Mitigations to Reduce the Law of Unintended Consequences for Autonomy and other Technological Advances

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The United Nations states that Earth's population is expected to reach just under 10 billion people (9.7) by the year 2050. To meet the demands of 10 billion people, governments, multinational corporations and global leaders are relying on autonomy and technological advances to augment and/or accommodate human efforts to meet the required needs of daily living. Genetically modified organisms (GMOs), Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) gene-edited plants and cloning will be utilized to expand human food supply. Biomimetic implants are expected to improve life expectancy with 3D printed body parts. Human functioning will be extended with wearables and cybernetic implants continuing humanity's path toward transhumanism. Families will be strengthened with 3 parent households. Disease will surely be eradicated using the CRISPR-CAS9 genetic engineering revolution to design out undesirable human traits and to design in new capabilities. With autonomous cars, trucks and buses on our roads and on-demand autonomous aircraft delivering pizzas, medical prescriptions and groceries in the air and multi-planet vehicles traversing space, utopia will finally arrive! Or will it? All of these powerful, man-made, technological systems will experience unintended consequences with certainty. Instead of over-reacting with hysteria and fear, we should be seeking answers to the following questions - "What skills are required to architect socially-healthy technological systems for 2050?" "What mindsets should we embody to ameliorate hubris syndrome and to build our future technological systems with deliberation, soberness and social responsibility?"

I. Nomenclature

AI	=	Artificial Intelligence
CAST	=	Commercial Aviation Safety Team
CRISPR	=	Clustered Regularly Interspaced Short Palindromic Repeats
CAS	=	CRISPR associated protein
FAA	=	Federal Aviation Administration
GM	=	genetic modification
GMO	=	genetically modified organism
IoT	=	Internet of Things
NHTSA	=	National Highway Transportation Safety Administration
NIH	=	National Institutes of Health
SAE	=	Society of Automotive Engineers
UAS	=	Unmanned Aircraft System

II. Introduction

Technology is a powerful, disruptive instrument of change. The ramifications of this change, at times, can be cumulative and substantial as to create inflection points, that is, points in time where a succession of technological advances are perceived as beneficial to humans and thus adopted seemingly en mass. Some major inflection points can be observed in the four stages of the industrial revolution (see Fig. 1) [1]. In stage one of the industrial revolution, the technology of water- and steam-powered mechanical manufacturing facilities created an inflection

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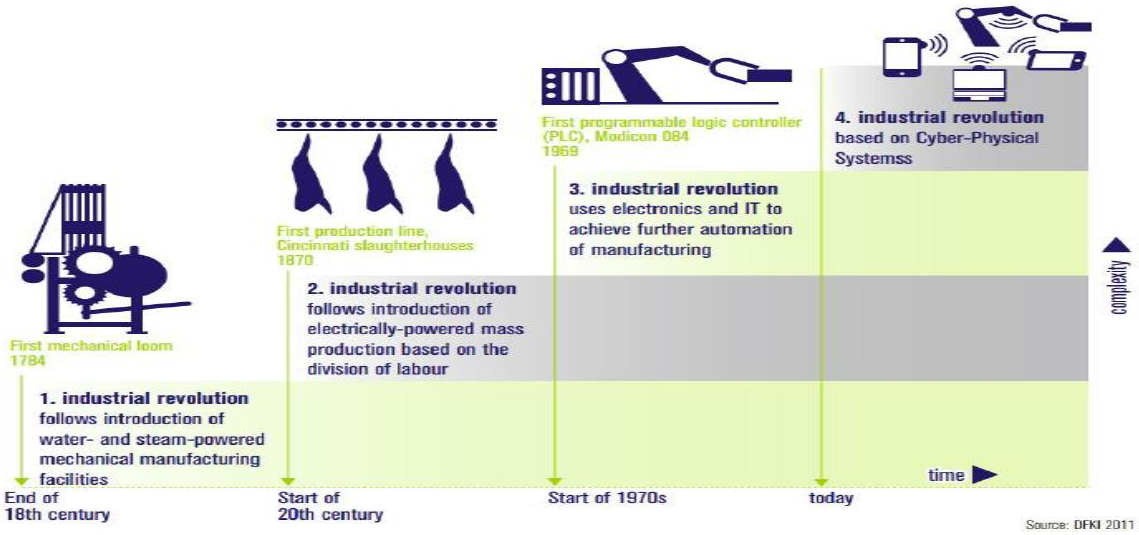

Fig. 1 The Four Stages of the Industrial Revolution [1].

point in the way humans produced work. Steam and water power replaced human and animal power with machines. In stage two, electrically-powered mass production led to assembly lines based on labor divisions. The development and distribution of electricity as well as the development of internal combustion engines led to airplanes, telephones, cards, radios and other forms of mass production. In stage three, the development of electronics, the internet and information technologies significantly increased the automation of mass production. This third inflection point can be termed the digital revolution or *the first information revolution* which represented the change from mechanical and analog electrical technology to digital computers, robotics and automation. The significance of this inflection point implies that machines, in addition to displacing humans for manual labor, are now assisting with cognitive tasks as well. In stage four of the industrial revolution or *the second information revolution* (where we exist today), the physical world and the virtual world evolve together to form robotic process automation and data exchange in manufacturing technologies. This includes cyber-physical systems, the Internet-of-Things (IoT), cloud computing, artificial intelligence (AI), machine learning, biotechnology, block chain technologies and genomics, to name a few.

