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# Towards Human Security through Personalized Trans-disciplinary Evolving Symbiotic Education Based on Cognitive Digital Twins

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## Abstract

*Education has been evolving through a complicated roadmap to serve varying objectives from the understanding of the world we live in through training of servers of production lines, after the first industrial revolution (IR1) to other commercial targets throughout the next three industrial revolutions. With the current scientific and technological progress, human security and sustainability were expected to take care of themselves and evolve naturally. Not only they have not evolved, but the threats triggered by the developments in artificial intelligence (AI) tools alone are becoming existential. Our insensitivity and neglect of the ecosystem must now be transformed very urgently. Education is central to that transformation. The traditional uni-disciplinary one-size-fits-all approach to education appeared to have been sufficient through the first three industrial revolutions as it served the learners for a lifetime. However, it must evolve now into a multi- and trans-disciplinary collaborative model to cope with the exponential growth of knowledge and the complexities of our ecosystem stressed to the limit. One of the possible enablers of the transformation is the concept of cognitive digital twins (CDT) which is maturing due to the developments in high-performance computing and artificial intelligence. This paper addresses some aspects of this view.*

## 1. Introduction

This paper is intended to highlight links between human security within our ecosystem and a new type of **personalized symbiotic education** facilitating community building through cooperation and knowledge sharing rather than competition alone. This new educational ecosystem moves away from the current **one-fits-all** methodology towards a **one-fits-one** model. This new model also moves away from the emphasis on **teaching** to theoretical and experiential **learning** and from the brick-and-mortar setting to a **hybrid**. This approach includes several classes of **artificial intelligence** (AI) [27] and not only Web 2.0 and Web 3.0 [26], but also other wireless networks, both terrestrial and low-Earth orbit (LEO) satellites. The new model of learning can be achieved through personalized symbiotic and memetic cognitive digital twins. "Cognitive" refers to the action or process of knowing. Cognitive informatics [95], cognitive computing and cognitive systems [103] have been studied extensively because they extend the data mining quest and are critical to knowledge mining.

People have been dreaming about knowing and understanding the world around them. When we were isolated geographically and culturally, sharing and acquiring knowledge was very slow, with the acquired knowledge, however, lasting a lifetime. When we learned how to write, print and travel, the exchange of knowledge accelerated. When we discovered how to compute and communicate electronically, knowledge and new ideas became available to many more individuals, and the pace of information doubling accelerated to a point where we could not absorb it without help. Connected machines and software entities have now materialized with abilities to recognize patterns and learn from observations and the corresponding data on their own. Their sophistication has reached a point where there is a fear that those machines could replace all our jobs and might even be a threat to humanity.

This section provides the industrial, business, and societal context in which the new education becomes so important.

## 1.1. How Secure Are Human Security and Sustainability?

The traditional definition of security refers to all the measures that are taken to protect: (i) a country (national security, defence); (ii) a place (security guards, airport security, energy security); (iii) access (only people with permission are allowed to be at a place or use protected documents, data, files); and (iv) financial assets (stocks, shares, bonds, or other certificates).

Human security focuses on the individual human being in the context of the ecosystem, and on all the measures that are taken to protect humans, and not on national security or industrial security only. It exists in three constitutive dimensions: (i) freedom from want, (ii) freedom from fear [69], and freedom to create in order to improve and deepen our existence. "Freedom from want" represents the ability of an individual to meet their essential physical and social needs. "Freedom from fear" signifies the ability of an individual to live without threats to physical integrity or intentional harm. "Freedom to create" represents the critical human ability to bring change to ourselves and the world we live in. Measuring human security often uses the human security index [70] with the corresponding data available.

Human security includes the following areas (often interdependent) all consistent with the UN 17 Sustainable Development Goals (SDG) [98]: (i) Food security; (ii) Water security; (iii) Energy security; (vi) Environmental security; (v) Health security; (vi) Economic security; (vii) Ecological security; (viii) Personal freedom, safety and mobility security; (ix) Community security; and (x) Digital, cybersecurity, cyber-physical security, and cyber-physical-social security.

Just at the time of the expansion of the generative AI (genAI) and its potential to transform our future more than any other technology, Max Tegmark [84] asked many human security-related questions about AI's impact on society, war, justice, crime, jobs and the very sense of being human. How can we balance our prosperity without leaving people lacking income or purpose? How can we make future AI systems more robust, so that they do what is beneficial to us without crashing, malfunctioning or getting hacked? Should we fear lethal autonomous weapons? Will machines be smarter at all tasks, replacing humans altogether? Will AI be used by us to gain more power than we can handle? Or will AI help life flourish like never before?

