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Original Paper

Science, Technology, and Medicine have Progressed Immensely during the Last Five Centuries, yet Mankind Is Threatened by Self-Destruction

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Abstract

During the last 5900 years, creative human minds have dispelled false beliefs about our universe, as well as chemical, physical, and biomedical phenomena. Life expectancies in most inhabited parts of our world have increased appreciably. A brief survey of those who contributed to the progress of science, technology, and understanding is presented. Yet, primitive instincts and ambitions still dominate our world, and conflicts threaten to destroy life on this planet by way of nuclear weapons. Societies are ruled by politicians and militaries, for scientists are "on tap, but not on top". The contrast between reason-based progress and instinct-based aggression is mind-boggling.

Keywords

abandoning false theories, physics/chemistry/biomedicine discoveries, technological inventions, nuclear armament

1. Introduction

A few centuries ago, physics, astronomy, chemistry, and biology were dominated by falsehoods: all matter was composed of four elements; astrology could predict the future; the universe rotated around the earth; akin to sound which needs a medium (air, water) to propagate, light needed "aether" to travel in the universe; phlogiston was lost during combustion; organic compounds could be synthesized only by living organisms; species were eternal; life could be generated spontaneously, etc. Summarized mostly by Aristotle and protected by tradition, such beliefs were hard to shake. Advocating heliocentrism was dangerous in catholic countries: the Inquisition sanctioned Giordano Bruno

(1548-1600) with burning at the stake and Galilei with house arrest. Yet, gradually, the Renaissance and its aftermath continued to conquer the arts and sciences. The poets had long known that the pen could be mightier than the sword and that they should be proud of their achievements:

> "I have created a monument more lasting than bronze
> And loftier than the royal structure of the pyramids,
> That which neither devouring rain, nor the unrestrained North Wind
> May be able to destroy nor the immeasurable
> Succession of years and the flight of time.
> I shall not wholly die and a greater part of me
> Will evade Libitina, the Goddess of Death; continually I,
> Newly arisen, may be strengthened with ensuing praise so long
> As the high priest climbs the Capitoline with the silent maiden…"

Was Horace (65-8 BC) conceited when he wrote these lines in his Ode 3.30? And was Shakespeare (1564-1616) immodest when he echoed these sentiments in Sonnet 65:

> "Since brass, nor stone, nor earth, nor boundless sea
> But sad mortality o'er-sways their power,
> How with this rage shall beauty hold a plea,
> Whose action is no stronger than a flower?
> …
> O fearful meditation! where, alack,
> Shall time's best jewel from time's chest lie hid?
> Or what strong hand can hold his swift foot back?
> Or who his spoil of beauty can forbid?
> O, none, unless this miracle have might,
> That in black ink my love may still shine bright."

On the contrary, I believe they underestimated the power of the pen. What could have been more permanent, in Horace's mind, than the high priest officiating the divine service, on the Capitoline Hill in Rome, in the company of the silent vestals?

Of course, the power of the sword should not be neglected, because it is responsible for the billion people today that speak Spanish, Portuguese, French, Italian, or Romanian, and for allowing Latin and Greek culture to rise from the ashes during the Renaissance and to be taught in our universities nowadays.

2. Of Swords and Pens, or Humanity at Crossroads

Every human lives at the intersection of many "dimensions". Some of them are the familiar geographical, physical, or temporal dimensions. In other cases, there are only two dimensions (male or female normal genetic chromosomes) and for most other dimensions, multiple possibilities (race, religion, nationality, political and economic factors).

Many of these dimensions are determined by birthplace, family, and birthdate, but there are also dimensions that can be changed voluntarily and individually. One's language and education are initially decided by family, but afterwards may be strongly influenced by the individual.

Mankind has so far benefitted enormously from science and technology, but it remains to be seen if technological advances in weaponry will one day be deplored as a "new Pandora's Box". Terrorist attacks and school shootings are the dark side of small-scale weaponry; drug addiction is the dark side of the global pharmaceutical industry; identity theft is the dark side of progress in information technology; car accidents are the dark side of improved transportation.