As we observe and analyze the relentless pace of technological change in our society, we wonder how Earth's population will adapt to these (and subsequent) changes and inflection points by the year 2050. Will genetically modified organisms (GMOs) and Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) gene-edited plants and cloning be utilized to expand the human food supply? Will biomimetic implants improve life expectancy with 3D printed body parts? Will disease be eradicated with CRISPR-CAS9 genetic engineering? Will autonomous systems eliminate human deaths caused by motor vehicle crashes?

As the authors discussed these perplexing questions about the role and impact of technology on humanity's future, we have been thoroughly surprised at the spectrum of informal responses received from NASA employees, particularly the future role and interactions between autonomy and humans. Given that NASA has been at the forefront of high-technology innovations for years, one would think of NASA generally as an organization that leans positive towards technology. After numerous informal discussions with various NASA engineers, scientists and safety personnel, the authors would differ with the general consensus. When it comes to predicting the future impact of automation and other technological advances, our impressions are that NASA employees experience the same underlying uncertainty (perhaps more constrained) as the general laity. In general, some employees were fearful (the sky is falling and humanity is doomed because of autonomy), some were excited (can't wait to have discussions with autonomously-directed robotic co-workers) while others were ambivalent (I will leave the autonomous agents alone as long as they leave me alone).

This led the authors to ask a series of questions. The first question was *"Is there anything certain we can say about the role of autonomy and other technological advances in the future?"* The answer to this first question was a simple "yes". We can be certain that the Law of Unintended Consequences will force its will on autonomy and other future technological advances. The second question follows the first, namely, *"What can we do as humans to mitigate the Certainty of Unintended Consequences in our future technological systems?"* We believe that the Law of Unintended Consequences can be mitigated through deliberate, mindful and rigorous systems engineering, where systems

engineering, in this context, is an interdisciplinary field of engineering and engineering management (people, hardware, software, processes, policies, etc.) that focuses on how to design and manage complex systems over their life cycles. Instead of engineers and architects over-reacting with hysteria and fear of the future, systems engineering should enforce rigor on the development process by helping organizations answer the following questions - *"What skills are required to architect socially-healthy technological systems for 2050?" "What mindsets should we embody to ameliorate hubris syndrome and to build our future technological systems with deliberation, soberness and social responsibility?" "What can we do to minimize the Dunning Kruger Effect in those who generate intriguing technological advances without considering detrimental negative implications?"*

This paper will discuss emerging technological trends in the present (stage four of the industrial revolution) including the technological advances that are sure to influence humanity in completely unexpected ways in the future. In the advent of stage four, humanity can collectively say that we live in interesting times. Technology has allowed us the ability to physically manifest (in whole or in part) an entire spectrum of technological creations that satisfy a vast range of human desires from the basest human desires to the highest aspirations that beforehand appeared out of reach to humanity as a whole. After discussing some emerging trends that the advancement of technology has permitted, we will discuss the alluring power that autonomy and advanced technologies provide for humanity. Afterwards, the Law of Unintended Consequences will be discussed including a recovery approach to aid humans to analyze themselves in order to have an appropriate relationship with our technologies. Do we as humans realize that collectively we are creating maladies and hardships as well as benefits from our own technological creations? How many technologists or scientist/engineers realize the down side risks associated with such fabulous inventions? Do we ever truly ask the questions about downside risks a priori or do we simply pay lip service by consenting with our words while dissenting in our hearts? We also wonder whether we positively assume that government or society will always mitigate the destructive aspects of our technological creations. These assumptions are a part of our collective hubris. Once our awareness is opened and we perceive the historical double-edged sword (benefits plus unintended positive consequences plus unintended negative consequences) presented by many of our technological creations, we would pause to consider a more sensible systems-oriented approach to architect future technological systems.

A. Future Emerging Trends

With an expected increase in world population by 2050, how will governments meet the demands of 10 billion people [2]? Governments will have to collaborate with multinational corporations and other global leaders as they rely on autonomy and technological advances to augment and/or accommodate human efforts to meet the required needs of daily living. Will genetically modified organisms, CRISPR gene-edited plants and cloning be utilized to expand human food supply? In April 2018, Missouri became the first state in the United States to prohibit anyone from referring to a product as "meat" if it isn't literally animal flesh [3]. The move is already causing a stir in "clean meat" and plant-based meat industries. Futurists expect biomimetic implants to improve life expectancy with 3D printed "living" body parts (see Fig. 2) [4]. Will human functioning be extended with wearables and cybernetic implants continuing humanity's path toward transhumanism [5]? Will families be strengthened with 3 parent babies [6]? Will disease be eradicated using the CRISPR-CAS9 genetic engineering revolution to design out undesirable human traits and to design in new capabilities [7]? In December 2018, the Chinese scientist announced that he successfully used CRISPR-CAS9 to create the world's first genetically modified humans [8]. Critics and concerned individuals asked the scientist if he had considered the potential long-term social effects, particularly how the genetically modified humans would be treated by society, the scientist replied that he had not considered the consequences that could be passed down to future generations.

Fig. 2 3-D Printed "Living" Body Parts [4].