Various institutions have also been investigating how organizations are considering **responsible technology** (ResT) and how they are implementing policies, frameworks, or strategies to meet the ResT objectives [MITT23]. The National Academies of Sciences, Engineering and Medicine addressed many concerns including the transition from STEM to STEAM in K-12 [65] and how people learn [63], [64]. Particular focus was also given to cyber-physical security [66].

After observing the tidal wave of AI and the impact of lethal autonomous weapons to cyber-physical viral sabotage, Stuart Russell [72] turned a red light on the potential conflict between humans and machines if we would not rethink AI from the ground up. While the near-term benefits are already seen in areas such as intelligent personal assistants to the accelerated scientific research in new medicines and materials, threats from misused AI are also seen. He suggests that we use a revised foundation on which we design AI systems with inherent uncertainty about the human preferences they are required to satisfy. Russell expects such machines to be humble, altruistic, and committed to pursuing our objectives, not theirs. Such machines could be provably deferential and provably beneficial.

Since human security has been weakened by many contemporary international and national events and conditions, many organizations are trying to improve it through impactful planning and actions. One example is the Human Security for All (HS4A) campaign by the World Academy of Art and Science (WAAS) and the United Nations Trust Fund for Human Security (UNTFHS). They had a presence at the Consumer Electronic Show (CES23) organized by the Consumer Technology Association (CTA)[CES23]. The HS4A has reached many individuals, industries and organizations at the event as it was attended by 115,000 from 151 countries, with over 3,000 exhibitors and nearly 250 conference sessions. The first CES1967 had 17,500 attendees and 200 exhibitors, making it one of the largest gatherings.

Many countries are also attempting to regulate hostile AI technological and economic developments affecting human security [37]. Examples include (i) the European Union AI Act in sectors such as health care and education, and (ii) the legally binding AI Treaty to protect human rights, democracy, and the rule of law. The treaty could potentially include a moratorium on technologies that pose a risk to human rights. Another example is the US Federal Legislative Proposals Pertaining to Generative AI [56]. Other examples include (i) The Autonomous Weapons Open Letter, 2016; (ii) The Asilomar AI Principles, 2017; (iii) The Jena Declaration on Sustainability, 2020; and (iv) The Pause Giant AI Open Letter, 2023, three of them organized by the Future of Life Institute.

None of those attempts is intended or designed to stop AI and similar progress, but to align it with human security for all.

## 1.2. Motivation for New Education: Evolution of Industries and Work

Over the past several centuries, the human condition has been changed profoundly by the agricultural and three industrial revolutions (Industry 1.0 to 4.0). The term "industrial revolution" was introduced by Arnold Toynbee in his 1884 Lectures on the Industrial Revolution [87].

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*"The time has come to revamp the educational system at its core. The new system must be personalized to match the diversity of individual abilities and styles of learning."*

