPR technique as scientific background for his narrative and emphasizes its importance in curing hemophilia, muscular dystrophy, cystic fibrosis, sickle-cell anemia, and Huntington's disease. He believes that CRISPR "edits increase both the quality and the quantity of human life"[147] and it can be passed to future generations in the family line. He even explains how editing a human embryo's DAF2 gene (metabolic pathway responsible for the rate of aging) could help with healthy growth and longer span life and

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[144] Daniel Suarez, *Change Agent* (New York: Dutton, 2017), 3.

[145] Ibid., 3.

[146] Ibid., 23.

[147] Ibid., 4.

BACAT1 (a protein coding gene associated with several diseases including Hypervalinemia and hyperle). Altering the DLG3 gene (protein Coding Gene) genetically within the M1 (receptors located mainly in the central nervous system) and M3 (receptors found in the eye muscle, blood vessels) could improve memory and increase intelligence (*Change Agent* 4 -5). However, further in the novel, Suarez uses DLG3 to show that such altering "creates laborers of low IQ. Low food requirements. Designed for docility."[148] They are called Worker Bees. Suarez evokes scientific facts of altering genes in his novel as he probably was influenced by the real experiment of baby gene editing that happened in 2015 where scientists at the Southern University of Science and Technology in Shenzhen, China, created the first gene-edited babies. "They planned to eliminate a gene called CCR5 in hopes of rendering the offspring resistant to HIV, smallpox, and cholera."[149]

COMBINING CRISPR AND STEM CELLS IN CLASS DISCUSSION

CRISPR technology may be successful in curing diabetes. In "CRISPR and Stem Cells to Cure Diabetes" (2020), Rasmus Jakobsen writes how scientists could find a potential cure for genetic forms of diabetes. Scientists, according to Jakobsen,

> "Take patient skin cells, turn them into stem cells, use CRISPR-Cas9 gene editing to correct a diabetes-causing mutation, and then transform the edited cells into the insulin-

[148] Ibid., 228.

[149] Antonio Regalado, "Exclusive: Chinese Scientists Are Creating CRISPR Babies," *MIT Technology Review*, November 25, 2008, https://www.technologyreview.com/2018/11/25/138962/exclusive-chinese-scientists-are-creating-crispr-babies (accessed March 15, 2020).

producing beta cells the patient lacks. Transplanting the beta cells into severe diabetic mice rapidly reverses their diabetes, providing a robust and functional cure.[150]

The transplantation of beta cells into diabetic patients as Jeffrey Millman, assistant professor at Washington University School of Medicine, in the United States, —explains— "promising alternative to insulin injections [by creating IPSCs, induced pluripotent stem cells that] can be transformed into any of the cell types found in the body …"[151] Wolfram's syndrome could also be treated and cured with this promising technique as one in 500,000 people suffers from it. Wolframs syndrome is a rare genetic disorder that develops diabetes in childhood and can cause vision loss due to optic nerve degeneration, balance problems and even early death.

To cure diabetic patients, CRISPR-Cas9 gene editing and IPSC stem cells were combined. The method consists of taking skin cells from patients and turning them into IPSC stem cells, then applying CRISPR gene-editing to correct the debilitating nucleotide in the WSF1 gene (the protein that produces wolframin to regulate the amount of calcium in cells). Then cells are grown in different growth factors to turn the IPSC stem cells into beta cells to produce insulin and lower the sugar level in the blood. However, Millman also discusses the possibility of mutation during this process which could lead to problems, including cancer. Millman explains that cells edited ex vivo are "performing whole exome sequencing of gene-edited cells to

[150] Rasmus Kragh Jakobsen, "CRISPR and Stem Cells to Cure Diabetes," *CRISPR News Medicine*, (April 2020) https://crisprmedicinenews.com/news/crispr-and-stem-cells-to-cure-diabetes (accessed October 25, 2020).

[151] Ibid.

confirm lack of off-targets in the protein-coding region of the genome [which] would allow us to select only clones with the correct gene edits without off-targets…"[152]

Exposing students to the potential impact of advanced scientific technologies on society could help students understand how diseases occur and how science alleviates some diseases to make life easier. It also helps them formulate ethical and moral decisions concerning issues that result from monopolizing gene engineering.

For some scientists, CRISPR revolutionized the medical field in eliminating genetic diseases; others see "a slippery slope to enhancements, designer babies, and a new form of eugenics."[153] Contrary to Canada and the United Kingdom that forbid using PGD for sex selection, the United States allows it for medical reasons to avoid genetic disorder transmission to off-spring. Jeffrey Steinberg, director of The Fertility Institutes, states that sex selection for non-medical reasons is already underway and in 2009, he declared that parents can even "choose their child's skin color, hair color and eye color in addition to sex."[154] However, the controversial debate about human embryo gene-editing is constant. Baltimore stated that genetically modifying embryos "would be inherited by future generations and could eventually affect the entire gene pool."[155] The fear of embryos' gene editing includes yielding the way to unwanted mutations, which might lead to disaster. However, the end of gene-editing also could end with the work that

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[152] "CRISPR and Stem Cells to Cure Diabetes," *CRISPR News Medicine*, (April 2020) https://crisprmedicinenews.com/news/crispr-and-stem-cells-to-cure-diabetes (accessed October 25, 2020).

[153] "Exclusive: Chinese Scientists Are Creating CRISPR Babies."

[154] "Are We Too Close to Making Gattaca a Reality?" *Scientific American Brainwaves*, 1.

[155] "Exclusive: Chinese Scientists Are Creating CRISPR Babies."

eliminates diseases. With that being said, students could be invited to brainstorm the idea of gene editing, research cases with gene editing to evaluate and measure to what extent gene editing could safely be used.

DNA AND IDENTITY RECOGNITION

Even in the fictional world of *Change Agent*, Suarez notes the implications of live editing humans. He believes editing the DNA in living people will change the identity of human beings, and it will be illegal. (*Change Agent* 129). In *Gattaca*, genetic profiling replaces all forms of identification since genetic samples are more reliable than other identification methods. Scientific facts are depicted in finger-prick blood identification machine where blood samples identify individuals. Analyzing DNA and removing fingerprints from the crime scene allow viewers to experience scientific methods in discovering people's identities. Other measurable biological characteristics that can be examined are facial geometry, voice, and iris patterns all of which are unique to each person. Even the film title *Gattaca* reveals to viewers that DNA is formed of the following letters G, A, T, and C (respectively guanine, adenine, thymine, and cytosine) which constitute the four nucleobases of DNA. Each nucleotide in humans' cells is composed of one of the four bases. Students can learn about genomes encoded in DNA representing human's hereditary information and they can be informed that amino acids in DNA are used to create proteins needed for life.

In *Using Medicine in Science Fiction: The SF Writer's Guide to Human Biology* (2016) H.G. Stratmann explains that genes can be located in nucleotides in alternative forms to create a

particular protein. For example, Hemoglobin A is formed with adenine at a particular location of DNA sequence that is called 'beta chain.' However, if thymine is found instead of adenine, Hemoglobin S is formed.[156] The formation of Hemoglobin S leads to anemia depending on how much is found in the blood cells. Marfan syndrome, for example, is caused by genetic disorder; a variant of the gene that creates a protein for fibers' elasticity is in place and can cause severe physical problems such as difficulties in vision, spine curving and even death. Some other diseases were also attributed to gene disorder such as schizophrenia, diabetes, and high blood pressure. Students may research deeper the genetic disorder behind these diseases and share their findings with their classmates.

Sharing scientific information through the film broadens viewers' understanding of genes structure and their role in specifying individual identity. Showing the nucleotides' letters G, A, T, and C at the beginning of the film blended with actors' names that vanish away and leave the letters in highlight confirms that Gattaca's society identifies its members by microscopic genetic code. The highlighting technique reveals from the outset of the film that individuals are reduced to their genetic code, but the ending of the film emphasizes the ability of humans to surpass their genetic obstacles and achieve their ultimate goals, rather than reducing human identity to invisible microscopic molecules. "The demarcation of identity no longer anchors to traditional forms of visual proof, including sight recognition itself,"[157] but it is analyzed by machinic technologies.

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[156] H.G. Stratmann, *Using Medicine in Science Fiction: The SF Writer's Guide to Human Biology*, 1st ed. (Champ: Springer International Publishing, 2016), 391.

[157] "The Postracial Imagination: Gattaca's Imperfect Science," *Discourse (Berkeley, California)* 33, no.2 (2011): 229.

The film's plot recounts the frustration that Vincent lives with due to his natural genetic disorder. According to *Gattaca*, naturally-conceived children are not guaranteed a secure future and a decent job. Using genetic selection is considered more reliable and assures a brilliant future. In the context, Vincent defies the "norms" of *Gattaca* to prove the wrongness of eugenics procedure. Passing all daily DNA tests at Gattaca aerospace corporation, Vincent is convinced that his birth disorder cannot stand in the way of his dreams as he realized that Jerome Eugene Morrow supposed to be the best swimmer, but he placed second in the Olympics, and his injury is self-inflicted. Genetic enhancement might not be the perfect solution for humans unless it cures diseases and hereditary disabilities.

In the film, the design of the staircase in Jerome's home takes the shape of double helix, the chemical components of DNA, mimicking the chromosome's structure and putting Vincent and Jerome at two different ends to illustrate the genetic material exchange between them. The film metaphorically presents Gattaca Corporation as a huge mechanistic human cell that considers unmodified people as parasites and choses the elites to send them to space. Although genetically inferior, Vincent's strong will and straightforward determination allow him to break through his "genetic walls" to fulfill his dream. Vincent, considered a renegade for refusing to succumb to genetic determinism and for embodying valid person genetically to achieve his goals, is represented metaphorically as a virus that human cell corporation rejects. He is also considered a biohacker who uses the genetic system illegally.

Moreover, Anna Petneházi, an English teacher, describes Vincent as a latent virus who "enters a host organism not to destroy its cells immediately but instead attaches to its surface

either to multiply or camouflage itself."[158] As Vincent states in the film: "We have discrimination down to the science… No matter how hard I study, in the end it makes no difference… my resume is in my cells."[159] His only hope is to borrow gene materials from a valid member of Gattaca community.

Physician and science fiction author H. G. Stratmann notes that some genetic defects might have significant impact on the neurological system. For example, Tay-Sachs disease (responsible for "gangliosides accumulation in the brain) and Lesch-Nyhan syndrome (causing overproduction of uric acid in the body) are diseases caused by DNA variants. Some damage might occur to the fetus with genetic therapy application and might have a disastrous impact. The gene insertion might interfere with the development of gene sequence and yield to unwanted results. Moreover, Stratmann argues that "animal studies have shown that injecting genes directly into fertilized ovum could not only result in them being incorporated into all of the resulting animal's cells but even be passed on to its offspring."[160] Applying genetic therapy early on a fetus with diseases prevent the disease's development and transmission to offspring. For example, Huntington's disease appears when individuals are in their mid-30s with 50% chance of transmission. Treating the defected gene in the fetus helps individuals with healthy growth. During the film, students are introduced to the technique of genetically modifying plants, animals, and bacteria to generate hormones used for medical purposes. For example, inserting

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[158] Anna Petneházi, "'Who Can Straighten What He Hath Made Crooked?': Eugenics and the Camp in Gattaca and The Island," *Hungarian Journal of English and American Studies* 22, no. 2 (2016): 356.

[159] Andrew Niccol and al., *Gattaca*, Special ed., DVD (Culver City, California Pictures Industries, 2008).

[160] *Using Medicine in Science Fiction: The SF Writer's Guide to Human Biology*, 1st ed. (Champ: Springer International Publishing, 2016), 400.

insulin, human growth hormone, and blood clotting factors into Escherichia coli bacteria (E. coli) serves as a biological host to generate those hormones. Some methods in gene therapy studied in animals showed success in treating fractures and regenerating bone using recombinant human bone morphogenetic proteins injected in potential candidates for treatment. Other examples of treatments include muscles disease such as muscular dystrophies and atherosclerosis, a risk of an increased level of cholesterol that blocks the arteries and causes inflammation. Many other illnesses could be treated with gene therapy, such as depressive disorder, schizophrenia, bipolar disorder, and epilepsy.

POTENTIAL RISKS USING GENETIC THERAPY

Genetic therapy's risks include serious issues "such as producing infection, triggering a life-threatening immune response, or promoting development of a malignancy"[161] but the promising potential of healing fatal and debilitating illnesses may be worth taking those risks. Adding to the benefits of learning about diseases or debilitating hereditary genes, students can learn about the process of gene editing. For example, they can learn that ex vivo gene manipulation is preferred to in vivo since the former is less risky and has more advantages over the in vivo technique: "It is much easier to genetically modify cells that are growing in the laboratory than to deliver the gene-editing machinery to a specific subset of cells in the human body."[162] However, some diseases such as Duchenne muscular dystrophy (DMD) are being

[161] *Using Medicine in Science Fiction: The SF Writer's Guide to Human Biology*, 420.

[162] Maria Schacker and Diane Seimetz, "From Fiction to Science: Clinical Potentials and Regulatory Considerations of Gene Editing," *Clinical and Translational Medicine* 8, no. 1 (2019): 3.

treated via in vivo editing. The disease progresses to cause muscle degeneration and eventually death.

Genetic engineering presents issues and problems that involve laws, moral and ethical decisions, and social and cultural factors. Fortunately, science fiction sheds light on the benefits of using such techniques to minimize diseases and illnesses or maximize humanity's hope in progressing and evolving. As Aine Donovan and Ronald Green argue: "vaccinating children against disease, timing one's family to be earlier in life rather than later, taking prenatal vitamins, avoiding situations known to cause birth defects, and even being choosey about with whom one procreates"[163] can be considered more nuanced aspects of eugenics. In this context, "Gene Therapies and the Pursuit of a Better Human" (2000), written by Sara Goering, helps students identify bioethics conditions and encourage questioning genetic engineering value in human life. The article draws the line between what is considered true diseases versus social prejudices to define the ethical use of gene therapy. Making a clear distinction between therapeutic gene selection and enhancement requires decisive delineation to prevent unfair exploitation and genetic discrimination. For example, in *Gattaca*, Vincent is described as an "in-valid" with a birth defection of a weak heart and expectation of death by age 30.2. His brother Anton, genetically enhanced at birth, was hired by the Gattaca corporation but Vincent defeated him during a swimming challenge at the sea. The film emphasizes this detail to pinpoint that the "genetically enhanced are physically and intellectually sound, [but] they are deficient in

[163] Aine Donovan and Ronald M. Green, *The Human Genome Project in College Curriculum: Ethical Issues and Practical Strategies* (Hanover, N.H: Dartmouth College Press/University Press of New England, 2008), 21-22.

willpower, impulse control, and grit."[164] The film's strength focuses on the power of Vincent's determination in achieving his dreams despite his genetic status to ensure viewers that genetic selection enhancement does not automatically lead to success as some believe.

In discussing such character, students could be asked to identify conditions from genetic disorders such as myopia, Alzheimer and Parkinson's diseases, or obesity to name a few, and determine whether these conditions fit the moral therapeutic obligations. Collecting their data, analyzing the causes and consequences of each disease on the human body, and sharing their findings with the rest of their classmates would help students acquire scientific knowledge by discovering these diseases. Students could also learn about genetic therapy using synthetic DNA (called centromere) elaborated in the laboratory to blend it with human DNA to cure inherited genetic diseases.

TAMPERING WITH MOTHER NATURE IN *GATTACA*

More interesting is the question raised about genetic enhancement and its impact on people's identity. How would genetically modified people change the terms of the nature/nurture debate? Which one will be privileged and why? And does genetic science do the world a favor, or is it worsening it? While addressing these questions, students will be able to identify issues related to "emerging genetic discrimination, access to genetic enhancement, the heightened social focus on the importance of one's genetic composition, and the potential hazards even within the family structure itself."[165]

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[164] *The Human Genome Project in College Curriculum: Ethical Issues and Practical Strategies* (Hanover, N.H: Dartmouth College Press/University Press of New England, 2008), 22.

[165] *The Human Genome Project in College Curriculum: Ethical Issues and Practical Strategies*, 90.

David Kirby considers genetic inheritance as equivalent to predestination because it is predictive of an individual's "future: Genetics offers answers. For genes can foretell the future…"[166] Socio-biologists argue that human behavior is defined much more by biological inheritance than the environment. Some bioengineers go further and suggest that genetic malfunction could be the reason for some cases of mental diseases and antisocial behavior such as misanthropy and criminality.

According to Jeremy Rifkin, heredity plays a major role in determining one's personality and "human activity is, in some way, determined by our genetic makeup, and that if we wish to change our situation, we must first change our genes."[167] Gene code can reveal important information permitting scientists to unfold new discoveries regarding human nature, and in the same way, they refuse to assert that genes can determine or control human behavior. In the film, the presence of DNA in genetic materials passed from Jerome to Vincent reflects the conflict of using genetic selection. The scene also demonstrates the science of gene therapy through which scientists try "to insert foreign genes into hundreds of patients in an attempt to correct a number of genetic disorders."[168]

Gattaca emphasizes the development of gene technology in broadening the gap between social entities. The biotechnology technique draws the line between improving human health with gene editing and human eugenics experimentation to create physically enhanced bodies,

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[166] David A. Kirby, "The New Eugenics in Cinema: Genetic Determinism and Gene Therapy in 'Gattaca,'" Science-Fiction Studies 27, no.2 (2000): 202.

[167] Jeremy Rifkin, *The Biotech Century: Harnessing the Gene and Remaking the World* (New York: Jeremy P. Tarcher: Putnam, 1998), 148.

[168] *The Biotech Century: Harnessing the Gene and Remaking the World*, 27.

sharper minds, and superior talents. The competition between genetically enhanced and naturally born people emphasizes perseverance's potential without regard to genetic enhancement. Will this be the case if genetic editing for biological enhancements is allowed in real life? Some teaching programs, like in nurse education, emphasize the role of films and literature in helping students "understand the ethical dimensions of, and current clinical practices surrounding, genetic testing, gene-based selection, discrimination against disability and bodily difference, reproductive services, and the use of numerical expressions to communicate future disease risk."[169]

Novelists and digital artists Bill and Alice K. Pomidor argue that although genetic screening may help reduce birth defects with early intervention, it still creates an increasingly rigid society empowered by the wealthy who can afford genetic enhancement. According to the Pomidors, "gene therapy in *Gattaca* has spread to encompass countless genetic enhancements to strength, intelligence, and appearance."[170] Learning about the technique of gene editing and the wide potential possibilities to help eliminate genetic disorders, make crops resistant to diseases, and enhancing the human race could improve students' understanding of such scientific innovations. Donovan and Green argue that using *Gattaca* to introduce students to genetic techniques would improve their critical thinking "as they grappled with the serious genetic issues that will surely impact their future in very concrete way."[171]

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[169] Amanda Müller and Adam Dalzotto, "GATTACA and Genetic Determinism," *Nurse education Today* 70 (2018): 95.

[170] Bill and Alice Pomidor, "Essay: 'With Great Power…' The Relevance of Science Fiction to the Practice and Progress of Medicine," *The Lancet (British Edition)* 368 (2006): S13.

[171] *The Human Genome Project in College Curriculum: Ethical Issues and Practical Strategies*, 119.

Agricultural gene-editing is also mentioned in Suarez' novel when he discusses the editing of rice strain LOC-OSO7 and p-SINE1 to highlight the new biotechnological technique called "gene drives" that enable scientists to change the rules of inheritance traits by modifying the gene transmitted down the line. "I [Bryan Frey is a fictional doctor who holds a degree in genetic engineering from the University of Bonne] edited LOC-OSO7 and p-SINE1 rice strains for the Shan to counteract Burmese government gene drives — some of which were developed by major biotech firms on the down-low, in violation of the UN treaties."[172] More interesting is the fictional narrative of the plot's setting: the story takes place in Southeast Asia where Wyckes, the leader of a powerful human trafficking cartel known as the Huli Jing practices genetic editing to conceal people's identities. Huli Jing, according to the Chinese mythology, is a creature endowed with either benevolent or malevolent spirits capable of shapeshifting. The butterfly is also a symbol of metamorphosis as it changes shapes from a caterpillar to its final form. It turns more scientifically interesting when Suarez explains that the caterpillar and the butterfly have the "same exact DNA [but] completely different forms. Epigenetic. Gene expression. Turning genes on and off. That's what happens during the butterfly's metamorphosis. It builds a chrysalis and secretes chemicals that cause it to fall into a comatose state as its body changes,"[173] which is what happens to the main character in the novel, the Interpole agent Durand, after being injected with the 'change agent' (supposedly responsible of genetic transformation of the physical

[172] *Change Agent*, 269.

[173] Ibid., 280.

appearance). Durand enters in a coma for a week (mimicking the butterfly phases of life) and woke up to see himself transformed into Wyckes, the most wanted individual from the Interpole.

By discussing such potential uses of gene therapy, students can learn about gene alteration to treat disease and nucleic acid-based therapy that uses a viral vector to deliver therapeutic genes to the nucleus cells. They can also learn about the non-viral vector-based gene delivery method that showed more promising results than the viral vector as it resulted in safer biological treatment with less antigenicity, less carcinogenesis and less-lethal immune reaction. They can be introduced to three ways of gene manipulation: recombinant DNA technology (rDNA technology), multicellular organisms, and human-gene therapy that directly alters human genes.

GENE THERAPY FOR DISEASES ILLIMINATION

Gene therapy, according to Patrick Arbuthnot, "has many applications and may be used for restoring the health of diseased cells, killing of malignant tissue, and induction of immune responses to gene-encoded proteins."[174] With the advancement of DNA recombination technology, the revolutionary polymerase chain reaction development and nucleic acid sequencing methods, gene therapy development has fundamental effects on reducing and even removing debilitating or mutated genes in human. For example, severe combined immune-Deficiency syndrome (SCID) is treatable with gene therapy as the disease is a genetic disorder caused by the gene mutation called adenosine deaminase (ADA) located on human chromosome 20. Gene therapy is able to insert non-defective gene of ADA into the bone cells of an individual and help producing ADA. Another deficiency that gene editing can fix is growth hormone

[174] Patrick Arbuthnot, *Gene Therapy for Viral Infections* (Amsterdam, Netherlands: Academic Press, 2015), 1.

deficiency. Many parents nowadays use human growth hormone (hGH) to increase their children's height because they believe tall people are better paid and have better chances in life.