In addition to advanced technologies physically connected to the human body and technologies swirling around within our human bodies (genetic re-engineering of our DNA, genetically modified food providing nourishment, living 3D-printed body parts, etc.), we are also confronted with various levels of autonomy, robotics and technologies outside of our human bodies. With autonomous cars, trucks and buses on our roads and on-demand unmanned aircraft systems (UAS) delivering pizzas, medical prescriptions and groceries in the air and multi-planet vehicles traversing space, will utopia finally arrive? Of all the diverse type of technologies humanity confronts, autonomy and artificial intelligence appear to be the most daunting of these technologies. In 2015, the *Chapman University Survey on American Fears* showed that several of the top American fears are in the technology domain, namely, cybersecurity, corporate and government tracking of personal information, robots replacing the workforce, trusting artificial intelligence to do work, robots in general and artificial intelligence [9]. In September 2017, The National Highway Transportation Safety Administration (NHTSA) released their Automated Driving Systems report [10] where they identified the Society of Automotive Engineers' (SAE) Five Levels of Vehicle Autonomy framework (see Fig. 3). Given how much humanity enjoys its physical and psychological autonomy, it takes no stretch of the imagination to see why full self-driving vehicle autonomy under all conditions (Level 5) is of immense concern. Humans do not easily enjoy releasing control of their lives over to machines. Near the end of 2017, American Automobile Association researchers reported that two-thirds of Americans are still afraid of self-driving cars [11].

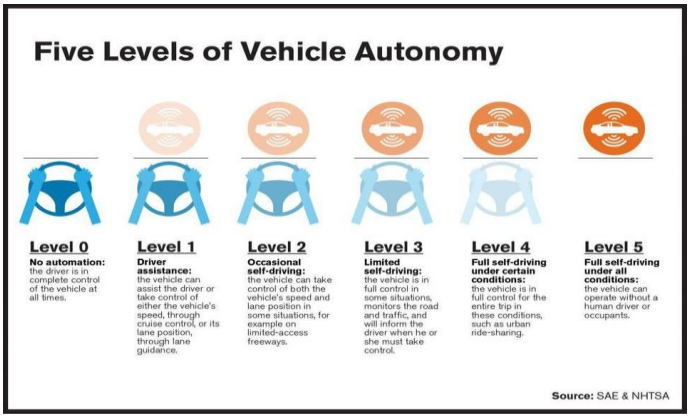

Fig. 3 Five Levels of Vehicle Autonomy.

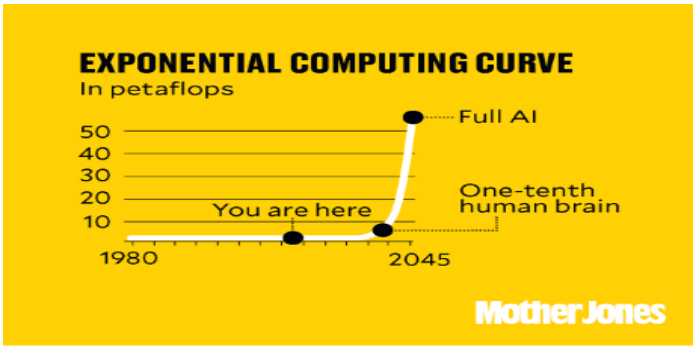

Fig. 4 Exponential Computing Curve [12].

B. The Power of Autonomy and Technological Advances

During the third stage of the industrial revolution (see Fig. 1), the use of electronics and information technology has advanced automation and manufacturing. Subsequent innovations have allowed computing to expand exponentially (see Fig. 4) [12]. This increased computational power allows more functions to be embedded into ever-increasing complex systems. The increase of these functions are more efficiently managed through software and computing algorithms. Over time, it has been seen that the increase in the computational power of computers has drastically improved humanity's ability to explore (data mine) large sets of data which have led to increased understanding for biotechnology, DNA sequencing and metagenomics. Coupled with advancements in stage four of

the industrial revolution, machines are not only displacing humans for manual labor, but also are encroaching on areas humanity has psychologically reserved for itself, namely, cognitive processing and creativity. To some degree, cognitive machines, for many humans, are perceived as a threat and advanced artificial intelligence is the pinnacle of that threat.

More importantly, it appears that the advancements of technology continue to cross boundaries previously established as the natural order. Natural order, in this context, is considered the manifested relationships established by God or by nature or by whatever we call the forces of creation. Natural order encompasses the natural relations of beings to one another in the absence of law, which natural law attempts to reinforce. These boundaries carry with them ethical and moral responsibilities and additional risks that need to be considered and managed. The power of technology appears to place god-like decisions within humanity's reach. With the help of technology, humans can presently create 3-parent babies [6]. Humans can create genetically-engineered offspring [8]. Humans through the use of advanced technologies can extend their reach beyond the natural order by creating chimeras or human-animal hybrids [13]. In 2017, a researcher sounded an alarm by providing an opinion piece to the National Institutes of Health (NIH) against their intentions to lift their moratorium on funding research that involved human-animal hybrids (chimeras). The researcher stated, "*The National Institutes of Health announced its plans to lift its moratorium on funding research that involves injecting human embryonic stem cells into animal embryos, which would allow for the creation of part-human and part-animal organisms known as chimeras. The NIH allowed only one month to receive public comments in the midst of a presidential election campaign. Lifting the moratorium means that, for the first time, the federal government will begin spending taxpayer dollars on the creation and manipulation of new organisms that would blur the line between humans and animals* [13]." Technology has indeed helped mankind to cross boundaries and to reach beyond the natural order and it is up to humans to establish a set of moral guidelines to minimize the risks and to mitigate the unexpected consequences which will result from our technological creations.