Although any connection between birthdates and one's personality traits is impossible, it is astonishing to see the faith people place in the newspaper's horoscope page. As long as this does not cause any harm to others, such idiosyncrasies can be tolerated and can be seen as part of man's desire for meaning.

Primitive instincts stand in high contrast to what we have reviewed above from the efforts of luminaries to understand our world. It is true that blood in the arena is nowadays no longer the result of gladiator fights, but of bullfights in Spain, Southern France, Portugal, Mexico, Colombia, Venezuela, Peru, and Ecuador.

Three or four millennia ago, thousands of people worked most of their lives to create the pyramids of Egyptian pharaohs or to defend the Emperor of China by crafting funerary armies of clay warriors. At present, most countries expend considerable effort on weapons which threaten to annihilate life on this planet. We are surrounded by mendacity. One disguises the truth by euphemisms: "Military Academies" instead of "Schools of Manslaughter" and "Defense Department" instead of "War Ministry".

The waste of Earth's resources (fossil fuels, irreplaceable minerals) for military purposes not only robs further generations of vital support but also hastens global warming. How could this happen when mankind has shown that it was reasonable and capable of great achievements?

The opening lines of UNESCO's Constitution are engraved in ten languages in the Tolerance Square Wall, UNESCO, Paris: "Since wars begin in the minds of men, it is in the minds of men that the defenses of peace must be constructed".

Instead of squandering federal funds for weapons, one should invest them into improving railways, roads and bridges, projects such as the anti-hurricane wall "Ike-dyke" for protecting the Houston-Galveston area against flooding.

One can predict, up to a certain point, the outcome of political decisions by computerized analysis. The power of computers for games such as Chess or Go is well known. Historically, the two Roman triumvirates evolved into two-player confrontations, ending with the victories of Julius Caesar and Octavian Augustus. A hypothetical Department of Ante-history that could rapidly predict probable consequences of various decisions would be much safer than the advice of one or a few presidential counselors. There are too many variables in today's global politics. Some of these are random events caused by weather (droughts or floods), epidemics, global warming, earthquakes, volcanic eruptions, meteorites, extra-terrestrial gamma-ray bursts, etc. Other events are connected with economic and political factors. In two-player games, a pre-emptive nuclear strike constitutes a valid temptation for world dominance, but the situation is changed in multi-player games. Random events such as revolutions, assassinations, or terrorist attacks sometimes backfire.

3. Physics, Astronomy, Chemistry, Technology…

In the present paper, we wish to show that human thought, inspired by experimental observations, developed theories that in turn stimulated new experiments, and so on. Knowledge developed despite wars, persecutions, and experimentally refuted beliefs. It is wonderful to admire the inquisitive minds that corrected wrong hypotheses and built today's understanding of the universe (Balaban & Basak, 2003).

In the 16th and 17th centuries, the major revolution was the understanding that earth is the third planet from the sun, due to observations by Nicolaus Copernicus (1473-1543), Tycho Brahe (1546-1601), Johannes Kepler (1571-1630) and Galileo Galilei (1564-1642). Galilei constructed a telescope that allowed him to discover Jupiter's brightest moons and formulated laws of mechanics that preceded those of Newton. By observing the eclipses of Io, one of these moons, Ole Christensen Rømer (1644-1710) was able to measure the speed of light in vacuum, *c*. Around the same time, Rene Descartes (1596-1650), Francis Bacon (1561-1626), and Blaise Pascal (1623-1662) put experimental observations above established beliefs.

The dissemination of discoveries was made possible by Joachim Gutenberg's (c. 1400-1468) invention of the printing press. Two great scientists, Isaac Newton (1642-1727) and Gottfried Leibniz (1676-1716) invented calculus and disputed priority, but Newton also created an encompassing physics that explained celestial mechanics. For speeds that do not approach the speed of light, it is still valid, but Einstein's relativity has widened our understanding.