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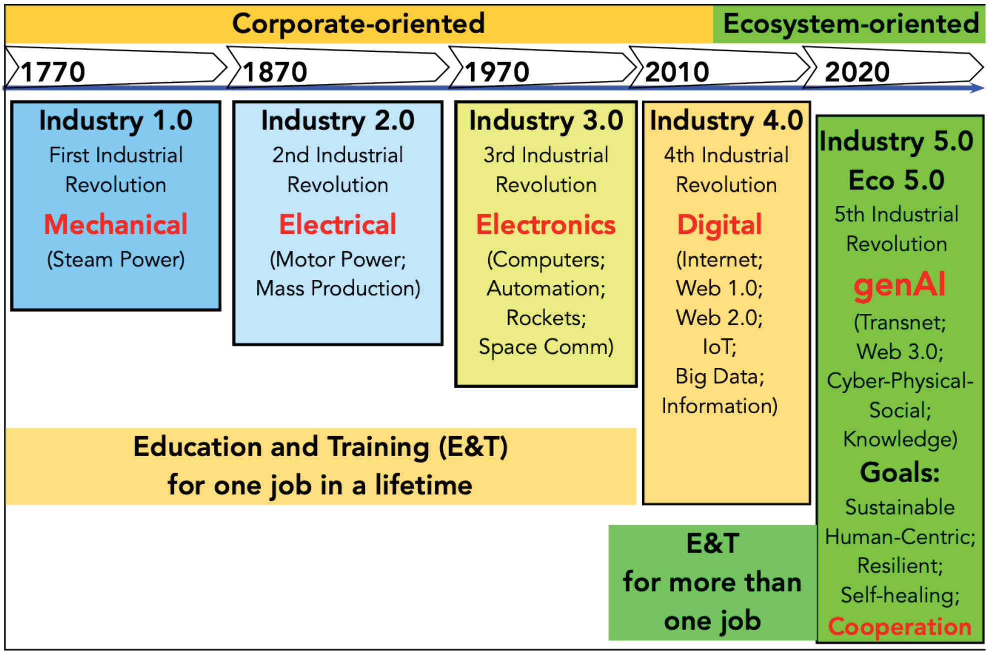
As shown in Fig. 1, Industry 1.0 was marked by the improvement of the steam engine and the resulting shift from human-muscle power and horsepower to steam power, leading to improvements in manufacturing and transportation. Industry 2.0 was marked by the implementation of electric generation, transmission and the electric motor which also triggered the need for assembly lines to improve manufacturing. Industry 3.0 provided a new set of developments due to the improvements in electronic devices and systems. Industry 4.0 was marked by the development of digital computers, digital data acquisition, digital processing, computer connectivity, telecommunications, and real-time control [75]. Notice that the first three revolutions lasted around 100 years each, while the fourth was only half of that period. Consequently, if someone learned the skills required for a given assembly line, the person could keep the same job for a lifetime.

*Fig. 1: Progression of Industrial Revolutions.*



Over the past several decades, a new augmented/ambient/artificial intelligence (AI) revolution (Industry 5.0) has evolved [102]. The last five years indicate that it may be far more transformative than all the previous ones. While many users are enthralled by the beneficial capabilities of generative AI (genAI), others are not only afraid of the risks and potential pitfalls that have already manifested themselves, but also see genAI as an existential risk to humanity.

The industrial revolution accelerated the need for many skilled individuals that could not be produced by the personalized master-student educational system of the old. What was needed was a well-organized one-size-fits-all educational system that could produce a large number of individuals with the expected skills within a short, fixed period of time. The Prussian classroom education system of 1770 produced magnificent results. At that time, the acquired knowledge and skills lasted for at least a lifetime.

The third and fourth industrial revolutions have accelerated the pace of knowledge, doubling from a lifetime to months. Are we capable of adjusting to that pace of knowledge acquisition? Furthermore, since the viability of jobs has also been below that of a single lifetime, young professionals are expected to have more than one job. How can they learn all of that in the old educational system?

The time has come to revamp the educational system at its core. The new system must be personalized to match the diversity of individual abilities and styles of learning. This personalization requires that the system have **cognitive abilities**. The new system must also be based not only on the body of knowledge (BoK), but also on the body of experience (BoX). We envisage that the new personalized system of education will be sufficiently agile and interactive so that will evolve in its symbiosis with humans. For that to happen, we must coexist with symbiotic autonomous systems, specifically those involving digital twins. This paper addresses some aspects of this view in the context of recent and projected developments [1].

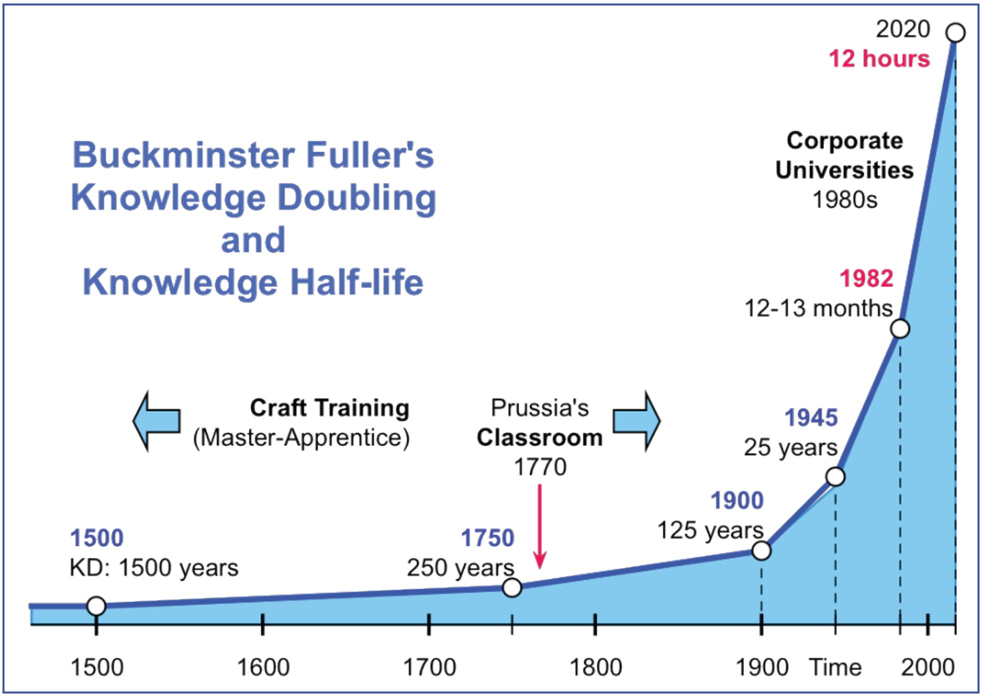
The paper gives definitions of the digital twins (DTs), their classes, and their applicability to industry, academia, and governments, as well as person-centred education and training. It also describes a new concept of cognitive personalized, symbiotic, and memetic digital twins to help in the transformation of education for sustainability and security for all.