Because of the serious ethical/moral implications as well as the existential threats encountered with weaponized autonomous systems, advanced artificial intelligence and biotechnologies, scientists and engineers have been sounding the alarm for some time. The late Stephen Hawking openly spoke about his fears of AI predicting that future developments in AI "could spell the end of the human race" [14]. Hawking's deepest concerns were focused on superhuman AI, the point at which AI systems not only replicate human intelligence processes, but also keep expanding them, without our support [14]. In 2018, Elon Musk also has warned governments and humanity about the dire consequences of the rise of artificial intelligence. Musk has said that autonomous machines are more dangerous to the world than North Korea and could unleash "weapons of terror" [15]. Musk also believes artificial intelligence could help trigger the next world war and has expressed how super-intelligent machines could come to dominate the world [15]. Other like-minded individuals who desire to find positive ways for humanity to steer its own course for new technologies join organizations like The Future of Life Institute [16, 17], the Machine Intelligence Research Institute [18] and the Centre for the Study of Existential Risk [19], to name a few.

Three serious question remain. First, when humanity crosses boundaries established as the natural order, can it ever go back? Second, with the power of advanced technologies to cross boundaries, will humanity ever give up god-like capabilities (abilities originally envisioned to be out of reach)? Third, is it possible to manage organizations or individuals with god-like capabilities for the benefit of humankind? These questions are pertinent given the history of technological advances where the creators did not envision nor contemplate the unintended consequences.

C. The Law of Unintended Consequences

Inherent to human existence is the desire to modify aspects of the environment for the fulfillment of needs and desires. Too often, these changes are brought about by the use of human-created tools. Human use of tools can sometimes have temporary or long-lasting effects that create dynamics of change within the environment or society. Deliberate and unplanned actions alike result in consequences, both desirable and undesirable. The law of unintended consequences states that actions of people (including the creation of technological inventions) always have effects that are unanticipated or unintended [20]. This law, though technically not a law of nature but one of observation of many different actions in many different areas of history, is at work always and everywhere. All human actions have unintended consequences, and they are the essence of what make for progress. Unintended consequences are part of the innovation process, and great inventions have been made during times of crises [20-21]. During the agricultural revolution, the scope of inventions was mostly regional and the intended consequences of them were commonly bound to the countries or groups of countries affected by those inventions. As discoveries and disruptive technologies revolutionized the world in twentieth century, developed societies as well as institutions and industries restructured themselves to evolve through technological advances.

The western view of an optimistic future created and served by technology fueled free enterprise and exploitation of resources, which at times were believed to be infinite [22]. Technological advances became both the motor and

prime matter source for the economy, especially in the United States of America, in which the expectation was that technological progress should result in gross domestic product progress [22].

The following list represents examples of successful technologies which (over time) were found to have undesirable unintended consequences. The consequences were considered secondary effects which only manifested after considerable times had passed. Unfortunately, the designers of the technology did not anticipate nor mitigate the design to prevent the undesirable behavior. The positive consequences are not listed here because they ordinarily do not elicit the same level of societal responses as the negative unanticipated consequences which often undermine the original purpose of the technology, cross over moral boundaries or add unacceptable additional risks which must be confronted.

- Automation in the Cockpit designed to Help Pilots Avoid Crashes causing Pilots to Lose Critical Skills

The FAA's NextGen initiative to modernize the air transportation industry introduced advanced automation in ground, airspace and flight deck operations in order to improve the safety and efficiency of air transportation. A study by the Commercial Aviation Safety Team (CAST) found, however, that overreliance on cockpit automated systems have a negative impact in pilots' skill retention [34]. Increasing complexity both in operational procedures and pilot-automation interaction impact crew workload and flight performance [58]. The FAA, that previously mandated the use of cockpit automated systems to help pilots avoid crashes, alerted operators on their effects regarding the "degradation of the pilot's ability to quickly recover the aircraft from an undesired state." This skill degradation is compounded by cost reduction practices by aircraft manufacturers and airline carrier and other factors, such as the reduction in obligatory training hours. For that reason the FAA also promoted that training and line operations provide appropriate opportunities for pilots to fly their aircraft manually [35, 36].

- Texting while Driving is more Dangerous Than Drinking and Driving

The advent of mass-market consumer electronic devices transformed the way in which people access and produc information, and connection to others. Advances in manufacturing and information and communication technologies enabled the production of personal computer devices that increasingly became more sophisticated and versatile while, at the same time, smaller and portable. The millennial generation that grew up during the times of the dotcom explosion, the launch of social platforms and invention of the smartphone rapidly adopted those technologies and even came with new ways of communicating. The adoption of texting as the primary form of communication among young adults, is the manifestation of a consequence that changed culture in technological societies. The emotional attachment of individuals to social platforms have resulted in compulsive behavior, such as the urge to check mobile devices frequently.