Understanding that different gases exist (not only "air") occurred only in the 17th century with Henry Cavendish (discoverer of hydrogen and carbon oxides) and Joseph Priestley and Carl Scheele (independent discoverers of oxygen). They all believed in phlogiston. Robert Boyle (1627-1691), Jacques Charles (1748-1823), and Louis Joseph Gay-Lussac (1778-1850) formulated laws obeyed by gases, arriving at the "ideal gas laws" in terms of volume, pressure, and temperature. Amedeo Avogadro (1776-1856), observing that gas volumes reflect the atomic composition of the gaseous molecules, formulated the idea that equal volumes of gases under the same conditions of temperature and pressure will contain the same numbers of molecules. With hydrogen being the smallest and lightest element, it is natural to use the mass of a hydrogen atom as the unit for atomic and molecular weights. The number of molecules in a mole of substance is called Avogadro's number and is known at present with high precision.

As far from reality as the four ancient elements or Ptolemy's epicycles, the phlogiston theory was put to rest by Antoine Lavoisier (1743-1794), who also showed that "chemical elements" were distinct from "chemical compounds". During the French Revolution, when Lavoisier had asked the Academy of Sciences for time to finish a report, their reply was: "The Republic does not need scientists", and he was sent to the guillotine. During the following century, in large part through its chemical and metallurgical industry, Germany surpassed France economically.

John Dalton (1766-1844), using weight measurements, contributed to the "Law of Definite Proportions" together with Joseph Proust (1754-1826). The notion of "atom" originated in chemistry and it was Dmitri Mendeleev (1834-1907) who called the elements to order with his Periodic System. He had the satisfaction to see that three newly discovered elements (germanium, scandium, and gallium) had the properties he had predicted. The chemist William Ramsay (1852-1916) and the physicist John William Strutt, 3rd Baron Rayleigh (1842-1919) discovered the rare gases, adding a new column to the Periodic Table.

Astronomical observations revealed that our solar system was one among many galaxies in our universe. The power of mathematics was proved by Urbain Le Verrier (1811-1877) when he calculated where the eighth planet, Neptune could be observed for the first time, based on the slight orbital perturbations of the seventh planet, Uranus.

The close connection between chemistry and physics was strengthened when Robert Bunsen (1811-1899) and Gustav Kirchhoff (1824-1887) discovered that spectra could characterize elements. After Luigi Galvani (1737-1798) discovered serendipitously that electricity could be produced chemically, Alessandro Volta (1745-1827) showed how to generate continuous electric current. The unit of electric potential is named after him. The unit for electrical charge bears the name of Charles-Augustin Coulomb (1736-1806), and the unit of electric current intensity is named after André-Marie Ampère (1775-1836).

Building upon these advances, Humphrey Davy (1778-1829) produced the alkaline metals electrochemically. A man who deserves admiration for his achievements in chemistry and physics is Davy's self-taught assistant, Michael Faraday (1791-1867). He made essential discoveries in both chemistry and physics: isolated benzene from coal tar and elaborated the laws of electrochemistry. His experimental genius allowed him to invent the first electromagnetic motors and electrical generators. The industrial revolution was based on thermodynamics of heat engines, steel and aluminum metallurgy and, more recently, reinforced concrete, railways, freeways, airports, and so on.

James Clerk Maxwell (1831-1879) converted Faraday's experimental results into a set of equations that allowed him to calculate the speed of electromagnetic radiation in vacuum, and -surprise!- it was exactly the speed of light, showing that what we see as light covers a range of frequencies or wavelengths. Heinrich Hertz (1857-1894) found a way to produce radiation with shorter wavelengths, which enabled Guglielmo Marconi (1874-1937) to invent radio communications. On the other side of the visible spectrum, Wilhelm Röntgen (1845-1923) discovered X-rays, which have been immensely useful in science and medicine.

For a long time it was believed that chemical substances found in living organisms could only be synthesized by "vis vitals"—the "living force". After Friedrich Wöhler (1800-1882) made urea from the ammonium salt of tautomeric cyanic or isocyanic acids, organic compounds isolated from nature or made by chemists account for over 99% of all 140 million known substances today. All organic compounds are based on the element carbon (often associated with hydrogen and a few other elements).