On the other hand, *Gattaca* not only introduces biological topics in the narration but it also discusses religious themes to highlight the interconnectedness of science with social and cultural life. Analyzing a work of art from multidisciplinary approaches enriches students' knowledge and challenges their beliefs. Altering genes, creating an eugenics population and hence genetic discrimination would be part of the controversial topics that *Gattaca* provokes. The film shows the daunting but infinitely fascinating role of science in shaping the society and culture, at the same time, it highlights how society and culture profit from science. The nurture versus nature debate will always be at the center of studies about the genetic impact on human behavior versus learning experiences from the environment. Through the studying of the film, Donovan and Green explain that:

> Biology students need to appreciate how their discipline shapes everyday life. Also, they need to realize how the types of questions they ask as well as the way they go about answering them are social processes. And humanities majors not only need to learn how the social, ethical, and legal implications of recent molecular biological discoveries can affect everyone, but should begin to comprehend how it is that a scientist think.[175]

BIOTECHNOLOGY AND THE PUBLIC PERCEPTION

Another voice emphasizing the importance of educating the public about science is that of Elizabeth Marincola who argues that science is not only about memorizing lists of long words

[175] *The Human Genome Project in College Curriculum: Ethical Issues and Practical Strategies*, 159-160.

that shortly will be forgotten after tests are over. She "states that it is imperative that the public is engaged in science issues which have an impact on their lives, in their own self-interest, to best thrive in modern society."[176] She explains that laypeople's understanding of critical, controversial topics such as the science of embryonic stem cell and climatology would be essential to help lawmakers in their legislation. "Yet no country, no matter how sophisticated technologically, can advance its society fully without the informed engagement of its citizenship,"[177] according to Marincola.

Other academic scholars who advocate teaching biology in a social context claim that "using real-word problems to thread a number of biological concepts together encourages students to move away from seeing biology as a collection of disparate concepts, subject areas, or chapters from textbooks that are far removed from society."[178] Students are typically influenced by the way their instructors deliver the lessons and follow their lead. Integrating social issues with science fiction in the biology curriculum could help biology majors visualize science in social contexts and could help nonmajors develop their biological literacy. By following this advice, students can develop the habit of mind to make connections and understand the interdisciplinary correlation between biology and society. Science careers allow students the freedom to choose from a wide range of possibilities simultaneously. Administrators, educators, and lawmakers need to ensure that students of the twenty-first century

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[176] Elizabeth Marincola, "Why Is Public Science Education Important?" *Journal of Transnational Medicine* 4, no. 1 (2006): 7.

[177] Ibid., 7.

[178] Katayoun Chamany and al., "Making Biology Learning relevant to Students: Integrating People, History, and Context into College Biology Teaching," *CBE Life Science Education* 7, no. 3 (2008): 267.

are well-equipped to compete in a world where technological advancements are rapidly expanding. Providing scientific education among students and laypeople improves science education in general and helps the United States advance economically. To become an influential and growing force, science education should be made a priority. Scientifically knowledgeable workers are more prone to make better decisions and be more productive. The Science for All American (SFAA) defines a relevant approach to reducing scientific memorization and increasing students' awareness of scientific learning. Through this lens, Carisa Ketchen argues that students need to:

- Understand how the scientific endeavor works and how science, mathematics, and technology relate;
- view the world of nature and the role of humans in it;
- grasp conceptual knowledge about science, mathematics, and technology in the context of history and the themes that cut across all fields; and
- acquire the habits of mind to be inquisitive, critical participants in the affairs of the world.[179]

PLAYING GOD IN *GATTACA*

More complex and profound issues arise at the beginning of the film in two sets of critical scenes where characters discuss gene editing from ethical and theological points of view. The first quotation is from the Ecclesiastes 7:13 "Consider God's handiwork: who can straighten what He hath made crooked?" and the second comes from the American bioethicist Willard

[179] Carisa Ketchen, "Teaching Science with Science Fiction," (master's thesis, Montana State University, 2014), 29.

Gaylin: "I not only think that we will tamper with Mother Nature, I think Mother wants us to." (*Gattaca*). Through these two scenes, students might present a project reflecting on the social and controversial dilemmas that could result when tempering with Mother Nature. As seen in *Gattaca*, genetic engineering is depicted as improving humans' genetic makeup directly which may lead to social discrimination, as Ted Peters explains in his book *Playing God? Genetic Determinism and Human Freedom* (1997). Peters believes that genes predict human behavior, and engineered humans in test tubes could be defined by their genetic code that ensures reproducing elite human race with specific characteristics and abilities. He argues that human freedom is a delusion if people believe that "It's all in the genes!"[180] and that human are determined and programmed by their DNA.

As depicted in *Gattaca* and *Change Agent*, genetic engineering could be used in different ways: to select physical characteristics; enhance human potential and to cure diseases. Scientists face great challenges in maintaining the natural order of human race. Through readings from Peters' book, students would be introduced to genetic determinism and to scientists "playing God" in gene creation. Peters claims that genetic engineering can also enable scientists to participate in creating an ethical future. They are constantly challenged to preserve the image of God in a world perpetually changing with technological progress. Considered created with the image of God in us by Peters, humanity is also in a continuous process that should embrace genetic engineering but be aware of its moral implications. "We have been created by God. Yet, God created us to be creative. The creation is ongoing. Nature is dynamic…"[181] Addresses the

[180] Ted Peters, *Playing God? Genetic Determinism and Human Freedom*, 2nd Ed., (Routledge, 2003), xiii.

[181] Ibid., 214.

dilemma of gene engineering, Peters notes that genes are the product of divine creation, and altering the genetic code might be considered a violation of natural order and even God's creation: "Would we the creatures become our own creators? Would we be playing God? Is it a sin to play God when we in fact are not God?"[182] Following the same argument, Henk Van Den Belt argues that synthetic biology does not create new life as much as it is rewriting the DNA sequence the same way software designers write their programs. He notes "the "informatization" of the biological world may have a disenchanting effect on our view of life. Life itself is increasingly understood in terms of "information processing" or "computation," and cells and organisms are seen as computers that can be easily (re)programmed according to our wishes. Rather than evolving naturally, living beings then, become regarded as the product of deliberate design."[183] He also notes that humans are creative and always looking for ways to renovate, engineer, and even mimic nature to improve people's lives. "In other words, Nature has designed man to be a designer, just as in the eyes of the liberal theologians, the Creator has created man to be a co-creator. In both cases, man's creations, including synthetic life forms, will be considered natural and acceptable."[184] While synthetic biology is not considered to create new life, it still casts a shadow on how life is perceived and how artificial life forms will affect the meaning of life. Through such complicated issues, students can be exposed to ethical and thus ontological questions regarding human beings' nature. Peters' book may help students develop their own

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[182] Ibid., 1-2.

[183] Henk Van Der Belt, "Playing God in Frankenstein's Footsteps: Synthetic Biology and the Meaning of Life," *Nano Ethics* 3, no. 3 (December 2009): 259.

[184] Ibid., 264.

critical opinions about metaphysical questions that arise when discussing whether humans are determined only by their genes or by the environment, religion, and culture.

MISUSE OF GENETIC EDITING

The novel *Change Agent* takes genetic engineering to another fictional level. The plot emphasizes the role of a black market corporation that allows parents to genetically modify the DNA of their growing embryos for a hefty fee. Parents, in *Gattaca*, can pick their future child characteristics by editing the child's DNA. However, what was intended to ensure parents of healthy and superior children transformed into creating embryos for experimentation and human trafficking in *Change Agent*. The hero of the novel, an Interpol agent named Kenneth Durand, is genetically transformed when he was unknowingly injected with a synthetic change agent to genetically alter his appearance and transform him into the spitting image of the most wanted human-trafficking dealer. All of his genomic code will transform him over a period of time while he is in a coma and ultimately will end with his death. The struggle to find his identity beneath the physical corporal change highlights the importance of individual uniqueness although most of the human genome is the same in all people. The quest for identity forms a common ground in *Gattaca* and *Change Agent* as both protagonists search for their identity after being genetically altered.

Furthermore, Suarez invites his readers to ponder the following philosophical question: "Does one's identity come from within our hearts or our DNA?"[185] One response is provided by Durand, who allegedly went through the genetic transformation and finds that genetics are only

[185] *Change Agent*, 388.

data; human beings are identified and recognized according to their interaction with their environment and their peers. The hypothesis that humans are defined solely by their genes is criticized by those who argue that "any high school science student could tell you that biology's basic equation is $Phenotype = Genotype \times Environment$. That is, the fate of humankind isn't written entirely in genetic code. There's a lot to be said for our interactions with the world and people around us."[186]

Through the plot of *Change Agent*, students can learn about biotechnical arts "algeny" inspired by the emergence of biotechnology that Rifkin defined as "chang[ing] the essence of living things."[187] He notes that algeny is perfecting and improving an existing organism or creating a whole new one. The same concept is developed in the *Change Agent* novel, where embryos are enhanced and developed to fasten the evolution of human beings. Discussing DNA, students may learn that all living things have DNA as a base biological material that scientists could extract, recombine, and program into a series of sequence combinations. Students learn about DNA paternity tests that use genetic fingerprinting or cheek swabs to extract materials to determine someone's biological parents. Students can also learn about genetic tests that allow newborn screening to predict diseases such as Huntington's disease. For this purpose, genetic compatibility tests are performed on parents who wish to determine disease transmission probability to their offspring. For example, Beta Thalassemia disease can be detected by genetic

[186] Yasmin Tayag, "Re-Watching 'Gattaca' at the Dawn of the Age of CRISPR and Genetic Editing," *Inverse*, November 23, 2015, https://www.inverse.com/article/8443-re-watching-gattaca-at-the-dawn-of-the-age-of-crispr-and-genetic-editing (accessed October 2019).

[187] *The Biotech Century: Harnessing the Gene and Remaking the World,* 33.

testing as the disease can cause premature death if found in both alleles. Lynch Syndrome (colon cancer) is another inherited genetic condition that parents might pass on to their children. Genetic engineering, according to Rifkin, is the ultimate tool "to accelerate the natural process by programming new creations that […] are more efficient than those that exist in the state of nature."[188] Genetic engineering constitutes the future hope of humanity to improve and evolve nevertheless genetic engineering can also take darker turns and enlarge the gap between the rich and poor citizens.

Rifkin shares Peters' views regarding life creation. He argues that life cannot be an invention created by scientists and at the same time be considered a gift of God. However, both agree that gene-splicing techniques could effectively be used for therapeutic purposes to improve humans' condition. For example, reading difficulties, behavioral issues, and criminal activities could be classified as biological deficits that require medical intervention. Attention deficit disorder is considered an illness and could be treated as "the problem relies in the brain chemistry and genetic endowment of the [individual]…"[189] The power of genetic engineering and biotechnology grant scientists an ultimate tool to control the future lives of unborn babies by genetically enhancing their genes and therefore, create individuals partially hostage to their own genetically enhanced blueprints, while reducing environmental factors that might negatively impact the individual's personality. However, as Rifkin recounts, "altering genetic code seems more intimate and noble, less cold and inhuman, if it's thought of as an artistic exercise."[190]

[188] Ibid., 35.

[189] Ibid., 166.

[190] Ibid., 225.

Science fiction films that discuss new technological advancements in medicine bring to light interesting critical opinions regarding their impact and the way they are perceived by society. Futuristic insights provided by science fiction films could be helpful to prepare for future technologies to be implemented and accepted by society. For Kirby, science fiction films preview social concerns and interaction with science and new technological advancements. Students, according to biology professor Fatma Onen Ozturk, "who can develop the relationship between science, technology, and society will make a connection between science and daily life, understand scientific knowledge more easily and develop beliefs about achieving science classes in a positive manner."[191] She indicates that science fiction films have a positive influence on students' academic success especially in biotechnology and bioethics. She notes "that science fiction films develop people's skills of imagination, problem-solving, comprehension, using scientific processes, and science literacy."[192] Additionally, Pomidor notes that science fiction brings potential futures to life and highlights moral and ethical issues often overlooked during science courses. "Science fiction can inspire new achievements while warning of possible dangers, frame moral and ethical dilemmas in understandable terms, […] help make sense of a rapidly changing world by putting a human face on looming technical development."[193] With today's technological developments, the educational system and teaching programs need to be

[191] "The Impact of Science-Fiction Movies on the Self-Efficacy Perceptions of Their Science Literacy of Science Teacher Candidates," 1577.

[192] Ibid., 1598.

[193] "Essay: 'With Great Power…' The Relevance of Science Fiction to the Practice and Progress of Medicine," S14.

updated to provide students with adequate skills and knowledge to transform them into scientifically literate individuals.

After the industrial revolution and technological progress, biotechnology and genetic engineering have now created an existential revolution that questions societal values and the meaning of life. For example, Rosalyn Berne sheds light on the progress of biotechnology in allowing parents to pick their children's emotional and physical characteristics even before they are born. She also questions whether parents would enhance their children's mental capacities by using biochemical medication or by implementing biomedical devices in their brains. Recounting the tremendous possibilities biotechnology would provide, she feels that it is closer to science fiction than actual science. She explains that "the imaginative work of science fiction can serve to both predict and experiment with possible futures of our sociobiotechnical existence, extrapolating from the present into worlds yet to come, to be experienced directly by the reader [or viewer]."[194] Berne compares biotechnology to science fiction, and she considers biotechnology an experimental tool that explores different forms of life to enhance human capabilities and reduce suffering. More importantly, Berne considers science fiction as a wake-up call that "through its capacity to bring forth awareness of [biotechnological] social implications, science fiction can be important beacon for guiding the incredible creative endeavor of biotechnology."[195]

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[194] Rosalyn W. Berne, *Creating Life from Life: Biotechnology and Science Fiction* (Singapore, Pan Stanford Publishing Pte. Ltd., 2015), 7.

[195] Ibid., 8.

Biotech engineering will reshape the future of humanity and will impact the global economy through its significant influence on Earth's environment. By mastering genetic engineering, scientists will be able to create new forms of life that will propagate and reproduce within the biosphere. They will create new biological energy sources that may replace fossil fuels and help reduce climate change. One serious problem with advanced biological engineering, however, is who we entrust to perform this genetic engineering. Who will guarantee social equity and ensure fair distribution among members of society?

Science fiction films raise important ethical and philosophical questions that help students develop their imagination and consider the future of technology that will "force us to move beyond the boundaries our society has created."[196] It is not surprising to witness the incorporation of scientific discoveries in science fiction films and novels that highlight social debates about science and technology's progress on humanity. More boldly, Kirby claims that genetic enhancement is a controversial topic subject to criticism, but he also admits that instead of "questioning what makes us human, recent science fiction literature takes the opportunity to ask: What will make us posthumans?"[197] With technology and great enhanced abilities, humanity will go a long way in solving environmental problems such as climate change mitigation, drought and agricultural scarcity.

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[196] José Van Dijck, "Cloning Humans, Cloning Literature: Genetics and the Imagination Deficit," *New Genetics and Society* 18 no. 1 (1999): 21.

[197] "The Devil in Our DNA: A Brief History of Eugenics in Science Fiction Films," *Literature and Medicine* 26, no. 1 (2007): 105.

In the following chapter, I will discuss issues of climate changes viewed through the lens of science fiction that introduces new biotechnological approaches that mimic natural design to reduce environmental warming and save the Earth.

CHAPTER 3

CLIMATE CHANGE THROUGH THE LENS OF SCIENCE FICTION

While this chapter was being written, the Tropical Storm Ida hit Louisiana, with sustained speed of 145 mph and 15 to 20 inches of rainfall and it made its way to the northeast to New York where Governor Kathy Hochul declared a state of emergency. This hurricane is one of many examples of natural disasters being encountered. On the west coast of the United States, wildfire devastated a huge part of California and forced thousands of people to evacuate their homes. Flood on the East Coast and fire and drought on the West Coast warn of an unsafe and unstable environmental future. Planet Earth is experiencing natural changes that some scientists attribute to climate change; others believe it is the normal cycle that Earth goes through. To shed light on the effect of climate change on the planet and specifically on humans' health, Adam Solomons reports that melting ice could cause a reoccurrence of rare diseases such as anthrax, tetanus, and smallpox. Leading biologist Anirban Mahapatra mentions in "Next Global Pandemic Could be Hidden in Melting Ice"[198] that "rotten corpses and animal carcasses infected with lethal diseases could cause the next global pandemic" when the Arctic ice sheets melt and glaciers recede, and consequently release diseases preserved within the ice sheets which can be contagious and infect every living creature. In Siberia, cases of anthrax have been traced back

[198] Adam Solomons, "Next Global Pandemic Could be Hidden in Melting Ice," The DailyStar.co.uk, August 7, 2021, https://www.dailystar.co.uk/news/latest-news/next-global-pandemic-could-hiding-24705011 (accessed August 30, 2021).

"to the 2,300 rotting reindeer carcasses contained in melting Arctic permafrost- or frozen soil."[199] The main problem is climate change.

Fictional narratives enable student-readers' imaginations to assess what social and behavioral changes may be needed to address the apocalyptic predictions of ecologists. Appealing to the power of human imagination, fictional works enable us to visualize new possibilities for actual problems. "The human imagination drives the world. Understanding the imagination is no longer a pastime or even a duty but a necessity, because increasingly, if we can imagine, we'll be able to do it."[200] Most science fiction works portray a future world that suffers from an imminent crisis either due to extraterrestrial invasion, genetically engineered diseases or natural disasters requiring urgent solutions. Rebecca Evans argues that "climate fiction comes clad in optimism about the ability of popular literature and film to build scientific literacy and eco-political engagement. Whereas scientific data can be dry and incomprehensible to non-experts […], climate fiction has the potential to sidestep this quandary, using the entertaining power of narrative both to instruct and to galvanize its readers."[201] For Evans, science fiction climate change stories envision possible futures by relying on historical events that contribute to the developments of those futures. She argues that Anthropocene science fiction can promote readers' thinking beyond the boundaries and help them rethink the present while engaging in

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[199] "Next Global Pandemic Could be Hidden in Melting Ice."

[200] Margaret Atwood, *The Handmaid's Tale* p. 517 cited in Gesa Mackenthun article "Sustainability Stories: Managing Climate Change with Literature," p.1 *Sustainability (Basel, Switzerland)* 13, no. 4049 (2021April 2021 https://doi.org/10.3390/su13074049 (accessed June 2021).

[201] Rebecca Evans, "Nomenclature, Narrative, and Novum: 'The Anthropocene' And/as Science Fiction," Science Fiction Studies 45, no. 3 (2018): 484.

discursive debate about climate change. “It (Anthropocene science fiction) estranges us from our expectations and experience of reality; it demands the cognitive logic of extrapolation as we ponder the future that is to come.”[202]

Science fiction authors are often devoted to finding solutions for real-life problems, warning society, and expanding scientific knowledge. One such urgent and immediate action may be decarbonizing the industrial economy by implementing new and advanced technological infrastructure with the population’s consent. Industrialization has devastated many places, and its consequences on the planet’s future are still impactful. Floods, hurricanes, cyclones, earthquakes, and deforestation are real threats. Even animal and plant species are affected by climate change. Literary works can both emotionally and intellectually shape human potential to respond to problematic social issues and make changes. The authors picked in this chapter to present their work about climate change such as Michael Crichton, Naomi Oreskes, Roy W. Spencer and Brian Clegg, each have a different explanation of why planet earth is warming up. For some, climate change is a myth as they believe that the Earth goes through a natural cycle from cooling to warming and vice-versa. Scientists name this phenomenon Earth’s Natural Climate Pulse. Professor David Dilley, senior research scientist and CEO of Global Weather Oscillations, Inc. (GWO), developed the idea of the Earth’s Natural Climate Pulse to explain the earth’s warming and cooling cycle as he defends his theory of Earth’s cycle of cooling weather that goes back two hundred and thirty years. His research “shows that global warming cycles like what we have been experiencing occur approximately every 230 years. There have been 6 global warming

[202] Ibid., 490.

cycles since the year 900 AD, with the ending of each warming cycle being followed by a long-term global cooling cycle. Earth is currently transitioning out of Global Warming Cycle #6 and entering Global Cooling Cycle #6."[203] To give examples of his theory, he claims that winters of 2019-2020 and 2020-2021 experienced milder temperatures as the cold Arctic Vortex hit several regions around the world and stretched from Alaska to Greenland, passing by Central Canada. In Texas (in the United States), the Arctic blast of winter cold had a dangerous impact on the state as it had not experienced such cold in more than a century. Dilley relates what is happening to the Earth's electromagnetic Climate Pulse Cycle. He explains that global warming #6 took twenty years to reach its peak in 2020 and 2021 and now Earth will take another ten years for the global cooling #6 to be recognized. It will reach dangerously cold temperatures between 2030 and 2050s according to Dilley. As Dilley mentions in his video presentation, global cooling will be much worse than global warming because cold and freezing temperature will cause shorter growing seasons and consequently shortage of food supplies which lead to famine. (https://www.globalweatheroscillations.com/videos--lectures-and-presentations).

To understand the conflict behind climate change, students should learn about the solar cycle and its effect on Earth. As Jamie Carter, an experienced science, technology and travel journalist argues: the Sun's new cycle "is running ahead of schedule — and that could mean it [is] hitting "solar maximum' much earlier than previously predicted."[204] According to Carter, in

[203] David Dilley, "2022 Winter Outlook: United States- Canada- Alaska," *Global Weather Oscillations*, (March 17, 2021), https://www.einpresswire.com/article/536940319/2022-winter-outlook-united-states-canada-alaska (accessed June 6, 2021).

[204] Jamie Carter, "The Sun Could Reach 'Solar Maximum' Just at the Right Time for North Americans," *Forbes* (April 21, 2021), https://www.forbes.com/sites/jamiecartereurope/2021/04/21/why-the-sun-at-its-most-potent-could-now-be-set-to-give-north-americans-a-precious-naked-eye-moment/?sh=452e91f9261a (accessed June 19, 2022).

April 2021, solar scientists predict that solar maximum will take place between November 2024 and March 2026 as the sunspots will reach their maximum and thus announcing the approach of Cycle 25. In addition, a recent publication by Nasa on July 27, 2022, confirms the high activity of the solar system that continues "to increase as we near solar maximum in 2025."[205] To add more explanation on how the activity of the Sun could predict the next climatic cycle on Earth and to prove that the Earth is entering a cooling phase, Professor Valentina Zharkova of Britain's Northumbria University published her research online August 2020 in which she revealed remarkable findings when researching and studying the sunspots which directly affect the solar radiation emitted toward the earth and the earth's climate. The research found that "solar activity, based on models that closely fit past trends, looks to be headed for a sharp downward turn. Indeed, activity could decline to levels not seen since the so-called "'Little Ice Age,' an unusually cold period that stretched across the Northern Hemisphere and lasted from roughly 1650 to 1850."[206] This period is referred to as the "Maunder Minimum." Zharkova explains in her recent presentation that the solar magnetic field activity is reducing, which allows to Super Grand Solar Minimum to take place. According to Zharkova, the Grand Solar Minimum "are prolonged periods of reduced solar activities, and in the past have gone hand-in-hand with times of global cooling."[207] The data of cooling temperature collected from 1645 to 1710 by Zharkova

[205] Abbey Interrante, "Solar Cycle 25 is Exceeding Predictions and Showing Why We Need the GDC Mission," *Nasa blogs* (July 27, 2022), https://blogs.nasa.gov/solarcycle25/2022/07/27/solar-cycle-25-is-exceeding-predictions-and-showing-why-we-need-the-gdc-mission (accessed September 25, 2022).

[206] "Global Warming Extremists Try to Silence Science- Again," Editorials (August 11, 2016), https://www.investors.com/politics/editorials/global-warming-extremists-try-to-silence-science-again (accessed April 15, 2021).