In an online survey of 2,000 US adults conducted by OnePoll in April, 2018, Americans check their phones an average of 80 times a day while on vacation, with some checking their phone more than 300 times a day [23]. According to the Pew Research Center [24] half of young adults in the US live in a household containing three or more smartphones. Smartphone problematic use is an obsessive technology behavior that particularly affects the youth. The propensity of using mobile devices while engaged in attention demanding tasks such as walking or driving have been the source of risky behavior that have caused injuries and fatalities. Texting while driving, a consequence of uncontrolled behaviors in relation to mobile technologies, is banned in many states of the U.S. Driver distraction has caused many accidents during recent years. In a study published by the American Automobile Association Foundation in 2015 [25], researchers found that drivers that engaged in cellphone use kept their eyes off the road for an average of 4.1 out of the final six seconds leading up to a crash. According to NHTSA, driving while texting is six times more dangerous than drunk driving [26]. Accidents are also caused by pedestrians that unsafely cross a road, walk into motionless objects such as poles, street signs or walls while using their cellphones. The Governors Highway Safety Association projects nearly 6,000 pedestrians were killed in motor vehicle crashes in the U.S. in 2017, marking the second year in a row at numbers not seen in 25 years [27].

- Social Media Companies Partially against Technology they championed (children are becoming addicted)

While the Government employs mechanisms to prevent or deter dangerous behaviors that are the consequence of unhealthy technological habits, companies that created mobile devices and/or developed apps and social platforms are fighting against the unintended use of their products and their consequences on society. Unlike gaming addiction, that has already been declared as disorder by the World Health Organization, problematic Internet use

and thus problematic social media use have not yet been recognized as mental disorders or as behavioral addictions [28]. Nonetheless, The Center for Humane Technology deliberately uses the term addiction, and boldly states in its website that the social platform "addiction is part of something bigger" [29]. "Our society is being hijacked by technology" and that prominent social platform developers are caught in a "zero-sum race for our finite attention", "Constantly forced to outperform their competitors, they must use increasingly persuasive techniques to keep us glued", and that "what's best for capturing our attention isn't best for our well-being", as social platforms are: "redefining how our children measure friendship, eroding our self-worth, and fragmenting our communities" [29].

In a 2017 Congressional hearing, technical leaders conveyed that user experience designers use technological platforms "to actively condition user behavior and refining products to be intentionally-habit forming" [30]. The manifestation of this unhealthy behavior, another unintended consequence of uncontrolled technology management, has provoked reactions from technology creators and captured the attention of legislators. Recent initiatives by major smartphone developers aim to help users manage the time spent on individual apps, handle interruptions and enforce parental controls [31].

- GMOs accused of endangering Monarch Butterflies

Monarch butterflies are an unexpected victim of the widespread adoption of genetically modified crops, Rep. Peter DeFazio, D-Ore., stated [32]. A genetically modified organism has had its DNA altered in a way that does not occur in nature. One purpose is to increase the plants' tolerance to pesticides and herbicides.

More than beautiful, monarch butterflies contribute to the health of our planet [33]. While feeding on nectar, they pollinate many types of wildflowers. The flowers they choose are varieties that are brightly colored, grow in clusters, stay open during the day, and have flat surfaces that serve as landing pads for their tiny guests. Monarch butterflies are also an important food source for birds, small animals, and other insects. Female monarchs lay their eggs on the underside of poisonous milkweed leaves [33]. As the caterpillar hatches, it eats its own egg; then switches to a diet of milkweed leaves. The milkweeds' toxins remain permanently in the monarch's system, even after the caterpillar metamorphoses into a butterfly. Animals that eat a monarch become very sick and, thereafter, will avoid this distinctively patterned butterfly.

Milkweed grows in and around crops such as corn and soybeans that are heavily concentrated in the U.S. Midwest. This is the monarch's spring, summer and fall habitat, and milkweed serves as both the species' primary food source and where its larvae grow. The problem is that, unlike the GMO crops in close proximity, the milkweed cannot withstand the herbicides. (Milkweed, like other weeds, can stifle crop yield, so farmers don't like it.) The biggest threat to monarch butterflies is the lowered prevalence of milkweed, due to the increasing use of GMO crops that can withstand a heavy dose of herbicides. A U.S. Geological Survey study revealed that during the decade of 2007-2017 "over 860 million milkweed stems were lost in the northern US [53]." In 2014, the U.S. Fish and Wildlife Service received a petition to protect the monarch butterfly under the Endangered Species Act. Ongoing conservation efforts are being documented in a Monarch Conservation database [54] and the U.S. Fish and Wildlife Service is expected to announce its decision by 2019. Individual conservation efforts of planting milkweed backfired when it was found that planting tropical milkweed in warm environments, instead of the native milkweed, might lead to unseasonal breeding, putting monarchs at higher risk of disease and reproductive failure [55, 56]. Since the tropical plants don't die off in the winter in warm areas of the US, neither do the parasites that are common to the milkweed. It is necessary for the milkweed to die off and renew so parasitic growth can be controlled. It is also necessary for the butterfly to migrate, since the strongest butterflies that complete the trip are the ones that reproduce.

GMOs are indirectly causing monarch butterflies to become extinct by causing secondary harm to the environment [32]. GMO technologies architected to increase plant yields for farmers are the very technologies that are destroying the monarch butterfly who pollinates the plants and contribute to the health of our planet.