### 1.3. More Reasons: Knowledge Doubling and Its Half-Time

With the explosion of data, information, knowledge and wisdom, we would have to spend all our available time searching for what is needed for our education and work. We cannot just ask a teacher or professor to answer our questions outside their class or research area. Today, search engines still provide millions of hits that have to be reviewed for relevance. Finding relevance in the sifted out and even prioritized material takes time. Since our reading and comprehension abilities are slow (the average reading speed is around 300 words per minute), it might take up to four hours to keep up with daily emails, news digests, blogs, magazines, and books. This keep-up time reduces the time for creative work.

According to Buckminster Fuller's "knowledge doubling curve" in 1982, all human knowledge generated and transmitted doubled in size around the year 1500. It doubled again by 1750 (only 250 years), and doubled again by 1900 (just 150 years). With those rates, humans were able to accommodate and adapt to the growth and change. It became harder to adapt when the doubling took 25 years around 1950. As shown in Fig. 2, the knowledge doubling today is much shorter (around 13 months). As an example, the number of annual patents increased from about 50,000 to more than 325,000 over the last 50 years. Many at IBM expect that around 2020s, the knowledge doubling could happen in 12 hours. It is not feasible for a human to adapt to that rate. The concept and implementation of digital twins that would act as an assistant and helper to each individual seem to be a necessity now [Wood18].

*Fig. 2. Buckminster Fuller's Knowledge Doubling Curve*




There is another reason for digital twins: the knowledge half-life. In his book Future Shock [86], Alvin Toffler stated that "the illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn." The knowledge and skills acquired in our schools and successive jobs diminish in relevance, thus requiring continuous updating, not once but throughout our lives.

How long does it take for knowledge to become outdated and irrelevant, or even incorrect? The half-life of knowledge (i.e., the amount of time it takes for knowledge to lose half its value) is often used to indicate the devaluation of knowledge in various disciplines. As might be expected, the knowledge half-life in aggressive disciplines like science, engineering and technology is also shrinking fast.

## 1.4. Knowledge Tsunami and the New AI Tools with Understanding of Language

We live in the knowledge revolution when knowledge-doubling occurs exponentially, while the knowledge half-time decreases. Attempts to solve the knowledge tsunami through artificial intelligence (AI) experienced several winters, and understanding the reasons for the bumpy road might prevent new slowdowns [45].

That available body of knowledge (BoK) and Body of Experience (BoX) are no longer confined to selected individuals or a single group of people only. The development of the Internet and the World Wide Web (WWW), first in the static informative form (Web1.0) and later in the dynamic interactive form (Web2.0) has shifted the BoK and BoX from a written form to an electronic hyperlinked form. The price we had to pay was lower security, with fraudulent use of the materials and personal attacks. A better form (Web3.0) is being developed to increase security through a more intelligent decentralized Web architecture [26].