[207] Cap Allon, "Professor Valentina Zharkova Breaks Her Silence and Confirms 'Super' Grand Solar Minimum," Electroverse: Documenting Earth Changes During the Next GSM and Pole Shift, November 6, 2018.

reveals that the terrestrial temperature will enter the phase of cooling era due to solar reduction activity. As noted in her study, the Northern Hemisphere of the Earth entered in "a deep freeze [where] alpine glaciers extended over valley farmland; sea ice crept South from the Arctic; Dunab and Thames rivers froze regularly during these years as well as the famous canals in the Netherlands."[208] The cooling phenomenon, as Zharkova argues, is related to less radiation emitted by the Sun and an abundance of ultra-violet light that prohibited the formation of ozone which affected the atmosphere of the terrestrial planet. Another contributor to climate cooling during the Maunder Minimum was the reduction of solar magnetic field "that control[s] the level of cosmic rays reaching planetary atmospheres of the solar system, including the Earth."[209] Her study shows that "the sun's interplanetary magnetic field [is] down to only 4 nanotesla (nT) from typical value of 6 to 8 nT."[210] Terrestrial temperature will consequently decrease during the modern grand solar minimum as planet's atmospheres will be affected by the intensity of cosmic rays. Zharkova believes that the immediate cooling temperature will not be observed and noted now, but it will take several years to drop and reach low degree. The reduction of solar activity consequently reduces the solar radiation and therefore drops the Earth's temperature by up to 1.0 ^{0} C throughout the next thirty years.

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https://electroverse.net/professor-valentina-zharkova-breaks-her-silence-and-confirms-super-grand-solar-minimum (accessed October 2020).

[208] Valentina Zharkova, "Modern Grand Solar Minimum Will Lead to Terrestrial Cooling," *Taylor Francis Online*, August 4, 2020, https://doi.org/10.1080/23328940.2020.1796243 (accessed November 2020).

[209] "Modern Grand Solar Minimum Will Lead to Terrestrial Cooling," *Taylor Francis Online*, August 4, 2020, https://doi.org/10.1080/23328940.2020.1796243 (accessed November 2020).

[210] Ibid.

This conclusion is also reached by climate scientist Drew Shindell who acknowledges that "changes in the stratosphere influence weather patterns"[211] as he observed the paleoclimate temperatures of the Maunder Minimum recorded between 1650 and 1710. The same findings lead scientists to question the influence of solar activity on terrestrial climate, including oceans' temperature and volcanic eruptions. The whole planetary system seems to be influenced by the solar cycle pattern that Zharkova, Dilley and Shindell describe in their observations. In contradiction to what is stated above, NASA Global Climate Change rejects the hypothesis of cooling terrestrial temperature due to the Maunder Minimum and argues that if a Grand Solar Minimum is happening, "it would only serve to offset a few years of warming caused by human activities"[212] as scientists consider the Earth's warming caused by human greenhouse emission "is six times greater than the possible decades-long cooling from a prolonged Grand Solar Minimum."[213] The United Nations' Intergovernmental Panel on Climate Change (IPCC) claims that satellites monitoring the Sun activity for over 40 years and the fluctuation of the Sun's energy output recorded up or down by 0.1 percent are not enough to impact Earth's climate. The conflicting data about climate change as discussed above creates a serious controversy among scientists that could influence the general public and engender negatives echoes in other fields.

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[211] Nasa Earth Observation, "Chilly Temperature During the Maunder Minimum," https://earthobservatory.nasa.gov/images/7122/chilly-temperatures-during-the-maunder-minimum (accessed April10, 2021).

[212] Nasa Global Climate Change, "There Is No Impeding 'Mini Ice Age,'" Nasa Global Climate Change Blog, entry posted February 13, 2020, updated September 1, 2021, https://climate.nasa.gov/blog/2953/there-is-no-impending-mini-ice-age (accessed May 5, 2021).

[213] Ibid.

CLIMATE CHANGE IN FICTIONAL NARRATIVES

Climate change theories are represented in fictional narrative. Some science fiction authors believe that climate change is a natural phenomenon, other consider it man-made. To help students understand the complexities of climate change, I will discuss a selection of science fiction novels and scientific documentaries that show different points of view from those who support the idea that Earth is experiencing a natural cycle of climate change versus those who claim that humans' activities have contributed to global warming.

In science fiction stories and films, scientific and technological advances are combined to highlight humans' ability to recognize current obstacles and think creatively to solve them. Luokkala argues that "our future will depend not only on the kinds of scientific and technological discoveries that might be made, but on the decisions that are taken, concerning what research projects to fund or not to fund, and how the newly discovered information or newly developed technology will be used."[214] Luokkala claims public perception and understanding of science is crucial in decision-making, and an inadequately educated public will crucially miscomprehend scientific topics and will negatively impact society.

Climate change has become a heated topic among scientists, and it definitely interests science fiction authors who write abundantly about the subject either to pinpoint the danger that the environment is encountering due to human activities or to argue for a contradictory point of view focusing on natural earth cycles that may contribute to such change. Many works of "cli-fi" broaden the description of climate change with the political and scientific discourse that

[214] Barry Luokkala, *Exploring Science through Science Fiction* (New York: Springer, 2014), 156.

amplifies the gap between advocates and opponents. Emanuel Herold and colleagues argue that "the utilization of scientific scenarios and fictional speculations as ways to conceive, visualize, and cope with uncertain possible futures"[215] provides students and the general public a dramatization of climate change. For example, readers can use "cli-fi" novels to assess and compare scientific evidence with the fictional plot and identify political and socioeconomic effects throughout the process. Uwe Schimank and Sonja Fücker (University of Bremen) noted, according to Herold, "that reading-group discussions of 'cli-fi' novels influence readers' pre-existing understandings of climate change when the novels comply with their conditions for plausible story-telling and tell stories that are embedded in actual societal discourses."[216]

In his book *Ten Billion Tomorrows* (2015), Brian Clegg discusses several technological advancements such as learning while sleeping to improve memory retention. However, his main concern remains climate change and its effect on the environment. He explains that the climate change theme in science fiction can portray natural disasters occurring with the return of an ice age that stretches down to cover the continents, freezes the crops, and floods agricultural fields. But the human race is encountering a deep existential threat, according to Clegg, as global warming is rapidly increasing the Earth's surface temperature. As a result, Clegg notes that the continuing rise of temperature will surely melt the Greenland ice sheet and make sea levels rise by 23 feet. At this pace, the Antarctic ice cap melting will raise sea levels by 200 feet, and

[215] Herold Emanuel, Sina Farzin, and Susan M. Gaines, "Between Fact and Fiction: Climate Change Fiction," *Science-fiction studies* 43 no.3 (2016): 610.

[216] Ibid., 610.

"Climate change would have a massive impact on everything from agriculture to the availability of fresh water."[217]

Mark LaRochelle and Peter Spencer disagree with Clegg's assessment and they explain that climate temperature is not accurately recorded and only weather satellites can provide global data of oceans, lands, and poles. This data shows no warming of air or water temperature. Other devices such as weather balloons with radiosondes support the satellites and show no warming. LaRochelle and Spencer argue "that there is considerable uncertainty in current understanding of how the climate change system varies naturally. […]. Uncertainty remains because of the level of natural variability in the climate system on time scales of decades to centuries."[218] Scientists need to constantly evaluate and compare their weather data, make assumptions, maintain an accurate explanation of the uncertainty of climate change. They need to explain their hypothesis and research data simply and easily so students and the general public understand their arguments.

Alexandra Nikoleris and her colleagues believe that climate fiction narration helps readers identify with the protagonists, and through those stories, "climate futures become close and personal rather than distant and abstract."[219] Exploring possible scenarios of the future helps readers envision alternative strategies to better prepare for these changes. For Nikoleris et al,

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[217] Brian Clegg, *Ten Billion Tomorrow: How Science Fiction Technology Became Reality and Shapes the future* (New York, N.Y: St. Martin's Press, 2015, 140-141.

[218] Mark Larochelle and Peter Spence, "Global Warming Science; Facts vs. Fiction," *Consumers' Research Magazine* 84, no. 7 (July 1, 2001): 13.

[219] Alexandra Nikoleris, Johannes Stripple, and Paul Tenngart, "Narrating Climate Futures: Shared Socioeconomic Pathways and Literary Fiction," *Climatic Change* 143, no. 3 (2017): 307.

scientific and literary scenarios both rely on narration to tell stories about climate change and how to adapt or mitigate to survive warming temperatures. They claim that the presentation and debate of possible solutions through fictional narrative gives students accurate and specific knowledge that helps them grow their interest and gain experience with such topics. According to Nikoleris, "doing something about climate change could be the start of exploring new ways of organizing a society and other ways of being human."[220] Identifying with the protagonist and experiencing the potential scenarios provided in the narration of climate change may promote personal reflections and closer engagement with global and local interconnections that explain how climate change is affecting readers' lives.

Despite conflicting opinions about climate change and the impact of warming or cooling temperatures on various parts of the planets, including plants, agriculture, and food provisions and supplies, we need a complete and thorough reform of sustainable strategies to maintain an adequate temperature that helps life continue on Earth. Climate change impacts the way we live, and how we eat, but mainly it deepens the disparity among those who believe that Earth warming is due to greenhouse emission and those who argue that the Earth goes through a climatic cycle. The next generation is encouraged to find solutions for many existing problems and be prepared for future, yet invisible ones. Conceptualization of climate fictional narratives will allow students to perceive the fate of the planet to mitigate or adapt to escape fatal disaster. As described by Gesa Mackenthun, fictional narration sheds light on social and ecological understanding that affects "behavioral change in recipients' minds: exemplary ecologically sustainable characters

[220] "Narrating Climate Futures: Shared Socioeconomic Pathways and Literary Fiction," 316.

and actions, […], cooperative communities, sources of epistemological innovation and spiritual resilience, and an ethics and aesthetics of repair."[221] Today, according to Mackenthun, imagination in fictional narration can lead the world as "imagination is no longer a pass time or even a duty but a necessity, because increasingly, if we can imagine something, we'll be able to do it."[222] Therefore, imagining a holistic change at the infrastructure level to mitigate global heating would be necessary and required to survive in the future. Kim Stanley Robinson wrote his novel *New York 2140* (2017) with the intent to create innovative reform that enables readers to envision the ecological future and find ways to promote the economy. According to Mackenthun, fictional and non-fictional narratives that generate confidence in humanity's ability to shape an ecologically and socially sustainable future are an integral component of rebuilding the global economy."[223]

Renewable energy technologies have contributed major breakthroughs, but unfortunately, polarized politics and the lack of investment capital in renewable energy make the shift from fossil fuels difficult to abandon. Loss of confidence in the federal and state governments leads communities to self-regulate and organize to mitigate and adapt to climate change. In this case, community members need to have enough scientific background and knowledge about the issue to enable them to be well prepared and engaged in the process of adaptation.

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[221] Gesa Mackenthun, "Sustainable Stories: Managing Climate Change with Literature," *Sustainability (Basel, Switzerland)* 13, no. 4049 (2021): 1.

[222] Ibid., 1.

[223] Ibid., 19.

Lianne Lefsrud and Renate Meyer in "Science or Science Fiction? Professionals' Discursive Construction of Climate Change" (2012) describe the deep chasm between The Intergovernmental Panel on Climate Change (IPCC) proponents who believe that climate change is the result of human activities and climate change sceptics who consider climate change to be caused by natural effects. They argue that professional experts in the domain of climate science are required "to establish the general perception in their audiences that (a) they are making informed claims based on their superior access to specialists' knowledge; and (b) that they are independent and their claims are objective and not driven by particularistic interests."[224] Most skepticism of anthropogenic climate change seems to be well ensconced among professional experts "who work as leaders or advisors to management in governmental, non-governmental, and corporate organizations."[225] The entanglement between climate science, political interests, and economic benefits from the petroleum industry makes it more difficult to reach a consensus that would avoid climate change challenges.

Risks of climate change are not limited to tornadoes, sea rise levels or drought, but include risks of population displacement, lower-income, poverty, and the surge of terrorist groups that take advantage of chaotic areas to develop and expand their power. To clarify the debate on the intricacies of climate science, Lefsrud and Meyer noted in their study that experts, specifically in North America, either considered anthropogenic causes for climate change or thought climate change a fraud and a hoax due to their political and economic interests. Some

[224] Lianne M. Lefsrud and Renate E. Meyer, "Science or Science Fiction? Professionals' Discursive Construction of Climate Change," *Organization Studies* 33, no. 11 (2021): 1481.

[225] Ibid., 1497.

experts support the Kyoto protocol and believe in regulating greenhouse gas emissions to prevent the risks of climate change on public life.[226] Others consider the change is due to the natural and normal phase of the Earth's cycle. Anthropogenic advocators state: "humans are too insignificant to have an impact on nature: It is a mistake to think that human activity can change this…"[227] and conclude that climate change is science "fiction," it is not real and they believe that issues such as famine, health, and infectious diseases are more persistent issues that need immediate attention.

Other experts, according to Lefsrud and Meyer, refute both assumptions and argue that climate change and natural events are both uncontrollable. These experts are also less likely to support the IPCC and the Kyoto Protocol, believing that they will harm the economy. Even though this group of experts encourages regulation of greenhouse gases emissions, the growth of the economy remains at the top of their priorities, although "[t]hey invoke the public interest and the need to promote an informed debate and to educate others, and recommend enhancing efficiency and competitiveness."[228]

In the twenty-first century, most wealthy countries (in contrast to developing ones that struggle to provide safe water and healthy living conditions) focus on the educational and health well-being of their human citizens. Increasing investments in education and health help grow a country's economy. To successfully recruit students into climatology, science fiction works

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[226] Kyoto Protocol is an International treaty operated by the United Nations Framework Convention on Climate Change that binds developed countries to reduce greenhouse gases emissions by adopting policies and measures to mitigate the risk of global warming.

[227] "Science or Science Fiction? Professionals' Discursive Construction of Climate Change," *Organization Studies* 33, no. 11 (2021): 1493.

[228] Ibid., 1493.

could help students learn about climate change and its consequences on environmental and social levels. Therefore, using science fiction to spread climate change awareness in academic and public settings would increase scientific knowledge so that individuals could make better decisions about fossil fuels consumption and greenhouse emissions. In order to globally mitigate climate change effect, wealthy countries have a huge responsibility towards developing countries to create funds to educate people and provide resourceful materials to spread scientific knowledge which help create healthy and sustainable conditions to keep the planet safe.

"Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development."[229] The investment and growth of the global economy is taking place at the expense of climate change. Lack of environmental concern about warming temperature, drought, storms, tornadoes, and rising sea levels do not prevent big capital and powerful politicians from wielding their power to promote investments in fossil fuel companies. This makes it harder on scientists, climate advocates, and general public to reach a unified decision to cut off fossil fuel usage and invest in renewable energy. More in-depth understanding of climate change issues needs to be researched, shared with the public and taught in high schools to help the next generation of students find solutions and create sustainable, effective, global strategies related to climate change risks.

[229] Brian C. O'Neill and al., "The Roads Ahead: Narratives for Shared Socioeconomic Pathways Describing World Futures in the 21st Century," *Global Environmental Change* 42 (January 2017): 174.

CLIMATE CHANGE: FICTION OR FACT

The novel *State of Fear* (2004) written by Michael Crichton, depicts how the misrepresentation of climate science facts initiates public fear about anthropogenic climate change and forces petroleum industries to shift from fossil fuel consumption to renewable energy. The plot revolves around a terrorist group that is planning to create a geo-engineered tsunami during a climate change conference to convince the public of the danger of climate change and "to keep resources flowing to their cause. Ecoterrorism […] is presented in the novel as a tactic designed to silence skepticism about whether climate change deserves to be high on the political agenda."[230] The group is "trying to break off an iceberg to coincide with the conference. [To] arrange an event with good visuals that reinforces the point of the conference."[231] Crichton portrays climate change from a political point of view that exploits the public's fear of environmental changes to keep political agendas funded and guarantee political power. Controversial opinions and theories about climate change create a chaotic situation for scientifically illiterate citizens. He considers his novel as a medium through which he can represent a different point of view about climate change using narration with easy-to-understand vocabulary. *State of Fear* is regarded by Joanna Radin not "as a piece of science denialism but rather a meta-fictional commentary on the politics of truth …"[232] Public understanding of such

[230] Joanna Radin, "Alternative Facts and States of Fear: Reality and STS in an Age of Climate Fictions," *Minerva (London)* 57, no. 4 (2019): 417.

[231] Michael Crichton, *State of Fear: A Novel*, 1st. ed. (New York: Harper Collins Publishers, 2004), 244.

[232] Ibid., 418.

scientific dilemmas are critical in future conversations about whether to fund scientific programs or support governmental programs.

Crichton describes realistic scientific details in his narration to promote the plot and give credibility to his story. For example:

> In Iceland the first half of the twentieth century was warmer than the second half, as in Greenland. […], most glaciers lost mass after 1930 because summers warmed by .6 degrees Celsius, but since then the climate has become colder. The reality is that since 1970 these glaciers have been steadily advancing. They have regained half the ground that was lost earlier. Right now, eleven are surging.[233]

To demonstrate the controversial political disagreement and the denial of climate change, Crichton acknowledges that "there are disinformation groups funded by industry —petroleum, automotive — who will seize on the report that some glaciers are growing, and use it to argue against global warming. That is what they always do. They snatch at anything to paint a false picture."[234] In the novel, Crichton includes many charts, graphs (extracted from the actual database of National Oceanic and Atmospheric Administration), footnotes from actual scientific articles such as "Global Warming and the Greenland Ice Sheet" (2004), an annotated bibliography and a non-fictional appendix to help students investigate further in this topic and evaluate the data provided to reach their own conclusions about the rigorous and continuous debate.

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[233] *State of Fear: A Novel*, 47.

[234] Ibid., 49.

Crichton gives specific facts and descriptions of locations experiencing climate change issues to situate the narration in a credible context. For example, he states that:

> More disturbing was the paper on the increase in ice thickness in the Ross Ice Shelf. Here Evans (a fictional character in the novel playing the role of a lawyer who manages the legal affairs of George Morton, an environmental philanthropist in the novel) found some troubling news. First, the author did say that the shelf had been melting for the last six thousand years, ever since the Holocene era. […]. If that were true, it wasn't exactly news. On the contrary, the author suggested that the real news was the end of this long term melting trend, and the first evidence of ice thickening. The author was hinting that this might be the first sign of the start of the next Ice Age.[235]

More evidence of climate change is added to the plot to make readers think about the issue and try to find solutions as Crichton's narration is based on scientific examples and explanations. He relates this information through the fictional experiences of Peter Evans, who hears on the local news two co-anchors announcing the following information: "two new developments emphasize once again the dangers of global warming. The first study, out of England, says global warming is literally changing the rotation of the Earth, shortening the length of our day. […] … even more dramatic was a study that showed that the Greenland ice cap was going to melt entirely away. That would cause sea levels to rise twenty feet."[236]

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[235] *State of Fear*, 200-201.

[236] Ibid., 264.

Crichton also recounts conflicting opinions about the reality of climate change. He states that in the 1970s, climatologists believed that a new ice age era was coming, but explains that this assumption was rejected "once the notion of global warming was raised, they immediately recognized the advantages. Global warming creates a crisis, a call to action. A crisis needs to be studied, it needs to be funded, it needs political and bureaucratic structures around the world."[237]

Crichton asks serious and critical questions that help readers to investigate the accuracy of scientific information provided in the novel. For example, Crichton evokes the difference in temperature records between New York City and Albany even though these two cities are close to each other. However, comparing the temperature of these two cities does not reflect an accurate result as large cities have different microclimates than smaller ones and many other factors are to be considered. Yet, Crichton mentions significant factors that increase temperature warming due to the urban heat island effect that contributes to warming temperatures. Is the urban heat effect related to global warming or is it only a local effect? Are the temperature measurements recorded around the globe accurate enough to decide on global warming? "How do you know that the dramatic increase in temperature in New York is caused by global warming, and not just from excess of concrete and skyscrapers?"[238] In the novel, the warming temperature that is causing climate change is triggered due to expansion of cities and urbanization. Clyde Freeman Herreid uses *State of Fear* as a case study to teach his college students the process of scientific inquiry in science. To prepare his students to study global

[237] Ibid., 316.

[238] Ibid., 383.

warming, Herreid asks his students to list all indications of global warming. Then, students had to evaluate the novel's scientific data accuracy. "As they worked their way through the graphs, students noted that the evidence supported the view that small changes in the gas composition of the atmosphere were occurring and that global temperature was rising slightly."[239] In addition, students supported Crichton's narration that humans are not responsible for climate change due to the inability to check the accuracy of climate change data such as sea level rising, melting of ice cap, CO_2 contribution to rising temperature, and other factors.

To add more suspense to the narration, John Kenner, one of the novel's fictional international law enforcement agents, explains how the threats of climate change can impact the world. He names a few such as "crop failures, spreading deserts, new diseases, species extinction, all the glaciers melting, sea-level rise, extreme weather, tornadoes, hurricanes, El Niño events in fashion, etc."[240] However, Crichton argues that ecologists have dropped the notion of "the balance of nature"[241] and now they support nature's dynamic disequilibrium, which means that "nature is never in balance. Never has been, never will be."[242] In addition, the conversation between Evans and Professor Norman Hoffman, presented as professor of the "ecology of thought" by Crichton, contributes to the belief that humans have never disrupted the natural order of the environment and they are too small to have any impact on nature.

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[239] Clyde Freeman Herreid, "Using Novels as Bases for Case Studies: Michael Crichton's *State of Fear* and Global Warming," *Journal of College Science Teaching* 34, no. 7 (2005): 11.

[240] *State of Fear*, 452.

[241] Ibid., 453.

[242] Ibid., 452.

However, some events narrated by Crichton in the novel cast doubt on his views about global warming. Some of these events lead to public misconceptions as they depict controversial points of view compared to IPCC revelations of global warming. For example, Crichton uses some graphs and charts with data that do not conform to global warming trends and presents suspicious information that contradict factual information recorded by climate scientists. The reason for cooling in some areas as Crichton describes it in his narration is to prove that global warming is a lie and that the increased emission of carbon dioxide (CO_2) into the atmosphere has nothing to do with warming temperature. "Shifts in clouds, water vapor, and the great currents in the ocean and air, […] cause complex responses in which some regions warm more than the average while others warm less than the average, or even cool."[243] Therefore, Crichton claims, the cooling in the Antarctic is nonetheless the effect of greenhouse gas emissions. Another scientific explanation for the climate's warming and cooling trends is based on sulfur dioxide emissions. The explanation states that emissions cool down the temperature as sulfur dioxide emissions convert into sulfate aerosols that reflect the sun's radiation which then creates a balance with the CO_2 emissions to reduce earth's warming.