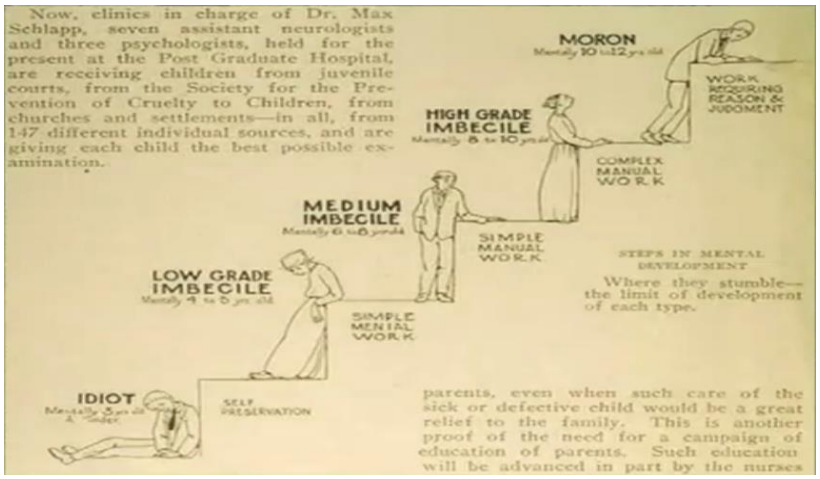

Fig. 5 Eugenics and the Feebleminded [40].

- Genetic Engineering developed to cure disease can now create superior humans which can lead to eugenics

The announcement that scientists are to be allowed to edit the DNA of human embryos will no doubt provoke an avalanche of warnings from opponents of genetic modification (GM) technology, who will warn that we are "playing God" with our genes [7]. The opponents are right. We are indeed playing God with our genes. When a Chinese scientist announced in December 2018 that he successfully used CRISPR-CAS9 to create the world's first genetically modified humans, he later acknowledged that he had not fully considered the future consequences of his actions [8]. Some wonder what could have been done to prevent the gene-edited babies experiment. To date, there are no international governing body to enforce bioethics rules [57].

Some scientists believe that DNA is simply a chemical and when God (or nature or whatever we call the forces of creation) makes a mistake, it is up to mankind to correct those mistakes [7]. Using genetic modification to correct a genetic or major birth defect is a positive contribution to the health of any society and should be considered to be ethically the same as using laser surgery to correct eye defects, or a surgeon operating on a baby to repair a congenital heart defect [7]. Some scientists believe there is the possibility of using GM technologies to genetically engineering designer babies for the super-wealthy or for genetic discrimination, but they choose not to worry about these possibilities until the future [7]. The America of the early 20th century was torn by social ills: massive inequality, urban squalor, tensions over immigration. Eugenics gave reformers a scientific answer to these problems. If social ills were caused by "feebleminded" people with bad genes (morons, imbeciles and idiots) (see Fig. 5) [37-39], as many eugenics champions argued, why not make the world better by eliminating bad genes? Eugenics was the planned extinction of the most marginalized people in society -- dressed up as a way to better society. GM technology is a double-edged sword. The same GM technology that can used to correct a major birth defect is the same technology that can be used for genetic discrimination. The technology should be managed with appropriate controls to prevent misuse.

D. Technology Recovery Overview

It is a given that we, as humans, enjoy our advanced technologies even as we simultaneously gripe about the trade-offs associated with them. We, as authors, support technological progress as long as its negative unintended consequences can be mitigated. However, we believe that all technologies are not created equally. Some technologies have the potential to destroy societies at alarming rates and because of this power, some technologies need to be managed and controlled more strictly. This, necessarily, includes the principles that guide the moral implication of various technological designs. Just like atomic or nuclear weapons technologies, the access and control of these technologies should be managed and controlled to prevent mass destruction to countless people.

As a core belief, we believe that technology is inherently neutral and that its function and purpose should be guided by humans (owners, designers, architects and operators). It is up to humans to guide and to manage technological creations. Starting with a fundamental set of basic principles, we promote a three-step process for humans to

intentionally conceive, architect, build and test socially-healthy technological systems. This set of principles is offered as an initial consideration and can be updated after future deliberation. The basic principles are:

1. Autonomy and other advanced technologies should be made to benefit humanity, hence, humans are more important than machines.
2. Designers of advanced technological systems bear primary responsibility for designs that cause harm to humans (intentionally or unintentionally), except in the case of sabotage.
3. Designers and architects of increasingly autonomous systems should be held responsible for the behaviors of their creations until governments decide otherwise. In other words, Victor Frankenstein should be held responsible for the behaviors of his creation.
4. Governments and society should outline morally acceptable and morally unacceptable uses of autonomy and advanced technologies for the good of humanity. This will provide clear communication to technological creators. This principle is guided by the assumption that society has the responsibility of removing and then establishing a different government if their government is behaving immorally.

Technology recovery is meant to express the principle that humans create technology and hence, it is our responsibility to manage it properly. Simpler technologies perhaps need little management. More than likely, increased management and oversight is required for large complex technologies.

Despite the size or complexity of our technological systems, we must start by managing the human element first. The following three-step process begins by analyzing the most important component to developing socially-healthy technologies, namely, the human. Therefore, the best way to mitigate unintended consequences starts by examining the fears, blind spots, cognitive biases, skills and mindsets of the human creators and stakeholders.