The electron, one of the fundamental elementary particles, was discovered by Joseph John Thomson (1856-1940) by studying "cathode rays" in discharge tubes. By measuring the curvature of electron beams in electric and magnetic fields, the ratio between an electron's mass and charge was found. In an ingenious experiment, Robert Millikan (1868-1953) measured the electron's charge: the falling drop experiment in an electric field: when X-rays ionized oil droplets, their electric charges changed by the same amount, corresponding to a single electron. The value agreed exactly with the earlier measurements by Faraday on the deposition of metals by electrolysis!

Even shorter wavelengths than X-rays are those that accompany radioactivity, discovered serendipitously by Henri Becquerel (1852-1908) who observed that a photographic film was activated by uranium salts. His doctoral student, Marie Curie (1867-1934) and her husband, Pierre Curie (1859-1906), showed that uranium and other heavy metals such as thorium, as well as two new elements discovered by them (polonium and radium), emit gamma-rays, together with beams of electrons and helium-4 nuclei.

Charles Wilson (1869-1959) invented the "cloud chamber", which allows one to see the trace of individual particles by liquid droplets formed on supersaturated gas on ionized centers. For more energetic charges beams, one uses overheated liquids.

A revolution in physics occurred when physicists tried to find an equation for the wavelength distribution law for "black body radiation" (light emitted by heated objects), found experimentally by Wilhelm Wien (1864-1928). No continuous function could fit Wien's curve. Then in 1900, Max Planck (1858-1947), in an act of despair announced that the only solution was to admit that energy is distributed in minuscule "quanta", according to a discontinuous combinatorial function. Planck's proportionality constant h between energy and radiation frequency plays a major role in contemporary physics.

Albert A. Michalson (1852-1931) used an interferometer to show that "aether" does not exist. Two decades later, special relativity would provide the explanation for this experiment. In 1905, Albert Einstein (1879-1955) published a series of four papers each of which was a major theoretical finding. He explained the photoelectric effect of electron emission from metals under illumination by assimilating Planck's quantum with a light photon. He replaced Newton's absolute space and time by the space-time of special relativity. He showed that Brownian motion can be modeled mathematically and is due to the finite size of molecules. He established the equivalence of rest mass and energy with his famous equation $E = mc^2$. General relativity would wait for several years and was confirmed by observations on Mercury's orbit and, during a solar eclipse, on bending sunrays.

Quantum mechanics was gradually developed after the First World War by Paul Dirac (1902-1984), Erwin Schrödinger (1887-1961), Louis de Broglie (1892-1987), Werner Heisenberg (1901-1976), and other physicists. We know now that there is a dualism between waves and particles. Each elementary particle has a corresponding antiparticle; nuclei contain neutrons and positively-charged protons, each composed of three quarks. The atomic number Z in the periodic system represents the number of protons in the nucleus. Henry Moseley (1887-1915) found that X-ray spectra could provide a direct determination of atomic numbers. Such spectra had been studied by Max von Laue (1879-1960), William Henry Bragg (1862-1942), and his son, William Lawrence Bragg (1890-1971).

Maria Goeppert Mayer (1906-1972) drew attention to the nuclear shell structure, which accounts for the higher stability of shells with 2, 8, 20, 28, 50, 82, and 126 protons or neutrons. Elements up to $Z =$ 83 consist of one or several stable isotopes. Each element also has several radioactive isotopes, which decay by emitting electrons, positrons, or α-particles, until they reach a stable nucleus position.

The induced radioactivity was discovered by Irène Joliot-Curie (1897-1956) and Frédéric Joliot-Curie (1900-1958). Ernest Lawrence (1901-1958) invented the cyclotron, which can accelerate heavy charged particles such as protons or α particles, and used such beams to make new elements. However, bombarding nuclei with neutrons is easier because it does not need to overtake electric repulsion. Many new elements with short half-lives were made by Glenn Seaborg (1912-1999), Georgy Flerov (1913-1990), Yuri Oganessian (1933-) and their coworkers.