CLIMATE CHANGE: DYSTOPIAN OR UTOPIAN FUTURE

Despite Crichton's discussions of science, Naomi Oreskes and Erik M. Conway, authors of *The Collapse of Western Civilization: A View from the Future* (2014), accuse Crichton of downplaying the role of science in climate change consensus. Oreskes fears "that the use of facts in fictional contexts could compromise efforts to introduce regulation intended to stem climate

[243] Brenda Ekwurzel, "Crichton Thriller State of Fear," *Union of Concerned Scientists* (July 16, 2008), https://www.ucsusa.org/resources/crichton-thriller-state-fear (accessed June 20, 2021).

change."[244] Oreskes, a professor of the History of Science, wrote her novel on science-based knowledge to help students and laypeople be aware of anthropogenic activities that might have dangerous consequences on the future of the planet and humanity. The book is a combination of science and history that helps readers explore possible potential futures based on actual facts that portray the future. The novel depicts a Chinese "historian" who blames scientists in the year 2093 for not mitigating climate change knowing the data collected throughout several years. The world imagined by Oreskes and Conway is undergoing severe threat by climate change, where social and political institutions collapse and scientists fail to address the issue by providing biased opinions based on the funding received or the political party that they serve: "Dramatizing the science in ways traditional nonfiction cannot, the book reasserts the importance of scientists and the work they do and reveals the self-serving interests of the so-called 'carbon combustion complex' that has turned the practice of science into political fodder."[245] Oreskes and Conway take advantage of fictional narration to promote their scientific knowledge to the general public and share their speculations about climate change observations from a scientific point of view. They acknowledge the consequences of climate change on humans, especially through disease spread and forced displacement.

In *The Collapse of Western Civilization*, Oreskes and Conway report accurate data about climate change with specific dates and locations to ensure sharing scientific facts with their readers to initiate their sense of curiosity and investigation. For example, "[i]n 2010, record-

[244] "Alternative Facts and States of Fear: Reality and STS in an Age of Climate Fictions," 423.

[245] Columbia University Website, https://cup.columbia.edu/book/the-collapse-of-western-civilization/9780231169547 (accessed August 14, 2021).

breaking summer heat and fires killed more than 50,000 people in Russia and resulted in more than $15 billion (in 2009 USD) in damages. The following year, massive floods in Australia… In 2012, which became known in the United States as the 'year without a winter,' winter temperature records, […] were shattered…"[246] Based on information through the national weather website https://www.weather.gov/iwx/2012_winter, the information is accurate and reliable. According to Oreskes and Conway, greenhouse gas emissions are another factor that increases warm temperatures. They argue that "365 billion tons of carbon had been emitted to the atmosphere from fossil fuel combustion and cement production. Another 180 were added from deforestation and other land use changes."[247] Climate plays a crucial role in determining the distribution of species and vegetation on geographic maps. An increase in temperature will jeopardize the lives of species not able to adapt quickly to the rate of warming temperatures. This leads to biodiversity loss and even extermination due to habitat deterioration by fire: "…These habitats are expected to decrease in size, leading to populations that are more isolated and to higher probabilities of extinction over time."[248] Moreover, ocean acidification caused by the uptake of CO_2 reduces the amount of pH in water impacting oceanic species. Consequently, it will affect the fish industry and food supplies: "… shellfish struggle because this acidification makes it more difficult for them to form their shell. Since shellfish account for almost half of the

[246] Naomi Oreskes and Erik M. Conway, *The Collapse of Western Civilization: A View From the Future* (New York: Columbia University Press, 2014), 8.

[247] Ibid., 18.

[248] Jay R. Malcolm and Louis F. Pitelka, "Ecosystems and Global Climate Change," *Center for Climate and Energy Solutions* (December 2001), https://www.c2es.org/document/ecosystems-and-global-climate-change (accessed April 19, 2021).

state's industry, this could have both economic as well as ecological consequences."[249] Students interested in marine biology and the impact of climate change on oceanography could further research the topic, learn about marine organisms' behavior and their reaction to oceans' temperature variation. They could brainstorm new ideas that could save or minimize the risks of climate change on marine organisms.

Oreskes and Conway acknowledge the importance of producing compelling scientific information and communicating effectively to students and laypeople to avoid disaster. Oreskes notes that "fiction gives [us] more latitude, and here we try to use that latitude in interesting and thought-provoking ways, but always with the goal of being true to the facts: true to what science tells us could really happen if we continue with business as usual…"[250] The continuous threat of climate change described in the novel reveals the battle between global warming's impacts and the political and economic agenda of those protecting their current prosperity. By introducing students to *The Collapse of Western Civilization*, teachers could spur dialogue about the changes and actions that need to be applied to diminish the impact of climate change.

While the novel assumes that climate change will increase and spread, no solutions are offered by the authors to help mitigate or minimize the impact of global warming. Natural disasters are already hitting several regions around the globe, shifting from flood disasters to wildfires catastrophes, drought, and agricultural problems. "In terms of anthropogenic climate

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[249] Megan Hall, Alina Kulman and Colleen Keenan, "How Will Ocean Acidification Affect Fish Populations and the Fishing Industry?" *The Public Radio Podcast* (January 20, 2020) https://thepublicsradio.org/episode/what-is-ocean-acidification-and-how-will-it-affect-fish-populations-and-the-fishing-industry- (accessed August, 18, 2021).

[250] *The Collapse of Western Civilization: A View from the Future*, 66.

change, the precautionary principle is moot. Precautions are taken in advance of damage, not after it has already begun. We have overwhelming evidence that we have already triggered a rapid rate of oceanic and atmospheric warming."[251]

CLIMATE CHANGE: SCIENCE VERSUS FICTION

Both novels, *State of Fear* and *The Collapse of Western Civilization,* amplify the scientific facts related to climate change and create chaotic situations through their narration to defend their point of views. On the other hand, *The Great Global Warming Blunder* (2010) written by Roy Spencer, a former senior NASA climatologist, argues that global warming results from a natural and chaotic cycle and is not man-made. Spencer refutes the idea that humans' fossil fuels emissions cause global warming. He believes that the Earth is similar to a car placed under sunlight. If the car's windows are open, the air will flow with no increase to the car's temperature. Conversely, if the windows are closed, the temperature will rise. Unveiling new evidence in his book, Spencer argues "that mankind's influence on climate is small and will continue to be small."[252] He considers greenhouse gas emissions to be too weak to cause global temperature warming. He suggests "that natural, internally generated cloud variability is responsible for most of the climate change"[253] as clouds intercept sunlight rays and provide a protective shield from warming.

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[251] Ibid., 75.

[252] Roy W. Spencer, *The Great Warming Blunder: How Mother Nature Fooled the World's Top Climate Scientists* (New York: Encounter Books, 2010), xii.

[253] Ibid., xxvi.

Spencer also claims that "New NASA satellite measurements reveal that the Pacific Decadal Oscillation causes a [climate change] on the Earth that is sufficient to explain most of the temperature variability during the twentieth century, including 75 percent of the global warming trend."[254] This fact contradicts the IPCC, which considers that changes in temperatures will occur only by external activities that force an imbalance in response to the energy imposed on the natural cycle of climate. For Spencer, "the climate system can generate an energy imbalance all by itself. […]. El Nino, La Nina, the Pacific Decadal Oscillation, and other natural modes of climate variability are a few examples of chaos in the climate system."[255] Therefore, the Earth can go for extended periods of cooling or warming as the climate system is complex and several variations control it. Another valuable information that should be considered in climate change, according to Spencer, is the change "in the general circulation of the ocean-atmosphere system [that] might cause associated changes in cloud cover, which then would change Earth's energy balance over long periods of time."[256] For example, during the positive phase of Pacific Decadal Oscillation, the average cloud number is below normal, allowing more sunlight to enter the Earth's atmosphere and creating a warming trend. According to Spencer, data collected since 2001 over a nine-years' period by global satellite show that Pacific Decadal Oscillation impacts the Earth's energy balance. "… The radiative imbalance varied over a range of at least 2.5 watts per square meter. Even though this natural source of radiative forcing is only

[254] Ibid., 104.

[255] Ibid., 105.

[256] *The Great Warming Blunder: How Mother Nature Fooled the World's Top Climate Scientists,* 109.

1 percent of the average flows of sunlight into and infrared radiation out of the climate system, […] it is sufficient to explain most of the temperature variability experienced in the twentieth century…"[257] Basically, the information presented by Spencer could be taught as outdated information that needs to be updated to inspire students to investigate about all the factors that interfere in the cooling or warming process and evaluate the accuracy of the information.

In addition to Pacific Decadal Oscillation, Spencer argues that CO_2 is necessary for life on Earth. Considering its crucial role in photosynthesis, CO_2 "has a surprisingly small concentration in the atmosphere: only 39 out of every 100,000 molecules of air are CO_2. And humanity's greenhouse gas emissions are so minuscule that it will take five full years of global fossil fuel burning to increase that concentration to 40 out of 100,000 molecules."[258] These numbers provided by Spencer could be contested by students to determine scientific accuracy and assess factual evidence in order to determine which point of view they will support. Based on a recent publication in June 2022, the "global average atmospheric carbon dioxide was 414.72 parts per million in 2021, setting a new record high despite the continued economic drag from the COVID-19 pandemic."[259] Other factors play a huge role in rejecting the anthropogenic causes of climate change. For example, in "Socioeconomic Roots of Climate Change Denial and Uncertainty among the European Population" (2022), people are more concerned about their economic status and may overlook or pay little attention to climate change. Individuals working

[257] Ibid., 120.

[258] Ibid., 124.

[259] Rebecca Lindsey, "Climate Change: Atmospheric Carbon Dioxide," *NOAA Climate.gov*, (June 23, 2022) https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide (accessed June 28, 2022).

in fossil fuels companies or any related work depending on these companies might be more concerned about their jobs and might perceive climate change as an imminent danger to their socioeconomic status. "Individuals who feel insecure about their economic future are significantly more likely to reject the existence of anthropogenic climate change. Furthermore, climate change denial and uncertainty are more common in […] countries more economically dependent on fossil fuels."[260]

Al Gore, the Former Vice President of the USA argues that humans' anthropogenic activity is responsible for climate heating. His goal in making *An Inconvenient Truth* (2006) and *An Inconvenient Sequel: Truth to Power* (2017) is to raise public awareness of the dangers of greenhouse gases' emission. The book and film stress the importance of investing in renewable energy and the necessity to reduce the number of fossil-fuels emissions globally. Using Al Gore's documentaries would be helpful to teach students about renewable energy. Students would learn about hydropower, solar power, geothermal energy, and wind power to design more efficient techniques to produce electricity. Students would learn about how renewable energy is used in many projects around the globe. For example, using renewable energy such as wind turbines and solar panels to generate electricity reduces gas emission into the atmosphere and decreases air and water pollution. Gore emphasizes how global warming is causing droughts and wildfires, not to mention animals' habitats loss and extinction. In the following science fictional works, climate change is depicted as if it is real experience. Envisioning climate change through

[260] Christiane Lübke, "Socioeconomic Roots of Climate Change Denial and Uncertainty Among the European Population," *European Sociological Review* 38, no. 1 (2022): 153.

literature allows students to investigate possible paths to mitigate the increasing impact of global heating.

PREDICTING THE FUTURE

Kim Stanley Robinson's *New York 2140* (2017) and *The Ministry for the Future* (2020) depict climate change's impact on Earth. The first novel, set in 2140 in a fictional New York City, depicts a dystopian narration resulting from the city being submerged under water. Cities and communities are endangered as natural resources are threatened. As described in *New York 2140*, many eastern zones will be filled up with water. "When the great ice monster melted ten thousand years ago, sea level rose about three hundred feet. The Atlantic came up and filled all the valleys of the eastern seaboard, […] and in that process the ocean sloshed into the Hudson, as well into the valley between New England and the Long Island moraine, creating Long Island Sound, then the East River and all the rest of the vast complicated mess of marshes, creeks…"[261] This change to the ecosystem initiated a shift on many levels that affected biodiversity and altered ecosystem composition. Exposing students to climate change fiction can help them understand the butterfly effect on environmental and social scales caused by warming temperatures. Students can help spread scientific awareness and employ their imaginations to think of possible solutions to reduce the risks of climate change and whether they consider a warming or cooling climate to be more probable.

New York 2140 discusses the danger that polar bears face due to the melting of the Arctic ice sheet. Robinson's novel emphasizes the extinction of polar bears and the possibility of their

[261] Kim Stanley Robinson, *New York 2140*, 1st ed., (New York: Orbit, 2017), 33.

relocation to give them a chance to survive warming temperatures. Robinson sheds light on the extinction to expose the danger of climate change on the ecosystem and therefore, on the imbalance caused in the web food structure. He claims that "some people seem to not understand what a problem extinction is! Hard to imagine that, but it's clearly true […]. Twenty bears are going to be transported eventually, that's about ten percent of all the polar bears left in the wild."[262] Robinson uses factual data in his story to record the emission of carbon dioxide in the atmosphere. He claims that CO_2 levels rise up from 280 to 450 parts per million in less than three hundred years, faster than had ever happened in the Earth's entire previous five billion years.[263] He continues to depict the dire situation of climate change in his fictional narration and explains that rising sea levels will trash "all the coastline of the world, causing a refugee crisis rated at ten thousand Katrinas. [According to Robinson], one eighth of the world's population lived near coastlines and were more impacted, as was fishing and aquaculture, meaning one third of humanity's food, plus a fair bit of coastal agriculture, as well as shipping."[264] As Robinson recounts, the issue of climate change is not only limited to warming temperatures and melting ice sheets as it has a larger domino effect on the planet. Raising these issues in science fiction novel complicate students' understanding of the real problems, shed light on entangled political and economic situations and most importantly propel them to think creatively to find radical solutions.

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[262] Ibid., 101.

[263] Ibid., 140.

[264] Ibid., 144.

Moreover, Robinson's story emphasizes the call for rapid decarbonization, which means advocating for "carbon-positive activities"[265] that rely on energy systems provided by solar and wind power, transforming sunlight and ocean currents into electricity, reducing diesel-burning of big ships by building solar panels on their tops and sailing them remotely: "Although it was true that quite a few parts of operating a sailing ship could be automated. Same with freight airships, which had solar panels on their upper surfaces and were often entirely robotic."[266]

The Ministry for the Future (2020), set between 2030 and 2048, describes the horrors of climate change and how to overcome a climate apocalypse. Robinson creates a credible story where humans are presented with creative ways of solving climate change problems. In the novel, Robinson considers fossil fuels' capitalism as the main problem of climate change and he advocates that to decarbonize the world, the financial system must be reformed and ecoterrorists must destroy fossil fuels companies. The novel depicts a small agency, led by Mary Murphy, an Irish diplomat who works with the United Nations, to encourage the immediate adoption of the Paris Agreement (2015) on climate change and spread awareness to reduce the consumption of carbon dioxide. The plot opens in January 2025 in Bogota, Columbia where the convention conference of the United Nations on Climate Change fails to achieve the goals of the Paris Agreement. To set his plot in convincing contexts similar to real events, Robinson creates a sub-agency managed by the character Murphy, to advocate for climate change. The novel recounts how a deadly heat wave hits Uttar Pradesh, a region that falls near India's border with Nepal and how Murphy tries to restore public and safety stability, while Frank May, an American

[265] Ibid., 378.

[266] Ibid., 379.

development worker who survived the extremely high temperature and humidity (heatwave), becomes increasingly mentally unstable as a result of the traumatic event which killed 20 million people. At the beginning of the novel, students learn about wet-bulb temperature, a phenomenon that climate experts consider dangerous signs of climate change. In the case of wet-bulb temperature, the temperature is measured with a thermometer covered with wet cloth as human beings can adapt to high temperatures, up to 50^0 C when humidity is low. However, humans cannot survive in high temperatures with high humidity since the air is not dry enough to allow sweat to evaporate and cool down the human body.

> Then the heat wave came. It got way hotter than it had been up until then, […] one day it was so hot even the people were scared… and that night some of the older people and the little kids died. The heat was beyond what the human body can stand. Hyperthermia, that's just a word. The reality is different. You can't breathe. Sweating doesn't work. You're being roasted, like meat in an oven…[267]

The Ministry for the Future suggests innovative ways to end the struggle of global warming and crucial scientific approaches to alleviate climate catastrophe. The problem described in the novel consists of pumping up melted water from beneath the glaciers using clean energy to limit carbon emission. An essential task to this process is stabilizing Antarctica and Greenland glaciers to prevent them from melting during global warming. Drilling a deep hole into the base of the glaciers in order to explore below the ice sheet and pump out the melting water is the first step to take. In Robinson's novel, this process known as Project Slowdown,

[267] Kim Stanley Robinson, *The Ministry for the Future* (Orbit, 2020), 67.

consists of extracting thirty cubic Kilometers of water from under Antarctica and Greenland glaciers. “If you suck the bottom water out and slow the glacier back down, it won’t shear as much, and you won’t get that friction melt.”[268] This process consists of extracting the water from underneath the glaciers to refreeze it on the surface of the ice sheet to increase the thickness of the glacier and reduce ice melting. This process is not without risk. For instance, in the novel, one of the glaciers had “no water in the hole, even two hundred meters down; this was a sign something was wrong, because when a hole is open from the bottom of a glacier to its top, the weight of the ice pushes water up the hole most of the way. But here we were looking far down the hole, and no water.”[269] Robinson explains to readers the reasons why glaciers melt. He gives three factual explanations: “Surface water draining down moulins … Then geothermal energy melts a little bit of the glacier’s bottom from below, as always. […] Third source is the shear heat created by ice moving downstream, the friction of that movement.”[270] Basically, Robinson attributes the glacier’s melting to the geothermal energy that resides inside the earth which is affecting the sliding behavior of the glacier and speeding the process of melting throughout the ages.

Although climate change science fiction novels depict an apocalyptic future and invite scientists, educators, politicians and lawmakers to intervene whether by spreading awareness or issuing new laws to control global overheating, Robinson argues that “we can only model

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[268] Ibid., 82.

[269] Ibid., 473.

[270] Ibid., 82.

scenarios, […] we track what has happened, and graph trajectories in things we can measure, and then we postulate that the things we can measure will either stay the same, or grow, or shrink."[271]

Robinson then models several options including geoengineering the Arctic water to make it more reflective of the sunlight: through this process, some scientists from California believe they could slow down the melting of the Arctic ice: "They want to make the ice whiter by coating it with glass. This is the latest entry in a series of large scale climate manipulation proposals known as solar geoengineering. The idea is that we can offset some of the warming caused by heat trapping greenhouse gases by reducing the amount of sunlight that adds heat to the planet."[272] Restoring wildlife and increasing biodiversity might also help by creating a balance among species that limits their migration. Evictions "were happening all over the upper Midwest, all over the West, the South, New England, the Great Lakes. Everywhere on Earth…"[273] Other suggestions include reducing carbon emissions through carbon-negative agriculture. Carbon-negative agriculture is one of the efficient ways to slow down carbon emissions and even reverse them not only by slowing down carbon emissions but by reversing them. The practice of composting is one of the common means that helps increase the storage of carbon in the soil at two meters deep from the surface and at the same time keeps the carbon storage safe from erosion and tilling. Students would also explore other creative agriculture such as hydroponics which consist of growing crops directly in water without soil. Urban

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[271] Ibid., 96.

[272] Bob McDonald, Engineers Want to Make Arctic Ice More Reflective by Coating it by Glass, CBC Radio BLOG Sept, 2020, https://www.cbc.ca/radio/quirks/preventing-the-loss-of-arctic-ice-by-spraying-it-with-glass-1.5739379 (accessed October 2021).

[273] *The Ministry for the Future*, 438.

environments would be ideal for hydroponic farming which can grow indoors and thrive in areas where traditional farms would not be available. Hydroponics farming could feed the growing population and reduce the challenge of transporting produce and crops long distances across the country while lowering the emission of carbon.

Exposing students to the above strategies would teach them that the reduction of carbon dioxide emission is not only helpful for humans but can also help save marine species from suffering the harrowing impact of climate change. Rising oceans' temperatures will negatively impact marine ecosystems, reducing the growth of phytoplankton which are the primary producers of omega-3 consumed by fish, an essential nutrient for human health. The lack of omega-3 in human nutrition leads to significant mental deficiency such as depression, anxiety, schizophrenia, and bipolar disorder. Fish get their omega-3 fatty acid docosahexaenoic acid (DHA) from algae consumption. With water warming, algae produce less DHA, a crucial unsaturated fatty acid for dietary supplements. With more carbon dioxide absorbed by ocean water, marine organisms that use calcium carbonate to make their shells and skeletons will spend more energy to restore their damaged shells instead of using this energy to grow and reproduce. Acidic water will alter the entire marine ecosystem and will cause a chaotic situation that affects the global economy and marine species. "Climate change caused by carbon dioxide and methane released to the atmosphere; [could be], now cached in the Arctic permafrost and the ocean's continental shelves; oceans unable to uptake more CO_2 and heat; rate of extinctions already as high as at any time in Earth's history…"[274] Studying and analyzing climate change through

[274] *The Ministry of the Future*, 293.

science fiction work might be beneficial to demonstrate the domino effect of rising temperatures and how one event sets off series of cumulative events.

Throughout the novel, potential policies are discussed that would limit greenhouse gases emissions, such as blockchain-regulated "carbon coin" that encourages processing carbon to reduce its emission into the atmosphere. Ecological engineering encourages airships and tankers to be powered by photovoltaic cells emitted by sunlight, and promotes the use of natural resources such as air and ocean currents to move sails and boats. These accounts in the novel warn student-readers of a dire and pervasive catastrophic future if the course of industrial capitalism which is based on investment in fossil-fuels corporations is not diverted from excessive usage of fossil fuel.

As Robinson's story suggests, to reverse climate change processes and promote a healthier environment for future generations, implementing some crucial solutions needs to be mandatory and immediate. Harnessing existing technologies can increase the possibilities of controlling climate change. Producing electricity with wind and solar power could be one of the most efficient solutions to decrease heat-trapping. Electric cars are another huge step in technological advancements that could reduce the gas emissions in the atmosphere and lead better and healthier living conditions. However, these changes will not happen without governmental action requiring the reduction of carbon emission, educating the population about climate change and establishing the necessary technological infrastructure to shift to renewable energy production. Robinson's account of climate change, the flood that submerged the city of New York, the agriculture and aquaculture, and lots of other events that resulted from a natural flood disaster highlight the risks that humanity may well encounter in the near future. Being

equipped with better understanding and accurate information will help encourage political climate change reform by rescinding wrongful laws and reshaping regulations to better fit the needs of economic and environmental health. The scenario presented in Robinson's fictional narrative may help create public awareness of climate change consequences and encourage students to think of innovative technologies to prevent or prepare for the future.

Reading and learning about climate change may help middle school and high school students think actively about the potential consequences of temperature change but vicariously experiencing the event through the science fiction protagonist of the story may further expand their imagination and involve them in critical problem-solving. Science fiction novels have the potential to increase readers' understanding and help them imagine the future to adapt and navigate from resilience to transformation. Imaginative texts inform readers about the prospects of imagining future cities submerged in water and the ability to create new customized cities capable of resisting rising seas and hurricanes. Paul Dobraszczyk argues in "Sunken Cities: Climate Change, Urban Futures and the Imagination of Submergence," (2017) that "read[ing] a text, watch[ing] a film or look[ing] at an image of a future city, we are not escaping from the real, but rather redefining its parameters by creating links between imagined and real cityscapes that make any clear separation between the two categories untenable."[275]

Through the science fiction works considered in this chapter, students are not only discovering Robinson's narration of climate change and how scientists are trying to solve the melting problem of the arctic, but they are also exposed to non-science fiction readings that

[275] Paul Dobraszczyk, "Sunken Cities: Climate Change, Urban Futures and the Imagination of Submergence," *International Journal of Urban and Regional Research* 41 no. 6 (2017): 870.

discuss bioengineered techniques to develop further their knowledge and learn about climate change reverse techniques. Students will learn how bioengineering is transforming and finding solutions to climate change issues as biotechnology is not only used for genetic enhancement of the human beings but it can be also applied to emulate biological organisms (biomimetics) and learn how they can survive heat and cold in severe weather conditions. In the last part of this chapter, I will examine how students can learn how to cope with climate change through recent innovations that bioengineers are proposing to help reduce and reverse the effect of climate change on Earth.