1. STEP 1 – Understand the Human Responses Toward Autonomy and Other Advanced Technologies
2. STEP 2 – Examine the Skills Required to Architect Socially-Healthy Technological Systems
3. STEP 3 – Examine Mindsets Required to Ameliorate Hubris Syndrome and the Dunning-Kruger Effect

The next sections will describe the three steps in detail.

III. STEP 1 – Understand the Human Responses Toward Autonomy and Other Advanced Technologies

"Tools are the products of our (human) brains" said a paleoanthropologist at the University of Colorado at Colorado Springs [40]. Humans made tools to perform physical tasks easier. By extension, technologies are more than tools in that they are a manifest form of organized knowledge for some human purpose [41]. They can be physical and/or informational. Regardless of the form technology inventions take, they were created by humans to serve some human purpose. As we march toward an uncertain future, some say that the pace of technology is accelerating while others state the pace of technology is becoming more diverse and thus more prevalent in society [42]. Because it is impossible to predict the impact of technology on our future world, some engineers and scientists respond with delight, some respond with fear-based emotions while others respond with cognitive carefulness and self-awareness. This section will describe at least two significant categorical responses toward autonomy and other advanced technologies that the authors have experienced during technological discussions at NASA. The first category deals with those who fear humanity's future interaction with autonomy as fraught with stress and trauma (fear-based responses). The second category deals with those who respond deliberately and cognitively to the co-creative design process with self-awareness and collaboration.

A. Four Human Responses to the Threat of Advanced Technology: Fight, Flight, Freeze, Appease

Technology represents change for most people and some people resist it. Resistance to change manifests itself in different forms, but the most we have heard concerns the loss of human control brought about by the use of increasingly autonomous systems. Some predict that in the future humans will be augmented with technology, others predict that humans will work alongside machines while other pontificate that humans will be replaced by machines [43]. In December 2017, the McKinsey Global Institute released a report describing how 800 million global workers will lose their jobs by 2030 and be replaced by robotic automation [44]. This has direct implications for one-fifth of the global workforce. One-third of the workforce in richer nations may need to retrain for other jobs. With Elon Musk

believing that artificial intelligence could help trigger the next world war [15] and Stephen Hawking predicting that AI "could spell the end of the human race" [14], is there any wonder why fear concerning AI and autonomy is growing?

Psychologists state that the human brain has a physiological reaction that occurs in response to a perceived harmful event, attack or threat to survival [45-47]. This is called the acute stress response or the fight, flight or freeze response. Some analysts state there are more than three responses adding an "appease" option to the original three [46]. In our technological discussion about the future of autonomy at NASA, we have experienced these responses in NASA personnel.

1) The Fight Response

In the context of autonomy, the fight response represents those who view themselves as fighting or competing against autonomy and other technological progress.

2) The Flight Response

The flight response refers to those who choose to say away (or to hide) from some forms of modern technology [48]. In the general sense, those who hide from new technology are not necessarily fighting against it. With respect to autonomy, those with the flight response will prefer to deal with a human bank teller rather than operate an automated teller machine.

3) The Freeze Response

The freeze response represents those who are (for all practical purposes) frozen. Being frozen, in this context, represents being disengaged from the argument. It represents being stuck or unable to make a decision. As humans, we tend to freeze psychologically when we feel the odds are overwhelming and the stressor is perceived as inevitable. The Cryogenic response is similar to a deer in headlights.

4) The Appease Response

The appease response occurs psychologically to those who make anxious overtures and undue concessions to satisfy the demands of an adversary. An appeaser simply agrees with an adversary. An extreme form of the appease response is blind obedience to the adversary's demands. In the context of autonomous machines, an appeaser will simply bow down to the machine asking it to have mercy.

B. A Different Response to Threat: Self-Awareness and Collaboration

Behavioral experts agree that an adequate amount of stress can help individuals keep an optimal level of performance. However, intense anxiety can be the cause of serious physical conditions including mental illnesses. Many people suffer from anxiety disorders while other are victims of fear. Stress-induced fears trigger physical responses on the individuals suffering from it. Some fears are unconscious and subsequently require a significant amount of effort to overcome them. A fundamental form of fear, such as the fear of the unknown, is caused by the absence of sufficient information. This fear is sustained by continual perceptions of uncertainty. No matter the source of the fear or anxiety, once the affected individuals are able to acknowledge the effects those have in their lives, and decide to cope, reduce or eradicate them, they start on the path of success to rise above those limitations [49].

Self-awareness is a key factor in conquering fear and anxiety. Self-awareness helps by identifying the source of the fear and the factors that feed into the fear, and then helps by analyzing how modifications in mindset, actions and the environment can help to overcome the fear. Overcoming fear requires humility and might even require a certain degree of bravery to disclose it to others who can be trusted [49]. Overcoming fear requires a firm conviction to move forward by modifying the undesired behavior. One way to modify previous behavior is to psychologically change the context. As stated previously, one of the manifestations of fear is the fight response. The fight response can be seen in those who view themselves as fighting or competing against technological progress. One way of changing the context in this scenario is to move from competition to collaboration. Collaboration, in this context, is viewed as working with technology in its design and architecture, therefore, providing human influence over its evolution. In collaboration, the human becomes a stakeholder with invested interest. Why the need to *fight* or to run away (*flight*) from something you helped create? Why the need to disengage (*freeze*) with technologies in which you were involved? Why the need to have blind obedience (*appease*) to something you helped bring into existence?