Chemical phenomena occur when there are changes in the electronic shells. All other phenomena (for instance those involving atomic nuclei) belong to physics. There are two kinds of elements (metals and non-metals) and three kinds of chemical bonds: metallic (strong) ionic (strong) and covalent (which provide both the strongest and weakest bonds). The strongest are found in molecules or in atomic nets, such as diamond or silicate rocks, and the weakest are intermolecular forces such as hydrogen bridges or Van der Waals forces, responsible for the various states of matter (gas, liquid, solid).

Elementary particles have spin and Wolfgang Pauli (1900-1958) explained the electronic shells of elements by his Exclusion Principle, which explains the successive electronic shells. Covalent chemical bonds involve electron pairs with opposite spin shared by atoms, whereas metallic bonds and nets characterize atomic nuclei embedded in a sea of electrons, and ionic bonds involve ions with opposite charges.

Fritz Haber (1868-1934), whilst investigating the catalyzed reduction of nitrogen by hydrogen to ammonia at high pressure and temperature, succeeded in solving the most acute problem for soil fertilization. Wilhelm Ostwald (1853-1932) had shown how to oxidize ammonia to nitric acid, so that both urea and ammonium nitrate could provide nitrogen fertilizers.

The Standard Mode in physics accounts for most of the elementary particles. Symmetry plays a basic part in the theory that led to the discovery of these particles, as first argued by Eugene Wigner (1902-1995). In his paper titled "The Unreasonable Effectiveness of Mathematics in the Natural Sciences", he discussed the astonishing ability of mathematics to model experimental findings.

Otto Hahn (1879-1968) and Lise Meitner (1877-1968) discovered the fission of Uranium-235 nuclei when capturing slow neutrons. In the USA, Enrico Fermi (1901-1954) led the team operating the first nuclear reactor, and the Second World War ended after two atomic bombs exploded in Japan. Soon afterwards, it was discovered how fusion of hydrogen to helium nuclei provides even more powerful explosions in hydrogen bombs.

Technological innovations based on electricity and high-frequency waves have considerably improved everyday life. We can call, see, and talk to any person anywhere on this planet, when only two hundred years ago, news traveled on land with the speed of a horse and overseas with the speed of a ship. Nowadays, crossing the ocean by air is measured in hours, and people take cruises just for pleasure. The manmade Panama and Suez canals allow cargo and passenger ships to shorten their journeys considerably.

Thomas Edison (1847-1931) invented the phonograph, the motion picture camera, and electric light bulb. The universal use of alternating electrical currents (and not Edison's direct currents) is due to Nikola Tesla (1856-1943) and George Westinghouse (1846-1914).

Transistors, replacing vacuum tubes in computers, were invented by John Bardeen (1908-1991), William Shockley Jr. (1910-1989) and Walter Brattain (1902-1987), thus inaugurating the era of informatics, computer programming, and portable cell phones. Television and the motion picture industry provide entertainment, and at the same time, they allow sporting competitions to attract spectators. The invention of the laser and the Global Positioning System provided even further applications.

The astronomer Edwin Hubble (1889-1953) argued that the space between galaxies expands. There is still a mystery about this expansion, which seems to accelerate, indicating that the observable matter in the universe is outweighed by "dark matter" and "dark energy".

Space travel started in 1961 with Yuri A. Gagarin (1934-1968). The first man to land on the moon was Neil Armstrong (1930-2012) in 1969. International collaboration allowed the Space Station to circle around the earth for experiments at zero gravity. Land-rovers have explored Mars. The Cassini mission made spectacular discoveries about Saturn's rings and moons. The space telescope named after Hubble is able to see the most distant galaxies back in time, until soon after the Big Bang about 13.7 billion years ago.