MITIGATION AND ADAPTATION TO CLIMATE CHANGE

In *Adaptation to Climate Change: From Resilience to Transformation* (2011), Mark Pelling, professor in Geography at King's College London, a lead author with the IPCC and a consultant for UNDP[276], DFID[277] and UN-Habitat, argues that climate change is the next challenge of the twenty-first century. He claims that "the annual impact from natural disasters associated with climate change alone accounts for tens of thousands of deaths, millions of people affected and billions of US$ lost, with drought, flooding, temperature shocks and windstorms causing the greatest impacts."[278] The impact of climate change is felt directly through flooding, sea levels rising and hot temperatures and also in indirect ways, through infrastructure damages, food scarcity, destruction. Both lead to chaotic economic and social perturbations. For that

[276] United Nations Development Program.

[277] (in the UK) Department for International Development.

[278] Mark Pelling, *Adaptation to Climate Change: From Resilience to Transformation* (England: Routledge, 2011), 24.

reason, Pelling argues that supporting vulnerable societies that economically suffer from climate change would decrease people's migration and stabilize the ecosystem demography. To prevent further global warming, ecological engineers develop new technologies to mimic biological structures of plants and animals in order to mitigate overheating climate and reduce carbon dioxide emissions. As Pelling puts it, proactive adaptation reduces disasters instead of reconstructing damage afterwards. Without adaptation measures to control humans' contribution to climate change, more chaotic and anarchic issues will result from disasters that threaten more lives, render many homeless and jobless and widen the margin between the poor and the rich. After discussing with students Pelling' argument and his perspective on climate change, students could be asked to prepare a list of potential risks that are revealed in Robinson's novels and collaborate with each other to find best ways to mitigate climate change or they can study the influence and threat of climate change on population. They can also compare Robinson's potential mitigation strategies with Pelling's to improve their knowledge and challenge their previous understanding.

Students could also learn the difference between mitigation and adaptation to climate change. As part of these lesson plans, they can seek or invent new potential regulations or strategies that they think would help alleviate the risk of climate change. In *Ethical Futures and Global Science Fiction* (2020), Zachary Kendal clearly distinguishes between mitigation and adaptation strategies concerning climate change. According to Kendal, mitigation deals with reducing emissions, while adaptation seeks possible advantages to create new strategies and infrastructures.[279] Therefore, the need for innovative ideas to circumvent climate extremes and

[279] Zackary Kendal and al., ed., *Ethical Futures and Global Science fiction* (Palgrave Macmillan, 2020), 80.

their effect on the infrastructure are valuable and immediate. Innovations in science and technologies and public education awareness are essential to manage potential risks of climate change and identify susceptible regions to warn people of any imminent danger. Creating new regulations such as the Flood Insurance Reform Act to improve risk management is not enough to mitigate climate change. More regulations and insurance policies need to be planned and investigated to limit the risk of natural disasters. For example, banning residential construction on the coastline would need more investigation and reorganization, especially since most cultures have already invested and lived for centuries on coastlines.

While Earth is falling under the heavy weight of climate change, mitigation and adaptation do not seem like enough to reduce warming temperatures. By learning to mirror natural ecosystem, biomimicry could help contribute to the resolution of these challenges. Discussing biomimicry in the classroom as a potential strategy and asking students to research prospective designs inspired from nature could orient students to the exciting practice of biomimicry and introduce them to topics ranging from science and engineering to environmental literacy and climate change.

BIOMIMICRY ARCHITECTURE: ANOTHER POTENTIAL SOLUTION

In some science fiction movies, biomimetics is at the center of the story as a combination of science, technology and engineering creates superhuman heroes. In *Black Panther* (2018), the film portrays some inventions based on biomimicry such as kinetic energy transformed into potential energy with a suit engineered to empower the hero or using sticky fingertips to climb a building. In *Spider Man* movies (2017, 2019, 2021), the main character has superpowers so that

he can release webs like spiders that allow him to swing through buildings. "Using a combination of our imagination in science fiction, and the incredible properties of actual nature, researchers seek to push forward the capabilities of real technology. […] Technology is often catapulted forward by what begins as science fiction."[280] To draw students' interest into biology, students could be asked to research examples of biomimicry and explain the process behind the invention. Through this practice, students could acquire scientific knowledge on how biological species contribute effectively to their ecosystem and how could humans save natural resources by imitating other planetary creatures.

As Robinson described in his novel *New York 2140* (2017) how scientists are trying to reverse climate change by implementing new strategies, for some climate change advocates, biomimicry, imitating the biological structures of animals and vegetation in building architectural constructions, could also help reduce the consumption of natural resources. Reversing climate change could be possible by learning from nature's models how to develop new ways to encounter environmental challenges to create sustainable and favorable systems that could enable humanity's survival. Science fiction authors often present climate change as a dystopic future that lies ahead of us, but few have written science fiction works that illustrate the potential of biomimetics. *Biomimicry in Architecture* (2019) presents efficient ways "to create a positive future and make the shift from the industrial age to the ecological age of humankind."[281] Imitating biological organisms becomes the inspiration and basis for innovative technological

[280] Dana Simmons, "Be a Superhero with Biomimicry," *Illinois Science Council* (May 27, 2019), https://www.illinoisscience.org/2019/05/superhuman-capabilities-biomimicry (accessed June 2022).

[281] Michael Pawlyn, *Biomimicry in Architecture*, 2nd ed. (Riba Publishing, 2019), 1.

tools that provide functional solutions for global heating based on biological designs. Biomimicry can be applied to the function of structures to improve people's well-being. Building campuses such as Cal Poly San Luis Obispo with white-spiraled modules lined on the roof to extract CO_2 from the air is an example of biomimicry that could help global warming. In addition, a group of scientists found an efficient solution to build a glasshouse by imitating the pliable materials used in cell membranes and spiders' webs, as they used ethylene tetrafluoroethylene (ETFE), a polymer that has a high resistance to a wide variety of temperature and weighs less than the glass. They also added a geodesic dome formed from laminated vinyl and ETFE. The structure allowed more sunlight and reduced the heat needed during the winter season. Using less steel in the construction compared to a conventional glasshouse also decreased the cost to one third of the cost of regular glasshouses. Ginger Krieger Dosier, a biotechnologist who studies microbial material in coral reefs, developed the "idea of using *Sporosarcina pasteurii* bacteria to bind sand with calcium carbonate"[282] to make bricks with the least amount of energy. Through such examples, students could learn how bacterial growth would lead not only to plastic degradation (as seen in chapter one) but to the design and construction of architectural forms. One more interesting finding that students could learn about is biomineralization, a new technology that allows the mitigation of climate change by reducing the amount of carbon dioxide released into the atmosphere. Unlike cement production, "biomineralization sequesters an atom of carbon with every atom of calcium in the process of forming calcium carbonate. Cement production, by contrast, releases a molecule of carbon

[282] Ibid., 50.

dioxide for every atom of calcium."[283] More inspiring examples could help students imagine and investigate innovative technologies to create a new industrial system that contributes to a healthier ecosystem. For example, the oriental hornet is a great example of thermoregulation strategy. The hornet's nest is covered with silk caps that function as a thermostatic regulator. The silk captures daytime heat as an electric charge and releases it when the temperature falls. This strategy could be useful in regulating temperature in buildings and halting carbon dioxide emissions.

Teachers could assign a project in which students are asked to research other examples that are inspired by biological structures and that could help with climate change. Students will realize the importance of biomimicry to create an innovative construction industry that shifts from emitting to absorbing carbon dioxide and would help mitigate climate change and promote substantial improvements that drive economic and environmental progress. Using efficiently natural resources coupled with biomimicry architecture will increase the chances of slowing climate warming while being inventive and innovative. While biomimicry is one of the solutions that bioengineers are developing to reduce world's warming crisis, educators and teachers could contribute to the understanding of climate change by spreading scientific literacy among students and pointing out global issues that need attention.

The scientific fiction works mentioned in this chapter depict challenging narratives of anthropogenic climate change that create potential scenarios for students-readers that may enable them to think of possible solutions. As Kendal states: "Climate change poses threats not only in

[283] Ibid., 57.

terms of global overheating, rising sea levels, desertification, super-storms, flooding and ecocide, but also to literature's capacity to grasp and make sense of these developments in narrative form."[284] Therefore, in the following chapter, I will stress the importance of introducing new media such as video games into the educational curriculum at the high school level as an additional tool to help students learn science and become active learners. Like works of science fiction literature, video games have the power to engage students while feeding their curiosity and broadening their imagination.

[284] *Ethical Futures and Global Science fiction,* 306.

CHAPTER 4

VIDEO GAMES AND SCIENCE LEARNING

In the twenty-first century, the field of learning witnessed the emergence of several innovations in teaching. Learning shifted from being teacher-centered to learner-centered, from students being passive listeners to interactive and active in learning, from memorization-focused to research-and problem-based instruction. Technological advances helped the growth of this shift, especially with the emergence of educational video games that have played an increasing role in engaging students in learning. The impetus for using video games in teaching is their potential for significantly improving students' "cognitive learning outcomes including knowledge acquisition, conceptual application, content understanding, and action-directed learning."[285] Such platforms can present scientific concepts that may otherwise be impossible or not feasible to engage through their application of visualization, sound, and animation. For example, video games can represent magnetic fields, atoms, galaxies and many other concepts through educational and collaborative game-playing and visualization. Integrating video games into instructional activities may improve some student learning outcomes. The visual and interactive features of video games are the main reason for their increasing importance in learning. For example, video games challenge players and increase their motivation and can be customized to "accommodate multiple learning styles and abilities."[286]

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[285] Dimitrios Vlachopoulos and Agorista Makri, "The Effect of Games and Simulations on Higher Education: A Systematic Literature Review," *International Journal of Educational Technology in Higher Education* 14, no.1 (December 2017): 25.

[286] Victoria Guillen-Nieto and al., "Serious Games and Learning Effectiveness: The Case of It's a Deal," *Computers and Education 58*, no. 1 (Elsevier Ltd, 2012): 436.

Science video games can expose students to complex systems where they can formulate and evaluate their own learning strategies with minimal fear of failure. Games may help develop critical thinking, promote problem-solving, hone creativity and increase students' engagement in science education. Through video games, students are able to share playing strategies and compare and contrast the accuracy of scientific information with other players, traditional textbooks and other learning materials. Given the proliferation of video games, many middle school, high school college students are informally exposed to science learning. In this chapter, I will explore the science in computer video games, console video games, virtual reality and augmented reality as student-players experience decision-making and interact with the science content in video games. Anthony Dudo, associate professor at The University of Texas at Austin, argues "that video games have the potential to enhance education in science, technology, engineering, and math (STEM)."[287] He believes that video games contribute to public engagement in the understanding of scientific information within informal contexts "and will help learners develop initial interests in science as well as their perceptions of science and scientists."[288] Since Dudo is interested in the intersection of science, media, and society, he claims individuals learn by observation and by modeling processes to "learn appropriate behaviors or ways of thinking based on the outcomes of those thoughts or actions"[289] outcomes which he calls "identification learning." Exhibiting cinematic and nonlinear features, modern

[287] Anthony Dudo and al., "Portrayals of Technoscience in Video Games: A Potential Avenue for Informal Science Learning," *Science Communication* 36, no. 2 (Sage Publications, 2014): 2.

[288] Ibid., 5.

[289] Ibid., 6.

video games are attractive to all age groups, specifically because they are so similar to movies with narrative qualities and plots.

Improving mental acuity, according to "Preparing for the Future with Games for Learning: Using Video Games and Simulations to engage Students in Science, Technology, Engineering, and Math" (2011), requires critical thinking as many complex issues are solved "based on preconceptions, incorrect information, and faulty assumptions."[290] To think critically, individuals need to rationally evaluate their position on an issue, consider the accuracy and relevancy of their claim, and accept or reject this claim based on evidence and objectivity in adopting such reasoning. To identify higher-order thinking skills, students need "to demonstrate creativity and innovation, communicate and collaborate, conduct research and use information, think critically, solve problems, and make decisions, and use technology effectively and productively."[291] Most of these skills could be developed and applied during video games as student-players advance in a game and achieve certain levels. Switching out of passive learning promotes critical thinking and problem-solving skills. Rather than remembering facts for assessment grades, game-playing students need to internalize the knowledge, and understand and apply what they learn to the idea game's environment. Citizens of the twenty-first century will need to be prepared to think critically to solve global issues such as bioengineering threats, climate change, and socioeconomic problems. Educational science video games may contribute to this preparation.

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[290] Robert Ormsby and al., "Preparing for the Future with Games for Learning: Using Video Games and Simulations to Engage Students in Science, Technology, Engineering, and Math," *Astropolitics* 9, no. 2-3 (November 2011): 151 http://dx.doi.org/10.1080/14777622.2011.625924 (accessed June 2021).

[291] Ibid., 153.

James Gee, an education professor at the University of Wisconsin, Madison claims that video games have the potential to increase the coordination between visual perception and motor control skills while inspiring learning and improving students' attention. According to Gee, playing video games is challenging and requires strategic skills. Playing video games is captivating as players actively interact with real time changes in the game. Video games' entertaining and interactive features keep students engaged while playing and learning. Some games offer players realistic problems and dilemmas they might encounter in real life. Looking at the bright side of video games, players also interact online with others to build social bonds and learn new strategies. Gee states that players need to think critically to find solutions, develop hypotheses, and test their strategies. If their game strategy fails, players immediately change and find another way to proceed. He argues that teachers should assign video games as practice activities the same way as the military uses them to simulate battlefield scenarios for training purposes and research.

SOLVING FUTURE PROBLEMS WITH VIDEO GAMES

In *Learning Science through Computer Games and Simulations* (2011), Margaret Honey and Margaret L. Hilton argue that "today's science students will become tomorrow's citizens, who will require understanding of science and technology to make informed decisions about critical social scientific issues, ranging from global warming to personal medical treatments."[292] They consider the lack of students' interest in science and the low degree of motivation to master more difficult science concepts to be related to science educational approaches that emphasize

[292] Margaret Honey and Margaret L. Hilton, *Learning Science through Computer Games and Simulations* (Washington, D.C: National Academies Press, 2011), 6.

memorization of facts instead of developing a deep interpretation of science concepts. Science learning requires investigations, observation of natural phenomena, and the formulation of explanations of phenomena. In the typical classroom, students do not always have enough time to pursue these steps, and hence they do not experience the connection of science to the real world that might help them fully develop a deep interest in science.

> Computer simulations and games have great potential to catalyze and support the new learning approach, by allowing learners to explore natural phenomena that they cannot directly observe, due to time scale, size, or form. […] Learners can manipulate virtual systems that represent these natural phenomena, a process that helps them to draw powerful mental connections between the representations and the phenomena and to formulate scientifically correct explanations for the phenomena.[293]

As Honey and Hilton argue, "simulations are computational models of real hypothesized situations or natural phenomena that allow users to explore the implications of manipulating or modifying parameters within them."[294] They claim that simulations in science games found at http://phet.colorado.edu could be a supplement for students practicing their understanding of science concepts and advancing their learning. Allowing players to apply theoretical concepts to real-world problems and practice their analytical skills can help develop critical thinking skills. Moreover, with augmented reality, students' attention is controlled through attention-aware features embedded in the device that help students refocus on their tasks.

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[293] Ibid., 119.

[294] Ibid., 9.

VIDEO GAMES' EFFECTS ON HIGHER EDUCATION

Recent research studying the effects of games and simulations on higher education, found that students appreciated visual feedback provided by simulations and were actively encouraged to explore their understanding which enable them to make "a move beyond knowing-in action and beginning to reflect-on and in-action during training, resulting in the contextual application of prior knowledge."[295] Engagement and motivation go hand in hand to spark players' attention with relevant scientific concepts and increase their cognitive abilities. Teachers also have to facilitate the learning experience and promote collaborative interaction among students to keep them interested.

According to Honey and Hilton, games and simulations have many advantages in science learning. Some of the games, such as *Geniverse* (2016), engage students in exploring heredity by breeding virtual dragons. Such video games may help decrease the practical and logistical constraints that regular science class require. For example, a trip to a museum or an experiment in the laboratory could be replaced by video games that enable students to have the same experience but virtually. Video games can support science instruction while providing the necessary environment for learning and experimenting. Students can visualize, experiment and formulate hypotheses while leading virtual investigations.

Learning science requires more than just memorizing facts, and students need to develop deep proficiency to relate the scientific concepts to real-world problems. To master science

[295] "The Effect of Games and Simulations on Higher Education: A Systematic Literature Review," *International Journal of Educational Technology in Higher Education* 14, no.1 (December 2017): 20.

concepts, students need to discuss arguments, model, represent and investigate scientific topics to develop their understanding. Video "games can spark high levels of engagement, encourage repetitions and practice, and motivate learners with challenges and rapid feedback."[296]

They can improve science learning at all levels in elementary, secondary, and undergraduate classrooms as they provide individualized learning that matches students' pace, needs, and interests. To successfully engage students in science learning, video games are best integrated into science instruction to allow them opportunities for related practice.

BENEFITS OF PLAYING VIDEO GAMES

Media stories report that video games could be responsible for violent behavior and aggressiveness, especially shooter games. Such research has linked the shootings at US schools to the violence that players are exposed to in games. However, recent research at Radboud University in the Netherlands shows that as video games have become more realistic and deal with social dilemmas, they can challenge players' cognitive skills and develop their emotional experiences. The benefits of playing video games are countless. Players are exposed to many visual images that require proper attention and higher spatial-visual processing to make good decisions and develop pattern recognition. Cognitive skills are enhanced and improved due to practice and repetition. In fact, with a recurring theme in a video game, students learn through multiple trials how to solve problems, refine their strategic approaches, and reflect on the logical narration of the game.

[296] *Learning Science through Computer Games and Simulations* (Washington, D.C: National Academies Press, 2011), 20.

In "Games as Text, Games as Action" (2014), Catherine Beavis notes "reading or playing video games requires the player to interpret all sorts of different symbol systems — words, pictures, sounds, symbols, color, and so on, simultaneously as well as alone and in combination."[297] Players gain understanding from diverse forms and recognizing the logical relationship between them. Although primarily considered entertainment platforms, video games also enrich players' learning and develop their knowledge of a variety of domains. Amy Green considers video games to be great digital tools for telling stories. She argues that stories delivered through books, films or video games "teach us facts about the world; influences our moral logic; and marks us with fears, hopes and anxieties that alter our behavior, perhaps even our personalities."[298]

In 2009, The Quest to Learn public school in New York realized that video games were growing very popular among students. The teachers at the school developed their curriculum following video games principles that expose students to multifaceted challenges and give them the opportunity to discover different solutions. Alan Gershenfeld, co-founder and president of E-Line Media, a publisher of computer and video games, and a Founding Industry Fellow at Arizona State University's Center for Games and Impact, claims that video games can be a very powerful tool to instigate inquiry and project-based learning if they are well managed and executed. Beyond the learning prospect of video games, players interact with visual displays fostering necessary skills to solve problems and provide instantaneous feedback. Teachers and

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[297] Catherine Beavis, "Games as Text, Games as Action: Video Games in the English Classroom," *Journal of Adolescent and Adult Literacy* 57, no.6 (March 2014): 435.

[298] Amy M. Green, *Storytelling in Video Games: The Art of the Digital Narrative* (Jefferson, North Carolina: McFarland and Company, Inc. Publishers, 2018), 6.

students then can examine that feedback and quickly determine the areas students need to work on.

CONNECTING WITH VIDEO GAMES

Besides entertaining and providing valuable practice, students experience while playing video games what author Mihaly Csikszentmihalyi calls "flow." He "states that flow helps to integrate the self because in that state of deep concentration consciousness is usually well ordered. Thoughts, intentions, feelings, and all the senses focused on the same goal. Experience is in harmony."[299] Flow experience, according to Csikszentmihalyi, "has the potential to make life more rich, intense and meaningful."[300] Not all sensory activities are conducive to flow; some exhilarating experiences "are generated inside the mind, triggered by information that challenges our ability to think."[301] In "Teaching Science through Video Games" (2017), players concentrate on many tasks, which keep them hyper-focused. "Game designers often describe this heightened concentration as being a state of flow, and often design mechanics and content with the express intent of helping players achieve and maintain flow."[302]

In addition, Gee argues in *Good Video Games + Good Learning: Collected Essays on Video Games, Learning, and Literacy* (2007) that the pleasure and emotional involvement that video games provide are crucial to thinking and learning. He claims that books are full of words

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[299] Mihaly Csikszentmihalyi, *Flow: The Psychology of Optimal Experience* (New York: Harper Perennial, 1992), 41.

[300] Ibid., 71.

[301] Ibid., 117.

[302] Ronald A. Smaldone and al., "Teaching Science through Video Games," *Nature Chemistry* 9, no. 2 (2017): 98.

that describe the worlds of biologists, scientists, artists, writers, engineers, etc. Students might understand the books, travel with their imagination into other realities but their experience will be limited. Therefore, Gee stresses that playing the game first and then reading the game's manual would make players' building of understanding easier and less stressful "because now players have an image, action, experience, or dialogue to associate with each word in the manual, not just dictionary definitions."[303] By getting to know the world from the inside, playing the avatar's role, and making decisions, players gain in understanding and valuing the game. According to Gee, humans think effectively when they can perceive the world in specifics temporal and location details. Understanding of the scientific concepts relies on the ability to simulate in the mind real experiences rather than just form abstract generalizations.

Video games also have the potential to externalize the mind's abilities. They provide a new world for players to explore where they develop new identities during learning and interacting in the game. Learning about medicine, anthropology, physics, and military strategies in video games help players learn about these professions and value their importance. This type of learning is called "distributed authentic professionalism, [since] video games are particularly effective at helping players assume a new identity, performing virtual actions and having virtual experiences that they are not yet capable of in the real world."[304] Players become active learners, contributing to the game they feel they are part of it, they are producers and not only consumers, hence, the benefit of playing. While traditional schools that focus on mastering knowledge and

[303] James Paul Gee, *Good Video Games + Good Learning: Collected Essays on Video Games, Learning, and Literacy* (New York: P. Lang, 2007), 3.

[304] Ian D. Beatty, *Gaming the System: Video Games as a Theoretical Framework for Instructional Design* (2014), 3.

measuring students' skills often use grades to evaluate students' performance, video games encourage players to find their own motivation and invest time to learn how these skills and knowledge make sense in the real world.