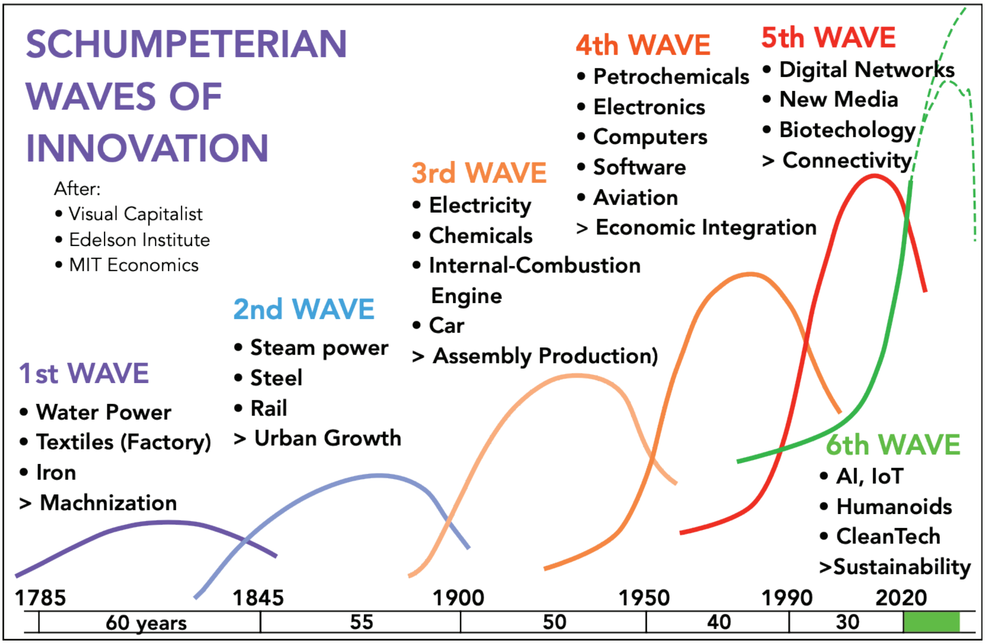
We live in the knowledge revolution when knowledge-doubling occurs exponentially, while the knowledge half-time decreases. That knowledge is confined neither to selected individuals nor to a single group of people because it is also in the possession of AI tools such as the *large language models* (LLM) [67], the *pathways language models* (PaLM) [9], and the associated chatbots such as the *chatbot generative pre-trained transformer* (ChatGPT) [77], and the dozens of other specific-domain applications [38], [39], [40], [41]. A large part of the cumulative BoK and BoX is also inside the AI tools. These conditions may have a tsunami effect on any society, organization, company, or other operating unit. It has a direct impact on learners and practitioners regardless of their age.

## 1.5. Second Context: Evolution of Business and Schumpeterian Waves

Economists observed that economic cycles behave like long composite waves pushed by the wind of inventions and innovation (Kondratiev, 45 to 60 years), with other shorter waves and ripples due to entrepreneurs' investments (Kuznets, 15-25 years and Juglar, 7-11 years), inventories (Kitchin, 3-5 years), as well as implementation and acceptance difficulties. The primary wave is followed by the next wave. The composite wave has a period of prosperity, followed by recession and depression and revival before entering another prosperity [AgAH15].

In his 1942 book, *Capitalism, Socialism and Democracy*, Joseph Alois Schumpeter (1883-1950) suggested a model of continuous innovation and "creative destruction" in which the old economic structures of society are destroyed, but replaced by new economic structures. Examples include word-processing software, e-Mail, digital camera, smartphones, LED light bulbs, electric vehicles and the latest generative AI. That process oscillates around an increasing equilibrium state [82]. For those cycles to function we need four ingredients (TIPS): Theories, Ideas, People and Systems. Figure 3 shows five such waves.

*Fig. 3: Illustrates the Economic Waves (After [NeMa21])*




The first economic wave (1785-1845; 60 years) coincided with that part of the first Industrial Revolution, water power was instrumental in manufacturing paper, textiles, and iron goods. Unlike the mills of the past, full-sized dams fed turbines through complex belt systems. Advances in textiles brought the first factory, and cities expanded around them.

With the second wave (1845-1900; 55 years), between about 1845 and 1900, came significant rail, steam, and steel advancements. The rail industry alone affected countless industries, from iron and oil to steel and copper. In turn, great railway monopolies were formed.

The third wave (1900-1950; 50 years) was critical because of the emergence of electricity to power lights, motors and telephone and radio communication. In addition, Henry Ford introduced the Model T with its combustion engine and its assembly line transformed the auto industry. Automobiles became closely linked with the expansion of the American metropolis.

The fourth wave (1950-1990; 40 years), expanded transportation to include aviation that revolutionized travel and supply chain. Integrated circuits led to computers.