Collaboration with technology creates for a better future as compared to competition with technology. Using the analogy of the business work culture, collaboration helps create cultures that produce results by coalescing individual strengths to move toward a common vision [50]. Collaboration permits for a more trusting environment. Competition, on the other hand, has the opposite effect. Competition creates a culture of in-fighting and resource hoarding (physical and intellectual) where trust is minimized. It is hard to obtain the best ideas when people (and machines) refuse to share and to work together [50]. For these reasons, a collaborative perspective should be chosen over a fear-based perspective for those who want to build socially-healthy technological systems.

IV. STEP 2 – Examine the Skills Required to Architect Socially Healthy Technological Systems

In addition to emotional or cognitive-based perspectives, engineers and architects should also have some level of competence in a technical discipline. They should be able to comprehend a range of complex designs and the risks associated with diverse complexity. They should also attempt to understand their own biases which they may unconsciously project onto others or onto the technological design. They should employ a systems approach with basic understanding in system thinking principles. With respect to the uncertainties present in the design phase, they should have a basic understanding of causal and stochastic inference. They should also have the humility to ask for help when answers are not forthcoming.

Particular technological designs may require specific disciplines or competencies to help develop. Designers need to ensure that they acquire the technical expertise to respond to design questions promptly and adequately. It is also useful to have diversity in thought and diversity in function to handle the complexities and constraints involved with complex technological systems.

V. STEP 3 – Examine Mindsets Required to Ameliorate Hubris Syndrome and the Dunning-Kruger Effect

Technology is a powerful tool to either improve or to destroy human lives. The eventual behavior of the technological system is governed (to a certain extent) by the mindset of the human creators. This section will describe a few human mindsets that have proven to be very detrimental to the development of systems. Individuals with these mindsets should take heed and learn how to overcome them if they want to create socially-healthy technological systems that benefit mankind. The systemic management of our human systems is first required in order to adequately manage our complex technological systems. This necessarily includes discipline and mindfulness to see and correct errors introduced by cognitive biases, deleterious mindsets, blind spots and other errors.

A. Hubris Syndrome

Hubris Syndrome is an acquired personality change that can occur in powerful leaders, successful individuals and successful organizations [51]. Hubris is often seen as an extension of the confidence and ambition found in people who seek power. Because the people who develop it hold power (in various forms, political, technological, economic, etc.), the effects of their hubris can be widespread and, in some cases, extremely damaging to many people. Some of the traits associated with Hubris Syndrome include:

- They fail to anticipate consequences by disconnecting with reality
- They have a gross overestimation of likely achievement through sustained belief
- They have excessive self-confidence accompanied by contempt for advice or criticism of others
- They have an unshakable belief that their approaches will be vindicated (despite a build-up of risks which they do not perceive)
- They have supreme overconfidence which leads to inattention to details

B. Overcoming Hubris Syndrome

In order to overcome Hubris Syndrome, individuals need to routinely connect with others who keep them grounded. They need to stay humble and exercise empathy for others. They also need to have their tenure limited if

they are serving in powerful positions. The longer they remain in power, the more power corrupts them. The US Founding Fathers provided for Separation of Powers and temporal limits to avoid hubris in government leaders.

C. Dunning-Kruger Effect – Unskilled and Unaware of It

People tend to hold overly favorable views of their abilities in many social and intellectual domains. The Dunning Kruger Effect suggests that this overestimation occurs, in part, because people who are unskilled in these domains suffer a dual burden - they reach mistaken conclusions and make regrettable errors because they have limited knowledge and their incompetence robs them of the metacognitive ability to realize it [52]. Several analyses linked this miscalibration to deficits in metacognitive skill, or the capacity to distinguish accuracy from error.

D. Overcoming the Dunning-Kruger Effect

Paradoxically, improving the skills of participants, and thus increasing their metacognitive competence, helped them recognize the limitations of their abilities. However, the participants had to first have the humility to accept that they made mistakes. Therefore, humility and the ability to receive correction are necessary ingredients for those who desire to build socially-healthy technological systems.

VI. Conclusions

Technology is a powerful, disruptive instrument of change. The ramifications of this change, at times, can be cumulative and substantial. Technology is rapidly changing biotechnology, autonomy, wearables and robotics with moral and ethical considerations. Of all the uncertainties about the future and technology, one thing is certain. All of these powerful, man-made, technological systems will experience unintended consequences. Whose is responsible for managing these complex technological creations? Do we as humans realize that collectively we are creating maladies and hardships as well as benefits from our own technological creations? How many technologists or scientist/engineers realize the down side risks associated with such fabulous inventions? Do we ever truly ask the questions about downside risks a priori or do we simply pay lip service by consenting with our words while dissenting in our hearts? We also wonder whether we positively assume that government or society will always mitigate the destructive aspects of our technological creations. These assumptions are a part of our collective hubris. Once our awareness is opened and we perceive the historical double-edged sword (benefits plus unintended positive consequences plus unintended negative consequences) presented by many of our technological creations, we would pause to consider a more sensible systems-oriented approach to architect future technological systems. The premise of this paper is that the change must first start with us by having an appropriate response to technology, by acquiring the skills required to successfully build them and by ameliorating the harmful aspects of our personalities that will certainly introduce unintended consequences into our future technological systems.

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