Albert Bandura, a psychologist in Clinical Psychology from the University of Iowa, and former president of the American Psychological Association argued back in in 1974 that learning occurs in response to observation, imitation, and modeling others or interacting with others, especially when reward or positive experiences are expected. As a fundamental rule for learning and a crucial part of intellectual development, models and modeling promote learners' ability to manipulate, transform, think with, and discuss models. This process of learning requires attention to the model, retention and rehearsal of the task learned, reproduction of the action learned, and motivation. Video games allow players to execute these steps and experience with models and modeling, "allow them to interpret and reflect […], and, at the same time, get them to interact with models at various levels of abstraction as part and parcel of those experiences."[305] Video games could be perfect tools to create new experiences useful for learning purposes. "They [could] offer problem sets integrated, worked, modeled, and ordered in intelligent ways."[306] Players enjoy the fun the games provide as increasing challenges are introduced gradually to master the game and not frustrate the players.

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[305] *Good Video Games + Good Learning: Collected Essays on Video Games, Learning, and Literacy*, 164.

[306] Ibid., 173.

PITFALL OF VIDEO GAMES

Gee also identifies the different approaches to learning within different political groups. He thinks that liberals' pedagogies empower learners by focusing on rich activities that emphasize learners' backgrounds. For example, teachers who support the use of video games as an academic tool for learning will shift easily and implement the technology in their classrooms. However, learners need to figure out "the rule of the game, the skills, values, and assessments, not to mention the massive effort, that learners must overtly recognize if they are to succeed in a world that no longer rewards commodity jobs."[307] On the other hand, conservatives' pedagogies are more likely to stick to the fashioned way of teaching and they emphasize skilling-and-drilling students on factual knowledge, but students cannot apply what they learn in the real world. Their knowledge is limited to textbooks' words. On top of these differences, video games could create a new gap between social groups. The rich may have access to new opportunities and experiences; while the poor may sink deeper into lower-income jobs and less privileged lives. In addition to the expensive infrastructure of video games installation that most schools cannot afford and other challenges that might create obstacles such as technical issues, staff and faculty training, troubleshooting, managing software and hardware. However, this should not draw away educators from trying to benefit from a large array of digital games to encourage students to discover science from a different lens.

[307] Ibid., 167.

BENEFITS OF VIDEO GAMES

Although video games have their drawbacks, we cannot ignore that we are living in a digital world where technology is pervasive and affecting not only academic life but most aspects of our culture. Some educators and teachers are trying to take advantage of this innovative tool amid many struggles. Kurt D. Squire argues that "schools appear to be facing a crisis of engaging secondary students in meaningful learning. Many recognize that the learning principles embodied in computer and video games reflect the best theories of cognition, yet are underutilized as an educational resource."[308] According to Squire, games provide players with representations of the world that allow them to understand the consequences of their choices and their impact on the game's succession. Understanding and mastering the game's rules gives players some factual background to build upon when learning in an academic setting. Video games sharpen players' brains through mental simulation and have the potential to improve visual awareness and spatial observation. They also enhance competition level by allowing players to repeat levels while playing and learning problem-solving.

In addition to visual enhancement skills, video games promote scientific thinking, which is needed in the workforce to meet the challenges of a digitized twenty-first century and advance the economy, the health, and the well-being of the general public. In "Gaming Science: The Gamification of Scientific Thinking" (2013), the argument is made that video games could support scientific literacy since they are part of cultural life. They can support content understanding, skills practicing, and interpreting scientific concepts. As Kathryn L. Lookadoo, a

[308] Kurt D. Squire et. al., "Designing Centers of Expertise for Academic Learning Through Video Games," *Theory into Practice* 47, no.3 (2008): 240.

clinical assistant professor in Naveen Jindal, School of Management at The University of Texas at Dallas, explains, players engage at two different levels: cognitively and affectively. They invest their attention, their mental abilities, and their emotional skills. Her research argues that the level of engagement and attachment to a game depend on players' feedback received during game play. "… Assessment within games […] could provide several advantages […]. It could encourage students to better understand the materials and achieve higher learning outcomes."[309] She also claims that assessment increases rapid acquisition of the material and provides better absorption of knowledge than traditional educational materials. Moreover, Bradley J. Morris, associate professor in educational psychology and associate director of science of learning and education (SOLE), argues that video games support students' learning "with number of motivational scaffolds, such as feedback, rewards, and flow states […], a number of cognitive scaffolds, such as simulations and embedded reasoning skills […], and video games provide metacognitive scaffolding in the form of constrained learning and identity adoption."[310] Metacognition abilities promote scientific thinking as video games require players to think metacognitively (be aware of one's own learning or thinking processes) to understand their play activities and advance in the game. In some educational video games about science, the scientific description mirrors real science as it follows all the steps taken by a scientist to solve a problem. Players need to construct a hypothesis, test it by experimentation, evaluate and analyze their

[309] Kathryn Lookadoo and al., "I Forgot I Wasn't Saving the World: The Use of Formative and Summative Assessment in Instructional Video Games for Understanding Biology," *Journal of Science Education and Technology* 26, no. 6 (December 2017): 601.

[310] Bradley J. Morris et al., "Gaming Science: The Gamification of Scientific Thinking," *Frontiers in Psychology* 4, no. 607 (September 2013): 1.

results, and conclude by supporting or refuting the original hypothesis based on observation and evidence. In addition to providing unlimited attempts for players to discover and experiment, "video games can encourage inquiry, engage learners so that they are motivated to spend time on the task and to develop expertise, and provide a contextual bridge between the concept learned and their applications."[311] According to Morris, discovery learning creates a state of flow that allows students to self-pace their learning progress. Learning becomes inherent to progress within the game.

LEARNING BY DOING THROUGH VIDEO GAMES

More powerful findings are also recorded in "Video Games and the Future of Learning" (2005), where David Williamson Shaffer, Kurt R. Squire and James P. Gee assert that players' experiences in virtual worlds reflect the concrete realities that they learn about. Shaffer and colleagues argue that players connect abstract ideas to real problems: "The virtual worlds of games are powerful because they make it possible to develop situated understanding."[312] Learning cannot be achieved without the ability of students to perform or apply the knowledge to the real world. Therefore, learning by doing and being made learners is part of the process of learning.

How can video games contribute to constructive learning at school? How they can be used as powerful tools to encourage students learning in science and enhance Higher Education? "Video Games: A Route to Large-Scale STEM Education" (2009) considers video games a great

[311] Ibid., 4.

[312] David Williamson Shaffer and al., "Video Games and the Future of Learning," *Phi Delta Kappan* 87, no. 2 (2005): 106.

medium to embed STEM education in schools. Some students find visual and auditory modes in video games more compelling in delivering information than in a lecture. Furthermore, players' autonomy while navigating through tasks and accomplishing their goals is "one of the few easily identified predictors of enhanced learning outcomes."[313] Some game-based tasks are very similar to inquiry-based learning (a learning process that enables students to make connections of real-world through exploration and high-level questioning) as both methods require hypotheses formulation, experimentation, and discovery of the results of the actions taken. Video games embed problem-solving and force players to find a solution to move to the next level. To complete all game levels, players need to master the skills in the game program. Learning to play a game is similar to learning at school. Games gradually teach players in an enjoyable way to reach higher levels. Experiencing difficulty when playing a game, players will feel frustrated and stop playing and the goal of learning will fail. Similarly, if the game seems boring and not challenging enough, players will stop being engaged and lose interest. "In fact, science-related games embedded with assessment software can even act as alternatives to paper exams for testing critical thinking."[314] New software can collect students' data and allow teachers to track their learning and evaluate their scientific problem-solving. Even cognitive assessments could be tracked with sophisticated software that enables students and teachers to track their progress. "An increasing number of games have built-in tools for assessment that keep track of how a

[313] Merrilea J. Mayo, "Video Games: A Route to Large-Scale STEM Education?" *Science (American Association for the Advancement of Science)* 323, no. 5910 (2009): 80.

[314] Amy Maxmen, "Video Games and the Second Life of Science Class," *Cell* 141, no. 2 (2010): 201.

person plays. New software can aggregate these data and let evaluators know how students go about solving scientific problems."[315]

Video games could help teachers in preparation of students' personalized learning as students learn differently and need new resources and tools to invigorate their learning and promote their enthusiasm. Many students prefer to be engaged in a game where they can learn about viruses, public health, molecular biology etc. Science games need to be compelling, enable students to engage in the dynamic gameplay and at the same time provide students with accurate scientific knowledge. The potential of science popularization via science games depends on the balance between the representation of scientific facts and the invention of analogies in a game. In the games discussed in the rest of this chapter, the scientific concepts that students are exposed to could benefit their understanding and deepen their knowledge in learning about genetics, CRISPR technique, viruses, and climate change.

Video games, like films, have the potential to influence general public opinion about the science represented in the game. Students are immersed with technology and it would be an interesting experience if video games were introduced into their curriculum to evaluate a new way of students' learning and identify non-traditional resources that might be effectively valuable in expanding educational resources. Some video games could trigger a deep and significant discussion about critical issues that are relevant to today's problems. For example, some video games portray science as destructive to humanity, while others promote progress and evolution. The video game *Bioshock* (2007) represents biotechnology as a destructive force that controls citizens, emphasizing the negative effects of science due to the genetic engineering

[315] Ibid., 202-203.

development of viruses and weapons. Therefore, video game designers need to consider the impact of science video games on players to stress factual information and help players practice their knowledge. "…There is considerable potential for popular representations, including video games, to influence public opinion of not only science, but also the related social and ethical issues."[316]

A large number of educational and commercial video games ranging from computer games, console games to virtual and augmented video games, all invested in developing games related to biology and bioengineering science to assist students in their learning tasks. Some video games allowed students to experience virtually scientific concepts that will not be possible with a traditional science textbook. Some of the video games studied below are great potential for teachers to add as new resources for students.

SCIENTIFIC LITERACY FROM DIGITAL GAMES

Video games can popularize scientific knowledge and create a new communicative medium among players where science is transmitted in novel ways. Learning science through the experimentation and experiences offered by video games may help spread scientific literacy. For example, "Playing at Scientists: Video Games and Popularizing Science" (2012) describes how scientific knowledge could be transmitted to players through video games. The list of digital games represented in this chapter reveals scientific topics that could help students deepen their learning about science and present a visualization of abstract concepts. For example, *Nano Legends* (2009) is an educational video game about the science of cells and cancer designed for

[316] Blake Murdoch et al., "Biotechnology and Science in Video Games: A Destructive Portrayal?" *Health Law Review* 20, no. 1 (Health Law Institute 2011): 16.

middle and secondary biology curricula and recommended by the National Science Teachers Association (NSTA). Among the students who participated in this game, there were some in each of the classes who participated classified as special needs students. The mission of the player is to destroy forms of carcinogens that attack animal lung cell. During the game, students learn about the cell parts and their functions. They also learn how white blood cells fights infection and how cancerous cells divide and travel through the body to develop additional tumor. They also learn about different types of cancer and how mitochondria creates energy by breaking down the glucose that is made of hydrogen, carbon and oxygen. The game was intended to enhance students' scientific concept about animal cell and carcinogens. However, according to the Canadian Journal of Science and Mathematics and Technology Education, some teachers who were interviewed after using *Nano Legends* in their class, raised concerns and refused to use the video games as instructional tools as they consider video games not serious learning experiences and their role as teachers is reduced to game-playing instruction. Their criticisms of this game included its "lack of pedagogically-appropriate games and the lack of understanding of cognitive learning supported by more complex role-playing modern games."[317] Some teachers stated that the video game included some topics such as the active and passive transport of materials across cells that were beyond the eighth grade biology curriculum. They also noted the missing elaboration on the different parts of the cell and the multifunction that organelles undergo.

[317] Jamani Kamini Jaipal and Figg Candace. "Using Video Games in Science Instruction: Pedagogical, Social, and Concept-Related Aspects," *Canadian Journal of Science. Mathematics and Technology Education* 9, no. 2 (2009): 118.

On the other hand, video games enthusiasts and teacher-gamers who advocate and promote video games' implementation in schools believe that as teachers become more comfortable using video games in their classroom as a tool for instruction and not only a supplementary resource to reinforce learned strategies, then video games could become part of the instructional curriculum that promote students' learning.

> The main value of video games as a means of popularizing science is their capacity to make the functioning of complex systems understandable via experimentation and experience […]. This way of learning, called learning by doing, is based on assuming knowledge implicitly, knowledge resulting from the theoretical basis being inserted into the game's rules and gameplay.[318]

VIDEO GAMES AND ENVIRONMENT

In the following game, scientific knowledge is transmitted through *In Other Waters* (2020), an exploratory video game that gives player a defined action to complete. Ellery Vas, a xenobiologist avatar in the game, is called to search for her missing partner Minae on a planet called Gliese 677Cc. She is guided by Artificial Intelligence (AI) to dive into the ocean and explore an underwater alien landscape. The game follows a storyline similar to a mystery novel where Ellery needs to catalog all the alien lifeforms in the ocean of the planet Gliese 677Cc. Players of this game "discover" the planet's life and learn about the differences between "natural" and "artificial" life. They map the ocean floor through experimentation and discovery, collect samples of species, scan and sketch evidence that leads to new ecosystem findings.

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[318] Olivia Merce, "Playing at Scientists: Video Games and Popularizing Science," *Quaderns del CAC*, no. 30 (2012): 34.

During the game's journey, players may choose to study creatures or investigate new areas in the ocean and come back to the lab to examine collected samples. In some cases, players have more than one path to choose from. They can explore the geology of the ocean with 3D line map or analyze the biology of alien sea creatures. Once players collect a certain amount of data on a particular species, Ellery, the xenobiologist avatar, names it. The species found, such as animals, fungi, and plants, are grouped and listed under taxonomy with detailed information for players. The taxonomy lists the appearance and behavior of creatures with a sketch that allows visualization. The game's objective teaches players about the ecology of the ocean, provides insights on the destruction of the environment and the problems that will encounter humanity in the future.

Many similar games include scientific facts and could be considered for use as additional practice for students to enhance their interest in science or to make science concepts more appealing to them. *Perfect Strain* (2017), for example, is a game designed by a biology faculty member to teach undergraduate biology students about natural selection. Players are on an expedition to save the Earth from destructive pollution, and they adopt the role of scientists to develop microbe strains that could resist the Earth's pollution and clean it up. The game requires players to create different types of strains on each level and to increase by artificial selection process the desired resistant microbes to clean up the Earth. Student-players learn that species will survive and adapt through genetic variation (natural selection) to the changes in the environment.

In the video games industry, game designers create games that look appealing to players. In the case of the *Biohazard* (2017), the game targets undergraduate students in biology and

environmental science. Student-players' mission is to save civilians from a chemical gas attack and locate the gas source. Players must investigate and communicate with their peers to increase their chances of success. Players' communication and collaboration simulate real scientists' work to solve a problem. Therefore, "the possible utility of video games as a vehicle for the development of scientific thinking goes beyond the explicit inclusion of cognitive skills relating to generating, testing, and revising hypotheses."[319]

VIDEO GAMES AND PANDEMICS

Learning science through video games could be the next engaging tool to increase students' interests about science, encourage students to pursue careers in science, and enhance their science education. For example, *Microscopya* (2022) is a new video game that allows students to explore inside of the cell. The game provides students with educational puzzles and discover the intricate dynamics of the molecular world. The game "encouraged students' participation in scientific arguments and led to the use of higher-level vocabulary words than [students]would use in everyday conversations."[320]

Eight hundred seventy-six students (6th to 9th grade) including students with reading disability participated in a study where science video games like *You Make Me Sick!* (2011) were conducted to measure science learning via non-traditional teaching methods. In this game, the students learn how to design their own bacteria and virus to infect a virtual human host and to spread infection as fast as possible. They were able to understand the process of infection and

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[319] "Gaming Science: The Gamification of Scientific Thinking," *Frontiers in Psychology 4*, no. 607 (September 2013): 7.

[320] Matthew Marino et al., "Students' and Teachers' Perceptions of Using Video Games to Enhance Science Instruction," *Journal of Science Education and Technology* 22, no. 5 (October 2013): 668.

familiarize with microbiology. Some students expressed their motivation to learn science through video games as they were "given choice and autonomy in learning decisions, learning was tied to novelty, and learning occurred socially with peers."[321] One student stated that the game provided the choice of making a virus an air-born or physical. Students were able to connect with the game and interpret the scientific facts that they were learning. Ninety percent of these students preferred playing video games instead of taking a test on paper. "One student who had Asperger's Syndrome (a neurodevelopmental disorder merged into autism spectrum disorder) noted that it would not be fair to play a video game instead of taking a test because a test was the only way to show what you have learned."[322] Teachers who participated with their students assert "that video games could be an effective way to measure struggling readers' scientific knowledge. [They] also noted that the games improved the accessibility of the science content and contextualized learning in a way that is impossible with traditional curricular materials."[323] Moreover, teachers claimed that students who had issues with science projects or tests were the most engaged when playing the video game. Some challenges still need to be addressed as Matthew Marino from the Department of Child, Family and Community Sciences at the University of Central Florida notes. He believes that besides the engaging features, "many science video games lack clear goals and objectives […]. Very few are capable of capturing student game play data and displaying the results to teachers in real time."[324] To guarantee

[321] Ibid., 676.

[322] Ibid., 674.

[323] Ibid., 675.

[324] Ibid., 676.

successful and effective results when using video games to assess scientific learning, teachers need to consider learners' disabilities, their background knowledge and their culture in order to improve STEM education.

Some video games do not only focus on scientific concepts and strategies that students need to develop, but they evolve around a plot that requires students to combine their critical and ethical thinking to solve the problem such as the case study of *Plague Inc: Evolved* (2015). This game could potentially help students "transfer insights from gaming sessions to real-world issues."[325] Players encounter an ethical frame within the game that enables them to reflect and "refine the logic they used to diagnose and propose solutions for important real-world problems."[326] During the game, students prioritize their choices, compare and contrast options available, and critically solve problems for the game to be completed and ultimately won. *Plague Inc: Evolved* is a remake of *Plague Inc*. (2012), in which players control the spread of a plague according to their pathogen selections to kill the world's population. In this earlier version, players manage the ripple effect between biology, socio-economic and geographic factors to measure a disease's infection transmissibility and death rate. For example, players enhance their plague (as they gain more "DNA Points") with deadlier symptoms to become more transmissible and adaptable to the environment. A challenging aspect of the game requires players to know the geographic and socio-economic areas where they want their manufactured disease to spread. Depending on these features, the infectivity and mortality rate of the pandemic will have more or

[325] Matthew Kelly, "Designing Game-Based Writing Projects to Foster Critical Ethical Reasoning in the English Classroom: A Case Study Using Plague Inc: Evolved," *Simulation and Gaming* 52, no.2 (Sage Publications, 2021): 158, https://doi.org/10.1177/1046878120953592 (accessed January 15, 2022).

[326] Ibid., 155.

less effect on the population. For example, spreading disease in developing countries is easier, especially when clean water resources are scarce or unavailable. Moreover, access to immediate medical attention or vaccination takes longer due to limited access to medical and technological advancements in medicine. The challenge in the game stems from managing the spending of "DNA points" to evolve the disease while considering the different geographical and socio-economic conditions of the locations. Players are also provided with a list that includes upgrading options with biological information and simulation describing the effect of the disease in a particular region. Players are required to expand the plague as much as possible by any accessible means. Training players in creating and controlling a disease depending on socio-economic and geographic features may increase their understanding of the plague circulation process and create a great opportunity to learn how different communities are impacted according to their geographic location and their economic status.

To spread scientific awareness, Ndemic Creations, the group that developed *The Plague Inc: Evolved*, was asked by the World Health Organization (WHO), and Coalition for Epidemic Preparedness (CEPI) to create a reverse game that will stop the pandemic instead of evolving it due to the current pandemic Covid-19 that the world is struggling to control. In 2021, the group created *The Cure* game to help players understand the influence of pandemics on the health and well-being of people and the possibility of developing a vaccine. *The Cure* allows players to control the expansion of a pandemic, stressing the disease's complexity and highlighting the global viral threat. Players learn how to manage quarantine periods, practice social distancing, and enhancing public services. They also try to control the disease expansion and boost healthcare system.

In a more sophisticated setting, the *Mission Biotech* (*MBt*) (2020) game was integrated into high school curriculum materials to measure students' learning outcome and how much the game support the science curriculum. The game-designers were from different interdisciplinary domains, including biomedical scientists, biology instructors, technology experts, and game developers and designers. The player is placed in a virtual laboratory to find the cause of a viral epidemic and learn how a biotechnologist isolates DNA from cells to perform a polymerase chain reaction (PCR) to identify DNA samples infected with the virus. The virtual lab is equipped with micro-pipettors, microcentrifuge, and thermocycler to simulate a biotechnologist's work. To advance in the game, players need to make multiple PCR reactions on patients' blood cells to detect the infection. According to the data collected from their experiments, students will define if the sample is infected. Players use clues in the game to create a PCR protocol to help them analyze and interpret the PCR reactions collected from different samples. The research conducted by Jennifer L. Eastwood, from the Department of Biomedical Sciences at Oakland University, and Troy D. Sadler, from MU Science Education Center at the University of Missouri, explain the steps of *MBt* game as follow:

> In level 1, players extract DNA from a patient sample using a lab protocol and appropriate reagents and equipment such as spin columns and a microcentrifuge. In level two, players reinforce and build upon this knowledge. They isolate DNA from two patients and perform PCR with specific viral primers. The idea of positive and negative controls for PCR is also introduced in this level. The third level adds complexity by

introducing RNA viruses and reverse transcription as a necessary precursor to standard PCR when the target virus is a retrovirus. In the final level, players are challenged to pull together all of the ideas and protocols they used in earlier levels.[327]

Beside the entertaining and innovation, video games can provide a supplement to the curriculum and reinforce students' cognitive skills. *MBt* helps students learn about biotechnology processes and offers a significant resource for learning about "important content, practical applications of science, and data analysis procedures. It also allowed them to extend their curricula to include cutting edge research and expose students to careers in growing science field."[328] Once the game is effectively integrated into the classroom, teachers can customize their students' goals and objectives expected to be learned. In that regard, *MBt* allows students to work in a virtual laboratory to stop a viral outbreak. Applying scientific concepts while playing the game helps students gain more practice in learning how to find the cause of an epidemic by applying virtual lab functioning such as micropipettors, a microcentrifuge, and a thermocycle. In this game, students learn about the structure of DNA, its functions and how DNA amplifies PCR (polymerase chain reaction). Players follow biotechnology lab procedures in performing PCR reactions to determine the viral pathogens in the blood samples of the patients on the game. They learn to interpret the data and "to perform PCR, students must learn the conceptual significance of isolating DNA from cells, using primers specific to viral DNA sequences, and carrying out

[327] Jennifer L. Eastwood et al., "Teachers' Implementation of a Game-Based Biotechnology Curriculum," *Computers and Education* 66 (Elsevier Ltd, 2013): 13.

[328] Ibid., 22.

cycles of DNA replication through temperature cycling."[329] They also learn specific vocabulary and techniques used in experiments such as denaturing, annealing, and elongation. Since the game allows students to practice these drills as much as possible, it will help the teacher reinforce these basic scientific concepts. Students navigate the game independently and learn at their own pace. Students usually learn about DNA extraction from plant cells or E. coli and *MBt* game reinforces their learning as it allows them to virtually extract DNA. "Overall, the teachers and students using the *MBt* game and associated curriculum reported that it was a positive experience that supported learning and generated interest in biotechnology,"[330] in science content and scientific processes. The game could also be used by teachers to discuss biotechnology careers with students.