4. …Biomedical Sciences

One can trace the development of physics as a true science starting with Galilei and Newton, when phenomena could be modeled mathematically. Chemistry as a science, freed from alchemical beliefs, started later, at the end of the 18^{th} century. Biomedical knowledge had an even later start. Charles Darwin (1809-1882) based his theory of evolution on observing the results of natural selection in the Galapagos Islands. The chemist Louis Pasteur (1822-1895) had to devise various experiments in order to persuade the French Academy that spontaneous life generation was impossible. His greatest findings are brilliant both in chemistry (isolation of enantiomeric tartaric acids and their racemic mixtures) and in medicine (anti-rabies vaccine, combatting anthrax). He proved that contagious diseases are caused and transmitted by various germs, today known as bacteria and viruses.

The first connection between biology and mathematics is due to Gregor Mendel (1822-1884), the monk-turned-botanist, who investigated the hereditary transmission of various phenotypes by cross-pollination of peas over many years. He found that characteristics (such as color) are transmitted according to binomial coefficients, and proposed the idea of trait genes. Experimenting with fruit flies, Thomas Morgan (1866-1945) confirmed the existence of genes and found the existence of chromosomes. Humans have 22 chromosome pairs, plus an X-chromosome and a Y-chromosome, inherited from the mother and father, respectively. Linus Pauling (1901-1994) showed that X-ray spectra of crystallized proteins indicated that polypeptide chains can form helical secondary structures. The structure of an important protein, insulin, was deciphered by Dorothy Crowfoot Hodgkin (1910-1994).

In the 1930s, sulfonamides were found to have therapeutic value against many bacteria. The serendipitous discovery by Alexander Fleming (1881-1955) of the first antibiotic, penicillin, the tool that mold uses against bacteria, benefitted from the need for more effective medicines. Its structure was also determined by Dorothy Hodgkin. Howard Florey (1898-1968) and Ernst Chain (1906-1979) brought the testing and production of penicillin to the industrial level. Many other antibiotics were later discovered to replace the previous generations when bacteria developed resistance. The fight continues, but life expectancy is now appreciably higher than ever before thanks to modern methods for drug design. Although global epidemics such as plague or Spanish influenza have disappeared for more than a century, viral epidemics can still be dangerous.

Several discoveries indicated that genetic information is encoded in deoxyribonucleic acids (DNA) that constitute the chromosomes and can be seen by microscope when cells divide. The molecular basis of genetics was revealed by Francis Crick (1916-2004) and James Watson (1928-), who found the structure of DNA using X-ray spectra [obtained by Rosalind Franklin (1920-1958)] and proposed how one strand might act as a template during DNA replication.

Genetic engineering is applied at present for gene transfer in medicine, using viruses depleted of their harmful components as vectors. Also, in agriculture, genetically modified plants help to protect harvests and to confer resistance against harmful insects or micro-organisms.

The fortune of the chemist Alfred Nobel (1833-1896), based on the invention of dynamite, has endowed prizes in science (physics, chemistry, and physiology or medicine), literature, and peace-connected politics or economics to be rewarded annually. Other fields of human creativity such as music, painting, sculpture, architecture, and pure mathematics were not included in Nobel's will, and they have also been reluctantly omitted in this brief review.

5. Conclusions

We have seen how exceptional human brilliance was able to decipher mysteries of atoms, living cells, and the universe. On the other hand, we see around us horrendous war preludes, which are not imagined by Steven Spielberg or Arthur C. Clarke, but are the cruel, unbelievable reality.

Ideally, several steps might remedy some of the present consequences of fear and primitive instincts:

1) Convert nuclear warheads into energy sources.
2) Invest more funds into research on nuclear fusion power.
3) Increase use of wind and sunlight as energy sources.
4) Eradicate the worst infectious diseases.

This list is by no means capable of solving all present and future problems, but it would be a welcome step forward. There is no reason why disputes over land should not be settled peacefully. In the past, Napoleon, Hitler, or Stalin dreamed about ruling the world, but such pathological ambitions must be stopped in their infancy.

One can trace the Second World War as the almost automatic consequence of the First World War, so that both wars were actually triggered by a single event: the assassination of Archduke Ferdinand of Austria in Sarajevo, followed by the "domino sequences" of European powers bound by interweaving treaties and alliances. Now the world is once again a powder-keg waiting for a spark. Is there any hope that in the conflict between instinct and reason, the latter could hold sway?

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