VIDEO GAMES GENETICS AND CRISPR

In a more advanced domain of sophisticated science learning, video game developers designed their games with the intent to explore real-world issues such as the biotechnology innovation, CRISPR, and the ethics involved in genetics decision-making. The Innovative Genomics Institute, composed of researchers from the University of California at Berkley and the University of California at San Francisco, created a virtual reality game called *CRISPR-VR* (2018) that allows student-players to venture inside sickle cell disease and learn through simulation how CRISPR therapy could be a potential cure. Players travel inside the cell and

[329] Ibid., 13.

[330] Ibid., 15.

tissues where and they will be able to "locate," "cut" and "repair" the DNA sequence to cure impacted cells.

To give high school biology students a unique and valuable experience where they can apply their comprehension of Mendelian inheritance, DNA fingerprinting, blood analysis as part of genetics unit included in high school biology curriculum, student-players were introduced to a virtual game to solve a mystery crime. In "Assessing Twenty-First Century Skills through a Teacher Created Video Game for High School Biology Students" (2010), Leonard A. Annetta, associate professor in Education and Human Development at George Mason University, notes that today's students' education relies heavily on innovative technological tools and software to "correlate with the future success of the country's economic growth and power"[331] as scientifically literate students lead the country in prosperous and advanced ways of living. On a broader spectrum and beyond teaching only genetics and CRISPR, he adds that new topics should be added to the curriculum that reflect the learning of novel technological skills and help develop students' scientific literacy to meet economic development challenges.

According to Annetta, "a primary challenge for US education is to transform [students'] learning processes in and out of school and to engage [their] interest in gaining twenty-first century skills and knowledge."[332] Therefore, Annetta considers video games as tools to assess students' knowledge. He claims that through video games, students could learn "the skills of

[331] Leonard A. Annetta et al., "Assessing Twenty-First Century Skills through a Teacher Created Video Game for High School Biology Students," *Research in Science and Technological Education* 28, no. 2 (Routledge Journals, Taylor and Francis LTD, 2010): 101.

[332] Ibid., 102.

manipulating, applying, analyzing, synthetizing, and evaluating knowledge."[333] Games could be a vehicle for learning and could aid in the learning process regardless of the game's complexity. Students who normally fail in science class and are not motivated might succeed in playing video games and be more engaged than traditional learning settings as video games are multidisciplinary. "Because playing does not feel like working, students may spend more time with a game than they would reading related material or doing problems at the end of the chapter."[334] Innovative advances in information technology could reshape students' learning in biology and genetics and transform it into more effective practice since students are already immersed in the digital age. Visualizations and scientific models in video games help students understand scientific concepts to construct scientific knowledge. "Science education […] is one area in which multimedia instruction has been increasingly employed to communicate complex ideas and concepts in instructional settings, providing additional entry points for students to leverage understanding through alternate modalities."[335] Although motivation and engagement are not enough to guarantee a player's learning, cognitive engagement is a crucial step in building an understanding of scientific concepts.

To assess students' knowledge through the steps that Annetta claims above, students are introduced to genetics concepts through a video game created for the specific goal where students apply their previous knowledge to solve plot in the game. The following game, the

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[333] Ibid., 103.

[334] Leonardo Annetta et al., "Investigating the Impact of Video Games on High School Students' Engagement and Learning about Genetics," *Computers and Education* 53, no. 1 (2009): 76.

[335] Ibid., 76.

Multiplayer Educational Gaming Application (MEGA) entitled *The Stolen Fortune of I. M. Megabucks* (2006) and intended for biology classes allows players to investigate, follow clues, and solve a murder case by using scientific inquiry. The game teaches players when to use Punnett squares (a diagram used by biologists to predict the genotypes of a cross or breeding experiment) and pedigrees (representation of family tree) to solve the mystery and find the murderer. They also learn about Mendelian inheritance theory, the classification of blood types, DNA and fingerprinting as part of genetics and the basic clues necessary to relate the crime scene to the murderer.

As Annetta explains, the game is based on the famous crime scene investigation (CST) television series as the game uses a background story to engage players in the mystery aspects of the game. The plot of the narrative recounts the sudden and tragic death of Mr. and Mrs. I. M. Megabucks who left a fortune behind to family members hidden in a safe at their home. The access to the safe's combination is restricted to family members only. However, when family members gathered to read the will, they found out that the inheritance was stolen and some blood was left at the crime scene. One more clue is given to players about the suspect seen by the butler; the suspect has a bent thumb, an inherited trait that leads to the elimination of possible suspects during the investigation. Clues are offered to players each time they click on a character or an object where they will be informed about the crime scene. After creating Punnett Squares, students reconvene in the mansion, where they discuss their analysis and data. If the players failed to recognize the suspect, they return to the beginning where they must re-examine potential clues and re-evaluate their genetics examination. To find the culprit, students need to make a pedigree to eliminate suspects and discuss the rationale behind their selection. The

MEGA game could be a supportive tool to review genetics features and characteristics and help students critically think and analyze data collected during play. Applying scientific knowledge into a practical setting is crucial for the learning process. "It can be argued that students playing educational games that have rich problem-solving and complex problems embedded in the back-story are being exposed to a new scientific literacy. This is literacy in the form of understanding real world problems and solving those problems in a simulated virtual environment."[336]

In Annetta's view, life in the twenty-first century requires students to have holistic knowledge based on scientific and technological literacy. Knowledge in global, multicultural, and economic management are key to countries' growth and the well-being of the world's citizens. Teachers have to train students to adapt, manage complexity, be creative and innovative in finding solutions and help them build the ability to apply higher-order thinking so they can contribute to the development and progress of science. According to Annetta, "these educational games commonly require the use of logic, memory, problem solving and critical thinking skills, visualization and discovery. Moreover, the use of these gaming technologies requires that users manipulate virtual objects using electronic tools and develop an understanding of the complex systems being modeled."[337] As a curricular tool, video games can be difficult to manage due to their complexity and to the 3D multiuser virtual environment that can causes distraction. Engaging and motivating students are not enough to sustain meaningful and high quality

[336] "Assessing Twenty-First Century Skills through a Teacher Created Video Game for High School Biology Students," *Research in Science and Technological Education* 28, no. 2 (Routledge Journals, Taylor and Francis LTD, 2010): 110.

[337] "Investigating the Impact of Video Games on High School Students' Engagement and Learning about Genetics," *Computers and Education* 53, no. 1 (2009): 75.

cognitive engagement. Video games could be used to initiate students' interest and gauge their existing knowledge, but they then "need to be designed with close attention to the embedded instructional content and less emphasis on animation, text and audio that does not aid in the learning process."[338] Annetta adds that to achieve academic enhancement with video games "technology companies should use classrooms as alpha and beta test centers […]. The skills gained by the students can be an avenue by which the twenty-first century skills can be acquired and used as a driver of economic growth and power. "[339] Building off of Annetta's explanation of the importance of video games in growing students' knowledge and promoting science, new platforms supporting learning are created with more sophisticated software that enables students to be immersed in virtual experience. Hence, the creation of virtual reality games with mounted devices that transform the learning environment and allow new exposure and new experiences to be developed.

VIRTUAL REALITY VIDEO GAMES

Virtual reality (VR) video games have also been used to support traditional learning by making intangible concepts easier to understand through visualization and immersion. Learning through VR experiences could optimize knowledge acquisition and add new practice to students' skills repertoire. Integrating VR into the science classroom could facilitate learning and discussion of many science topics. Innovative technologies' pervasiveness in our daily lives needs to be redirected for fruitful purposes. Students are spending lot of time on their devices,

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[338] Ibid., 80.

[339] "Assessing Twenty-First Century Skills through a Teacher Created Video Game for High School Biology Students," *Research in Science and Technological Education* 28, no. 2 (Routledge Journals, Taylor and Francis LTD, 2010): 110.

consuming whatever is offered. Therefore, creating more relevant games that help students connect with real problems and their reality could greatly impact their intellectual growth, creativity and problem-solving skills. Learning through experience remains the ultimate way of transmitting knowledge and understanding concepts. In VR games, student-players become part of the game as active learners and are thus able to manipulate complex concepts through simulation and visualization.

For example, *Maroon* (2017) is an immersive interactive virtual reality game that teaches students about physics. Abstract concepts such as Faraday's Law and Huygens's Principle are experienced through the VR game. These experiments allow players to visualize the concepts of induction and diffraction. The first experiment Faraday's Law presents the concept of induction when a conductive non-magnetic ring interacts with a permanent magnet. Students experiment with changing magnetic flux with magnet movement and visualize how electric current is induced. Students can also change the magnet and the coil parameters to change the force of magnetism. The second experiment demonstrates the Huygens's concept of diffraction. The experiment consists of using water waves in a basin with a slit plate to demonstrate diffraction. Once the wave hits the plate, a new source of waves propagates. Students could control the result of the experiment by placing three types of slit plates or changing the frequency, amplitude, and wavelength to make the diffraction concept visible in the basin. "Some pupils mentioned that learning with *Maroon* was easier and more engaging than traditional learning methods."[340] They also expressed their enjoyment of trying a new experience away from their school routine.

[340] Michael Holly et al., "Designing VR Experiences-Expectations for Teaching and Learning in VR," *Educational Technology and Society* 24, no.2 (International Forum of Educational Technology and Society 2021): 113.

However, a small group of students expressed their concerns while using the VR. They used the wrong buttons to interact with the game and few felt dizzy and nauseous while using the device. In addition some limitations were also observed due to classroom setup, costs and lack of some students' experience with digital games.

In 2021 study, VR tools showed great learning potential. "When using VR as a complementary tool to traditional learning methods, students showed higher performance in understanding and recognizing concepts. Furthermore, learners using VR technologies remain more motivated during their learning process."[341] VR offers students a safe environment where they can conduct otherwise dangerous experiments, practice their theoretical knowledge, and boost their engagement and interest in learning about complex scientific concepts. The growth of technological applications of VR in the educational domain could contribute to a shift in students' appreciation of scientific knowledge. VR games share a symbiotic relationship with traditional video games, as both technologies develop interactive and compelling experiences. Traditional video games focus on repetitive interactivities while VR games are more interactive to the player. VR focus more on haptics[342] instead of using 2D system, locomotion and movement of the entire body which makes the virtual game completely a different experience from traditional video games. In recent research, students who were "using VR as a complementary tool to traditional learning methods, […] showed higher performance in

[341] Ibid., 108.

[342] Merriam-Webster definition of "haptics": The use of electronically or mechanically generated movement that a user experiences through the sense of touch as part of an interface (as on a gaming console or smartphone).

understanding and recognizing concepts."[343] For example, students in the medical field could have an immersive surgical experience through a recorded video from a camera placed on a helmet. Medical trainees could experience the surgical room and the operating surgery in virtual reality. Moreover, in the Immersive Learning Laboratory (ImmLL), science students were exposed to the interaction of various biomolecules such as DNA and proteins to understand how these molecules are structured and how they function to maintain internal body homeostasis. To improve students understanding of homeostasis, students interacted with 3D-model software in ImmLL to gain not only an understanding of "how intermolecular forces are at play in the folding of proteins, but also to recognize key motifs in protein structures and how these contribute to the reactivity and function of protein enzymes."[344] VR also contributes to the learning process by supporting learning through different teaching methods. The novelty of this technology might be appealing to students who show a lack of interest in learning complex scientific concepts by enabling them to engage in an immersive experience that allows them to be part of a virtual world.

AUGMENTED REALITY GAMES[345]

Due to challenges such as a lack of students' interest in the topic studied, conventional learning and teachers' inability to customize individual time for each student, educators struggle to keep their students engaged and interested. Moreover, the science curriculum is overloaded

[343] Ibid., 108.

[344] Kiran Ijaz et al., "The Immersive Learning Laboratory: Employing Virtual Reality Technology in Teaching," Proceedings of AAEE 2017 Conference (December 2017): 7.

[345] Augmented Reality games are games that allow players to overlay digital graphics and sound on an environment captured by the camera of a tablet or a portable phone.

and textbooks are voluminous with excessive content that require students to memorize the scientific concepts. Finding an interesting and engaging way to teach science could be by itself sufficient innovation to improve students' learning about science. Augmented reality (AR) games may also help revolutionize the learning experience. AR could promote students' interest in learning and support content knowledge construction. Using videos, sounds, and pictures is an attractive method to hold students' attention and has proven to provide an easier way to retain information. AR games have properties that combine real and virtual objects in the real world and in real time to potentially increase students' imagination and creativity, and the ability to view class materials from different perspectives. "The coexistence of virtual objects and real environments allow learners to visualize complex spatial relationships and abstract concepts, experience phenomena that is not possible in the real world."[346] Student-players could develop new forms of literacies that assist them in the twenty-first century. For example, *The Human Respiration System*, an AR game developed in 2013 increased students' understanding of the respiratory system through visual contexts. The "AR app allowed students to visualize the workings of a set of lungs situated inside a student's body using marker-based AR and handled display."[347] Students were able to see the lungs from different angles, observe the inhalation and exhalation, and visualize different body parts. "Students stated that, owing to the AR app, they gained a deeper understanding of lung function and better understanding of physical

[346] Hsin-Kai Wu et al., "Current Status, Opportunities and Challenges of Augmented Reality in Education," *Computers & Education* 62, no. C (Marsh 2013): 42.

[347] Brigitte Nielson et al., "Augmented Reality in Science Education-Affordance for Student Learning," (September 2016) https://www.researchgate.net (accessed April 30, 2019): 160.

dimensions."[348] To increase engagement, students could further explore human anatomy, discover each organ and learn how organs function together. Students could also change the size of the organs or increase the amount of blood cells in experiments. They can discover inside the human body while "travelling in" a blood cell and explore the heart, veins, and arteries. Students can also see layered illustrations of the skin, nerves, bones, organs, and they can remove layers to focus on each particular item. Students can view the molecules' structure in 3D, rotate the simulation, and explore the interaction between molecules. Learning about the human body structure in traditional textbooks requires illustration, pictures, diagrams, and memorization of scientific information. AR could bridge the gap between the scientific concepts learned through textbooks and the applicable knowledge of their understanding. Through AR, students could visualize the structures in an easier way and conceptualize scientific information. In AR, students could be able to see how each organ reacts if attacked by a particular disease through interactive visualization techniques.

Augmented reality game designers attempt to design games that present not only human anatomy but also illustrate other scientific concepts that are challenging to conceptualize. In "How Augmented Reality Enables Conceptual Understanding of Challenging Science Content" (2017), the Bernoulli principle is explored by visualizing the underlying causal mechanisms in a science museum setting. The phenomenon states that the internal pressure of a fluid decreases when the fluid gains speed and vice versa. Stated differently, fluid speed and pressure have an inversely proportional relationship. Visitors experiment with these concepts through a dynamic

[348] Ibid., 160.

visualization, called the Bernoulli Blower, which consisted of air blowing to keep a plastic ball afloat. To illustrate the Bernoulli principle, a physical plastic ball is floating in midair due to the interaction of fast air coming from the blower and the still air of the room. On a screen, a digital illustration shows diagonal arrows going up as fast air and shorter arrows going down, illustrating the room air. Since the ball is not floating away due to the fast air, the room air is exerting a greater pressure on the ball and keeping it afloat. Therefore, "the speed and pressure of flowing air are inversely proportional."[349] Through this experiment, students grasp the concept of the Bernoulli principle and see the relationship between two different air speeds, which help them understand that air moves faster when it has lower pressure and slower when it has high pressure. A great representation of Bernoulli's principle with AR could help students understand how this principle is applied in aviation. The architecture of the airplanes' wings is curved on the top and flat on the bottom. Since the air in the sky moves concurrently, it is slower at the bottom and creates more pressure but faster on top with less pressure. This is what creates "lift" and enables the airplane to fly.

Using AR games in educational settings to facilitate students' understanding of complex concepts could also provide a rich resource to exemplify the application of knowledge in informal contexts. While discovering AR games, students practice theoretical aspects learned in textbooks through AR and develop new skills in learning. It is important to use AR games with an educational purpose in mind to support students' learning and ensure engagement. Students could be asked to think of their own hypotheses, "what happens if questions," and collect data to

[349] Susan Yoon et al., "How Augmented Reality Enables Conceptual Understanding of Challenging Science Content," *Journal of Educational Technology & Society* 20, no. 1 (January 2017): 160.

analyze them. In that way, students are not only consuming information and being passive learners, but also collaborating and contributing to their learning process as AR "is not only enhancing but also transforming student inquiries in science."[350] Therefore, technology use in the classroom needs to endorse "the five learning principles of active construction, situated learning, cognitive tools, reference to learning goals and scaffolding to support students in completing challenging tasks."[351] With the incorporation of recent technology such as video games, VR and AR in the field of education, educators and teachers may teach scientific concepts that improve the ability of students to understand scientific hypotheses, evaluate, analyze their findings and proceed according to scientific method.

However, some critics of the field, such as Cagdas Erbas, School of Education in UK, and Veysel Demirer, Department of Computer Education and Instructional Technologies in Turkey, caution that while AR has the ability to motivate students' education and expose them to new supportive materials but AR cannot replace teachers in the classroom. They conducted a study on a number of students in ninth-grade biology where students learn about cell biology. This topic usually needs special high-tech microscopes, which are expensive and unaffordable for many schools. In this case, AR provide a more affordable medium besides textbooks for visual illustration of invisible or abstract content in biology. Cells of euglena, paramecium, and plant cell were represented with AR. The study claims that students who experienced cell biology through AR were more motivated and excited about learning since they could visualize

[350] Ibid., 172.

[351] Ibid., 162.

through interactive digital representation the different parts of a cell. "AR activities positively affect student ability, development of interaction, and motivation in all age groups. It can be said that AR activities significantly influence student's motivation and improve their motivational beliefs."[352]

The goal of using AR in science learning is not to replace teachers in the curriculum but to redesign teaching in order "to make it more interesting, captivating, engaging, and learner-centric."[353] Explaining science with new approaches and techniques might improve students' learning about scientific topics as they discover innovative and interactive methods of science learning that are complex. Research conducted in a high school biology class in 2019 aimed to measure learning improvement in biology using an AR application that focused on food biotechnology. The subject was developed to help students visualize biotechnology with 3D animated pictures. Students were asked questions such as: Do microorganisms transform soybeans into soy sauce? Could they transform milk into yogurt and cheese? What is the difference between these products, and what microorganism is responsible for this process? "Teaching with visual materials can provide more concrete meaning, show connections among ideas, and also make lessons more interesting to students."[354] The study emphasized the role of AR in enabling students to process words and pictures simultaneously. According to the

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[352] Cagdas Erbas and Veysel Demirer, "The Effect of Augmented Reality on Students' Academic Achievement and Motivation in a Biology Course," *Journal of Computer Assisted Learning* 35, no. 3 (Wiley Subscription Services, Inc, 2019): 456 https://doi.org/10.111/jcal.12350 (accessed December 2020).

[353] Cathy Weng et al., "Enhancing Students' Biology Learning by Using Augmented Reality as a Learning Supplement." *Journal of Educational Computing Research* 58, no. 4 (Sage Publications, 2020): 748 https://doi.org/10.1177/0735633119884213 (accessed June 2021).

[354] Ibid., 764.

research, learning occurs due to spatial and temporal contiguity on one hand and redundant actions and knowledge retaining on the other hand. Because AR has the feature of overlaying virtual and real object simultaneously and providing information and pictures in 3D, learning becomes more interesting. The animation on the screen with audio text immerses students in learning and keeps them engaged. In addition to overlaying virtual objects and objects from the real-world, AR technology facilitates the connection between the knowledge acquired through AR and connects it with real world. In the case of food biotechnology, students are able to see the microorganism moving due to the animation feature of AR. The implementation of AR reinforces the statement "that students learn better from words and pictures than from words alone."[355] It also showed that students who participated in the AR learning were more highly motivated than the rest of the students. The learning outcome was measured according to Bloom's cognitive levels where students had to evaluate, analyze, understand, remember and scaffold knowledge in an effective way. "…The experimental group showed significantly higher motivation and self-efficacy than the control group […]. Students' ability to visualize and understand abstract concepts increases and hence the increased motivation and self-efficacy."[356] Cathy Weng, from Graduate Institute of Digital Learning and Education at National Taiwan University of Science and Technology, notes that learning with AR should be supported as students showed "better understanding, recall, concentration, interaction"[357] and they enjoyed the

[355] Ibid., 751.

[356] Ibid., 753.

[357] Ibid., 764.

entertainment aspect better than learning from traditional textbooks. However, AR cannot be a universal tool to teach all students. Some students with special needs or visual impairments would find the use of AR challenging due to difficulties in manipulating the sets and the overhead devices. Even though digital games might not be accessible by everyone, they still provide some values to education since they offer new experiences, new tools and new resources as a variety of learning approaches.

SUGGESTIONS FOR DIGITAL GAMES SUCCESS IN EDUCATION

To show students how professionals solve problems in real-life, it can be helpful for students to learn through video games, virtual reality and augmented reality to experience the values of a given profession and to conceptualize the interconnection of different systems in this world and how interference with or change in one subsystem would affect other systems. Being part of such scientific discourse encourages student-players to engage in learning, and video games might be one tool to achieve this goal. "Video games […] represent one of the primary platforms through which youth observe and interact with scientists. […] Video games are fast becoming a key science touch point for average citizens."[358]

Similar to any new technology or innovation that becomes reliable and pervasive, video games are here to stay and it is important to make their presence useful. However, they are not a panacea and might even be considered an obstacle by some. "The challenge for our education system is to leverage the learning sciences and modern technology to create engaging, relevant, and personalized learning experiences for all learners that mirror students' daily lives and the

[358] "Portrayals of Technoscience in Video Games: A Potential Avenue for Informal Science Learning," *Science Communication* 36, no. 2 (Sage Publications, 2014): 23.

reality of their futures."[359] To improve STEM education, the educational system is invited to invest in innovative and creative ways to attract students to learn science and pursue careers in science. Introducing various materials to teach students about science could be very beneficial as students would communicate together, share experiences, and even reach valuable insights when connecting virtual world problems in games with real-world. "Game design needs to take into account four meta-principles to support knowledge integration: making science accessible, making thinking visible, helping students to learn from each other, and promoting autonomous learning."[360] Learning experiences involve several cognitive, affective, and psychomotor skills to reach educational goals. Students need to recall information from previous knowledge, construct meaning from the instruction given, combine previously acquired skills with new ones, evaluate and apply their learning to solve new problems, and make good judgement related to real-world problems. Therefore, digital-based "learning material can significantly enhance students' higher level cognitive capabilities, enabling them to scaffold knowledge effectively."[361] It also assists students in retaining knowledge and promotes cognitive skills to be stored in long-term memory.

To reach the greatest potential, educational game designers need to balance the educational content embedded in digital games with appealing graphics, audio and engaging text. "What is crucial in the learning process is our ability to parlay student attention and engagement

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[359] *Learning Science through Computer Games and Simulations,* 58.

[360] "Investigating the Impact of Video Games on High School Students' Engagement and Learning about Genetics," *Computers and Education* 53, no. 1 (2009): 80.

[361] "Enhancing Students' Biology Learning by Using Augmented Reality as a Learning Supplement." *Journal of Educational Computing Research* 58, no. 4 (Sage Publications, 2020): 753 https://doi.org/10.1177/0735633119884213 (accessed June 2021).

to aid them in the development of more robust understanding of complex science concepts. If this occurs, then game on."[362] In other scholars' opinions, such as Annetta, the success of educational video games relies on teaching students to be game developers as "educators often subscribe to the notion that you learn material best when you have to teach it."[363] When students develop a game, they will have to ensure that the scientific topic is fully correct and bears no misconceptions, hence, they are required to have full knowledge acquisition of scientific materials to guarantee the game's success.

Commercial and educational digital games have achieved a prominent presence in the twenty-first century due to their immersive and compelling interactive engagement and to mounting evidence that supports the idea that digital games have the ability to promote students' learning outcomes. They have gained great popularity in both public and school settings and to the increasing interest of students in participating in scientific discourse, developing scientific inquiry, and investigating socioscientific issues. Digital games might well be part of the solution in improving the educational system and supporting students' early development of a positive attitude for STEM education. To help teachers keep students interested in science, curriculum developers and digital game designers will need to combine innovative educational technologies with specific educational goals. Giving students more opportunities to connect textbook content with game-play experiences may promote teachable moments as students make connections and

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[362] "Investigating the Impact of Video Games on High School Students' Engagement and Learning about Genetics," *Computers and Education* 53, no. 1 (2009): 81.

[363] "Assessing Twenty-First Century Skills through a Teacher Created Video Game for High School Biology Students," *Research in Science and Technological Education* 28, no. 2 (Routledge Journals, Taylor and Francis LTD, 2010): 110.

"learn strategies to link in-game and out-of-game curricular elements [that] support richer, more integrative student experiences."[364] Digital games allow players to put in action their strategies and plans and provide them a common ground to check their skills and performance.

According to recent research "The Effect of Games and Simulations on Higher Education: A Systematic Literature Review" (2017), "games and simulations lead to improved affective outcomes for university students such as attitudes, motivation, emotional involvement, self-efficacy and satisfaction."[365] Immersive technologies help shift teaching in the new digital age to better mirror complex real-life scenarios and allow students to navigate through the game while discovering and experimenting in a safe and low-risk approach. In addition, it is crucial to make educational games relevant and at the same time ensure that they present accurate scientific content. Moreover, game designers should take in consideration the lack of expertise with gaming for a wide variety of teachers and students, not to mention the absence of developed gaming infrastructure and technical support system at most schools. "The conditions for the success of educational technologies in schools [should] include complimentary shifts in curriculum, pedagogy, assessment, professional development, administration, organizational structures, strategies for equity, and partnerships for learning among schools, businesses, homes, and community."[366] In addition to emphasizing STEM education and enhancing students' scientific literacy, game designers also need to be informed about the development of scientific

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364 "Gaming Science: The Gamification of Scientific Thinking," *Frontiers in Psychology* 4, no. 607 (September 2013): 23.

365 "The Effect of Games and Simulations on Higher Education: A Systematic Literature Review," *International Journal of Educational Technology in Higher Education* 14, no.1 (December 2017): 24.

366 George Koutromanos and al., "The Use of Augmented Reality Games in Education: A Review of the Literature," *Educational Media International* 52, no. 4 (October 2015): 269.

thinking skills for them to create engaging and compelling video games that develop scientific literacy and promotes students' learning about scientific concepts. Since the twenty-first century is imprinted with scientifically and technologically advancements, perhaps including digital games in the scientific curricula could be one answer to improving access to science knowledge and raising scientific literacy that might help reduce conflicts in public opinion about such topics as the viral pandemic, vaccinations, bioengineering weapons, climate change and creationism.

CHAPTER 5

EPILOGUE

Today science has become an essential power in the prosperity of every country. With advanced technology and scientific discoveries, a country can achieve a lot in the fields of medical, health, economic, and the military. Today, the world is facing many challenges, including the Covid-19 pandemic and the war Russia launched on Ukraine, including its threat of nuclear attack. This dissertation aims to highlight the importance of scientific literacy among students and the general public so they can make better decisions and respond to controversial dilemmas. The digitized twenty-first century requires skilled citizens who can function in a technologically advanced environment. Scientific literacy empowers students to engage in reasoning about societal issues, understand scientific inquiry and investigate scientific ideas.

Today, the planet's most powerful economic assets rely on science and technology. Powerful countries are racing to possess the most advanced technological tools and compete in science to create innovative ways to become the dominant global power. Scientific innovations promote better human health and economic development. Scientific literacy is a crucial goal "across the globe: Scientifically literate citizens are critical thinkers who are able to effectively deal with the consequences of our technologically-enhanced world."[367] Investment in science education and research may help humanity solve its current societal and environmental issues. Upgrading the science curriculum by integrating science fiction into classroom teaching can contribute to a useful interdisciplinary and holistic education. As Tom Shippey argues in his

[367] Christine V. McDonald, "STEM Education: A Review of the Contribution of the Disciplines of Science, Technology, Engineering and Mathematics," *Science Education International* 27, no. 4 (2016): 533.

book *Hard Reading: Learning from Science Fiction* (2016) "science fiction is an interest in cultures, in the ways in which intelligent beings could live and think, as dictated by circumstances, their technical ability, their systems of thought."[368] In this final section, I will summarize my research findings and discuss the valuable role of science fiction in influencing and contributing to the spread of scientific literacy. I will also discuss the limitations and constraints that inhibit the use of science fiction in science educational curricular, while proposing opportunities for new research.

This study aimed to discover science fiction's potential for spreading science literacy. The results indicate that science fiction materials provide valuable support for teachers and students to learn more about science in unusual and nontraditional ways. As Amy Green argues, humans learn through storytelling. She states, "the desire to tell stories, to contextualize experience, and extrapolate upon it across all possible genres, lies at the heart of what it means to be human."[369] Students feel more interested and encouraged to learn through science fiction novels, films, or video games. The learning process in such courses changes from teacher-centered lectures to student-centered exploration. Some teachers find that the implementation of science fiction in the curriculum acts as a springboard to introduce relevant and current topics. Problems such as infectious diseases, bioweapons, and climate change are major topics for discussion. With only slight additional technological advancement, these problems might threaten the entire Earth. The need to have well-educated and scientifically literate citizens is

[368] Tom Shippey, *Hard Reading: Learning from Science Fiction* (Liverpool University Press, 2016), 101.

[369] *Storytelling in Video Games: The Art of the Digital Narrative* (Jefferson, North Carolina: McFarland & Company, Inc. Publishers, 2018), 6.

crucial for societies that must make valuable and ethical decisions to save the planet, as well as humanity. The scholarly studies investigated in this dissertation show that science fiction can play an impactful role in supporting teaching and learning about scientific topics through novels, films, and video games. Interestingly, science fiction need not accurately predict the future to encourage people to think creatively about it. Science fiction can motivate science research to move forward and encourage a new generation of futurists.

As discussed above, science fiction can help students compare and contrast real science with fictional information. It can reinforce students' focus on the future with critical engagement with new and innovative technologies. Students can also share their ideas and thinking about current and global issues. Using science fiction to trigger students' interest in science may also make a difference in students' attitudes toward science. Many SF authors have a solid background in science and creatively introduce realistic scientific concepts into their writing. Considered as a sociology of the future, science fiction may help train students in the mind-stretching necessary to the habit of imaginative anticipation. Integrating science fiction into the curriculum could introduce students to a better interpretation of scientific processes and how scientific concepts develop through controlled experiments and connections between science and society. Giving students the opportunity to explore science through fictional narratives and exposing them to relevant issues might expand their scientific knowledge and trigger further curiosity.

Through exposure to science fiction works, students vicariously experience the essential methods of scientific investigation: speculation, data collection and the framing of hypotheses, all of which are effective ways of exposing students to scientific problem-solving and evidence-

claiming. Imaginative science fiction also works as "speculative fiction" to predict possible futures. Such complex narratives help readers develop their own imaginations: "Nothing fires imagination like science fiction and even science fantasy, so why not use it more, as a creativity and imagination aid?"[370] Developing imagination and creativity in students' minds further empowers their cognitive processes to learn new ways of thinking. Science fiction could be a key tool to expose students to that training.

Unlike "fantasy" fiction, works of science fiction maintain a sense of plausibility. Many SF stories are inspired by present-day scientific reality that the authors use to extrapolate into the future. Such narratives can teach analytical thinking skills "because they implicitly or explicitly question existing social arrangements in the process or creating alternatives."[371] Presenting abstract information and scientific theories through realistic characters' experiences can engage students' interest and improve their ability to make logical inferences and connections with real-world problems.

Stimulating students' imaginations and creativity help increase students' motivation to explore, experiment, and formulate their own ideas and opinions. Scientific literacy is essential to address intelligently and conscientiously ethical issues and questions that deal with the social consequences of science and technology and their impact on the well-being of humanity and the future of the Earth. As in other types of learning experiences, science fiction reading prepares students to ask valuable questions and consider political, medical, ethical, and religious issues.

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[370] Harry Roman, "Science Fiction- An Inspiration for Creativity," *Tech Directions* 76, no. 8 (April 2017): 25.

[371] Cheryl Laz, "Republication of 'Science Fiction and Introductory Sociology: The Handmaid in the Classroom,'" *Teaching Sociology* 48, no. 1 (Sage +Publications, 2020): 55.

Such interdisciplinary connections may further help students develop their observation skills and methods of critical thinking. Science fiction texts can also be read as separate stories that engage specific topics such as biotechnology. They can reinforce the teaching of other topics across the curriculum, such as viruses, the pandemic, bioweaponry, bioengineering, and climatology. Through the what-if narratives of science fiction, students can imagine and re-create unique scientific hypotheses that challenge them to critique and assess the strength and weaknesses of arguments and policies.

To maintain competitive growth in STEM education and sustain economic expansion for a better future, scientific literacy is tremendously valuable to global societies. "Science education at all levels should focus on creating a society where well-educated adults are equipped to bring scientific thinking to bear on issues that affect them as citizens."[372] An uninformed and scientifically illiterate citizen is at a disadvantage when making choices regarding important public policy dilemmas. Even economic decision-making requires well-informed citizens. Any effective vector to spread scientific literacy, whether science fiction novels, films, or video games, should be welcomed to foster a broader knowledge and greater awareness for science, and scientific literacy among students and lay people.

> …Informed lay people can indeed do better with regard to many problems and decisions involved in or required for scientific questions than so-called experts. The latter are

[372] Elizabeth Marincola, "Why Is Public Science Education Important?" *Journal of Translational Medicine* 4, no. 1 (2006): 2.

frequently blind to innovation and solutions which challenge the status quo of and benefits for the nominal experts.[373]

Encouraging students and the general public to learn more about science through science fiction may help enable them to make better educated evaluations and knowledgeable assessments. Equipped with the skills to distinguish facts from opinions and science from non-science, students and the general public would not be "predominantly influenced […] by the prevailing perception in their communities."[374] Popular appreciation for science through the humanities, should be encouraged as Menadue and Cheer conclude: "convergence of research between the humanities and natural sciences may be one route to supporting and encouraging more positive communication with the public […]. This convergence should be driven by the increased application of structured and quantitative methodologies to the analysis of science fiction, and other traditionally humanistic forms…"[375] Through STEM-HUMA collaboration, science communication may more effectively impact the public mind. This echoes Negrete and Lartigue's views who state, "science can be learned through literary stories. In particular, they suggest that narrative information is retained for lengthier periods than factual information and that narratives constitute an important means for science communication to transmit information in an accurate, memorable and enjoyable way."[376] Students are educated and entertained by

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[373] "Research Insights and Insides: Science-in-Fiction as a Contribution to the Third Culture Concepts," *Medical Hypotheses* 72, no. 5 (May 2009): 489.

[374] "Why Is Public Science Education Important?" *Journal of Translational Medicine* 4, no. 1 (2006): 1.

[375] "Human Culture and Science Fiction: A Review of the Literature, 1980-2016," *Sage Open* 7 no. 3 (August 2017): 13.

[376] "The Science of Telling Stories: Evaluating Science Communication via Narratives (RIRC Method)," *Journal Media and Communication Studies* 2, no. 4 (April 2010): 104.

science fiction works since "a narrative is a series of casual links, which is why readers are drawn to it as a source of information."[377]

As previously discussed in this dissertation, science fiction highlights the impact of technology on the human species and emphasizes the potential of human intellectual, physical, and psychological enhancement. "Using real-world problems to thread [connect] a number of biological concepts together encourages students to move away from seeing biology as a collection of disparate concepts, subject areas, or chapters from textbooks that are far removed from society."[378] In *The Andromeda Strain*, the focus of the science fiction narrative was on the risk of bioengineered viruses. The plot addressed bioweaponry engineering, a crucial and controversial topic that students should be aware off to address ethically and socially the conflicts that might arise. In *Gattaca*, the main focal point was genetic determinism and the fear of creating a homogeneous genetically enhanced society. In addition, *Gattaca* generates more questions than answers and raises many doubts about biotechnological enhancement itself. Hence, the transhumanism theme emerges and creates more conflictual dilemma at the religious and ethical levels. What human qualities need to be enhanced and who make such decisions require new legislations.

More interestingly, science fiction evokes issues that are not close to being solved such as climate change and warns of the dangerous impact of increased temperature which affect every aspect of human life. Heat waves, droughts, and floods will negatively reshape economic

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[377] "Using Science fiction to Teach Science Facts," (ProQuest Dissertations Publishing, 2011): 24.

[378] "Making Biology Learning Relevant to Students: Integrating People, History, and Context into College Biology Teaching," *CBE Life Sciences Education* 7, no. 3 (2008): 267.

prosperity, impact human and environmental health, and destabilize national security. In chapter three, we have seen that "cli-fi" presents some solutions in a remarkable narration that could promote students' independent thinking to visualize the dire situation and imagine the future while trying to answer the "what if" question. Scientifically informed people will be better equipped to respond to the new situations' changes and challenges.

Overall, science fiction novels and games cover many topics and a range of scientific subjects that offer students and teachers a common ground to express conflictual opinions regarding biotechnology use, bioweapon, and climate change. Through such materials, students may develop an interdisciplinary understanding of current problems. It is critical that students learn ways to assess their current knowledge, metacognitively evaluate their understanding, and engage in learning that allows them to improve and develop their initial understanding of scientific concepts. Topics such as genetics, bioengineering and climate change explored through science fiction may help students make the transfer of knowledge and investigate real-world problems. "Knowledge that is taught in a variety of contexts is more likely to support flexible transfer that knowledge that is taught in a single context."[379]

As Norris and Philips explain, scientific literacy has always extended beyond the reading of science textbooks. Learning about science requires students to have hands-on activities, manipulate and work with the natural world. Students' active and critical engagement with science can also be achieved while reading, watching, or playing video games. "…Well-researched science embedded in diverse forms of fiction […] can provide key scientific information for cultural progress which more often than not will come from unexpected

[379] *How People Learn: Brain, Mind, Experience, and Schools* (Expanded ed., National Academy Press, 2000), 236.

corners."[380] Digital games may help students develop strategic skills and affiliate themselves with other partners who support their learning by providing insightful and interesting feedback. For many, digital technologies are intrinsically motivating and give students a sense of control over the learning tasks that they are performing. While playing digital games, students can be exposed to models of real-world issues represented through visual and virtual animated images. Moreover, "the ability of the human mind to quickly process and remember visual information suggests that […] visual representations of information can help people learn."[381]

Providing science fiction works as a supplemental resource for students may enrich and enlarge their textbook and classroom learning. As Amy Green argues, information learned through science fiction narratives could be easier to identify and relate to by students and the public as information is consistent with current scientific understanding and hence retained for much longer. For example, learning that some equipment in the medical field, such as the exoskeleton that might help paralyzed people walk again, was actually inspired by science fiction can inspire the creativity in some students to improve the well-being of humanity.

Teachers who efficiently guide students in the process of learning, recognize the intertwined relationship between science, science fiction, and culture. Providing a variety of resourceful materials of teaching science might engage students and lead them to discover scientific knowledge in contexts which might motivate them and help them personalize their own

[380] Ibid., 489.

[381] John Bransford, *How People Learn: Brain, Mind, Experience, and Schools* (Expanded ed., National Academy Press, 2000), 215.

learning. Building on previous conceptual knowledge, students can be directed to think about current problems, predict solutions, and develop new ideas.

Other creative works are coming onto the market that may also prove valuable in spreading scientific literacy. For example, a game called *MoleculeGo* (2021) is a digital game developed by Professor Faruck Morcos at the University of Texas at Dallas. The goal of this game as Morcos states is "to disseminate science to general audiences and interact with high school students."[382] Players learn about molecules, they collect amino acids, DNA sequences and molecular building blocks. They are able to discover the genes that encode for proteins by synthesizing DNA segments. On an advanced level and in a more sophisticated way, current discussion is focused on what we call the "Metaverse" a digital, 3D network that provides users with extended reality (XR) enabling them to experience the combination of physical and digital world through virtual reality (VR), augmented reality (AR) and mixed reality (MR). This network offers whole new approach to teaching. In social studies, reading, math and science class, students would be brought into the metaverse with boundless potential to reinvent the classroom as we know it. The Metaverse Forum gathered in 2022 to discuss games inspired by science fiction technology. Dean Takahashi states that "The Metaverse merges science fiction, tech, and games."[383] Kimberly Unger, a science fiction author who works at Meta's Reality Lab believes that technological developments were brought forth due to science fiction ideas. She

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[382] Laura Rice, "Molecules are Everywhere. Now, You Can 'Catch' and Explore them with a New Game," Arts and Culture, Health and science, Sounds of Texas, Tech and Innovation, *Texas Standard* (August 10, 2021), https://www.texasstandard.org/stories/molecules-are-everywhere-now-you-can-catch-and-explore-them-with-a-new-game (accessed February 2022).

[383] Dean Takahashi, "The Metaverse Merges Science Fiction, Tech, and Games," *Venture Beat* (May 3, 2022), https://venturebeat.com/games/the-metaverse-merges-science-fiction-tech-and-games (accessed June 2022).

also states that the metaverse is the place where people will feel connectedness and where they will socialize, as she thinks that "no matter how easy it is for us to isolate ourselves because of technology, it's all still in the service of bringing us together, which is this weird dichotomy that's going on right now."[384] The new vision of the Metaverse to meet educational needs is underway and as technology advances to immerse students in the learning process, academic researchers, instructors, policymakers and digital designers are encouraged to guide and embrace the new opportunities that the Metaverse is considering. For example, one potential use of the metaverse as described in "A Whole New World: Education Meets the Metaverse" (2022), may immerse students in the tales of the Greek myths where they might experience virtually the power of Zeus and the great stories of Hercules. The metaverse could transform the classroom into mounted white boards surrounding the walls and movable chairs and students are projected into the year 300 BCE where they are immersed and mesmerized by the Greek culture. They enter the metaverse and experience Greek reality through their avatar. "Carts buzz by them, traders in marketplaces surround them and high atop the hill, they see- with their own eyes-the temples of the gods and the people who worship them."[385] In the metaverse, students, through their avatars, become archeologists and unravel the history of the Greek culture. They discover that myths are part of former religion known as paganism and they were worshiped a while ago. The Metaverse is a whole new experience where interconnection and immersion in 3D combine concurrent online space with the actual world through augmented and virtual reality. Students

[384] Ibid.

[385] Kathy Hirsh-Pasek et al., "A Whole New World: Education Meets the Metaverse," *Brookings* (February 14, 2022), https://www.brookings.edu/research/a-whole-new-world-education-meets-the-metaverse (accessed May 2022).

could also build geometry concepts (vertex, sphere, Torus concept, Möbius strip, etc.)[386] in virtual spaces or visit galaxy and planets which enrich students' learning experience. Using this new tool would add a significant academic layer to students' academic life. "The metaverse is coming to education. The question is whether as designers, policymakers, educators, and parents, we can mold intentional and appropriate opportunities that are truly educational within the new and exciting context."[387] This new tool will need some time to prove its effectiveness in academics and will require careful research and implementation.

In this dissertation, I have begun to provide teachers and students with an overview of some of the potential science topics in SF that would constitute great springboards for classroom discussion and lesson plans. The scientific topics discussed in these chapters also have great potential for applications to other coursework beyond the teaching of science. These materials could also be used to teach creative and expository writing skills. Science fiction can offer a lot of great educational opportunities in many academic settings. For example, teachers could discuss *Frankenstein*; or *The Modern Prometheus* to explain how the novel reflects the experiments with electricity and Galvanism that were popular at the time the novel was written. Other teachers have used the *Jurassic Park* (1990) novel and film (1993) to discuss scientific

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[386] J.L. Rodriguez, *Exploring Dynamic Geometry Through Immersive Virtual Reality and Distance Teaching* in Richard P.R. et al. *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era*, 17 (Springer, March 10, 2022), https://doi.org/10.1007/978-3-030-86909-0_15 (accessed October 5, 2022).

[387] "A Whole New World: Education Meets the Metaverse," *Brookings* (February 14, 2022), https://www.brookings.edu/research/a-whole-new-world-education-meets-the-metaverse (accessed May 2022).

facts such as cloning even though "it was not discovered until 1994 that it was possible to get DNA out of dinosaur bones."[388]

Science is at the heart of progress for nations that desire to succeed in economics, technology, and medicine. People who have control over the money and policies need to be scientifically educated. Engaging and challenging the public to capture their support for science research funding is crucial to keep progressing as a nation. Students need to become aware that "technologies are created for very particular purposes, often to address societal problems, alleviate human suffering, or seek militaristic and economic gains."[389]

By studying the science fiction works in this dissertation and highlighting crucial topics that might pause and hinder the progress of societies, it is beneficial to make students aware of the challenges that emerge with innovation and development of new technologies. The role of teachers is not only to supply students with the materials and oversee the completion of their homework but to encourage them to develop "an actively inquiring, flexible, creative, innovative, tolerant, liberal personality who can face uncertainty and ambiguity without disorientation, who can formulate viable new meanings to meet changes in the environment which threaten individual and mutual survival."[390] With the development of scientifically literate citizens, chances to create new solutions to current and relevant problems are highly anticipated especially that science fiction extrapolate the future. With that being said, scientific literacy

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[388] Stephanie Putt et al., "Using Science Fiction to Teach Science Facts," (ProQuest Dissertations Publishing, 2011), 13.

[389] *Creating Life from Life: Biotechnology and Science Fiction* (Singapore, Pan Stanford Publishing Pte. Ltd., 2015), 4-5.

[390] "Science Fiction: Serious Reading, Critical Reading," *The English Journal* 94, no. 2 (November 2004): 86.

would help students make better decisions, write new novels, make new films or invent new video games or new software to educate and provide solutions to a given problem. Developing new cures for disease, finding solutions for hunger, reducing greenhouse gas emission and creating a better place for next generation require people with scientific knowledge and skills. Creativity and anticipation combined with scientific advancements and technological evolution become the new catalyst of well-developed and prosperous nations.

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