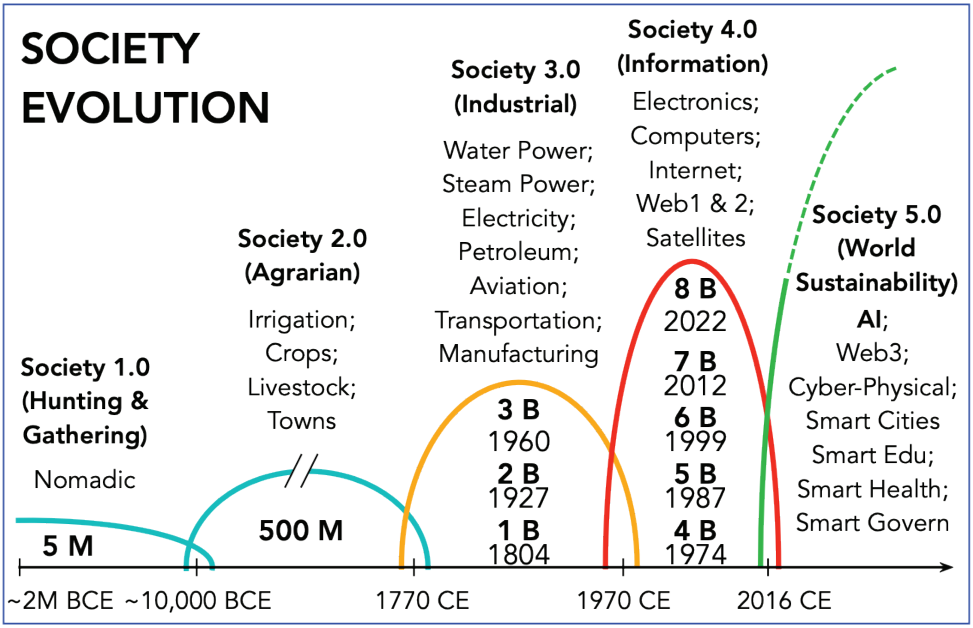
The fifth wave (1990-2020; 30 years), brought the internet which erased many barriers to information exchange, and the new digital media changed news cycles and political discourse and changed the role of the post office. It also ushered in a new frontier of globalization.

The sixth wave (2020-2030; 10 years), marked by three ingredients: (i) digital-tech (connecting and automating everything and everyone), (ii) human-tech (waste avoidance, reduction, recycling and reuse in a closed ecosystem), and (iii) human-tech (living healthier, happier, and maybe longer; personalized education). Those elements include the Internet of Things (IoT), virtual reality (VR), augmented reality (AR), mixed reality (XR), robotics, drones, humanoids and the automation of systems with predictive analytics, and physical goods and services will be digitized for digital twins. The time to complete tasks could shift from hours to real-time. Furthermore, to survive, clean tech must dominate to solve complex problems behind climate concerns.

## 1.6. Third Context: Evolution of Society

Most of the discussion today focuses on the evolution of industry and economy. In this paper, we will place society in the center. The evolution of our society follows a path that is very different from the other two revolutions, though they become intertwined around the first industrial revolution, as shown in Fig. 4.

*Fig. 4: Evolution of Society and Population Growth*




Society describes a group of people who share similar values, laws and traditions, and live voluntarily in organized communities for mutual benefits. Members of society often share religions, politics or culture. A society is successful if people agree to certain laws and a code of conduct (the social contract). They also agree to the process of selecting a leader/ referee who mediates and voice an opinion on the rules.

A society is called modern when it is industrialized, literate, live in cities within a nation-state, and is not confined to a specific geographical area. A society often includes more diversity, with people from different backgrounds, social classes and races, and the relation between individuals are often indirect.

In contrast, a community is limited to fewer individuals located in a specific geographic area, with individuals often sharing similar characteristics, and interacting regularly and directly.

Much has been written about the evolution of humankind, its struggle, successes, failings, aspirations and potential future (e.g., Harari's three takes on the past, tomorrow and our approaches to coping with the challenges [32], [33], [34]).

***Society 1.0: Hunter-Gatherer Society***

The hunter-gatherer society produces none of its own food. Hunter-gatherers spend an inordinate amount of time seeking food.

***Society 2.0: Agrarian Society (12,000 years)***

An agrarian society develops its economy based on agriculture and the cultivation of large fields. This distinguishes it from the horticultural society, which produces food in small gardens rather than fields. The transition from hunter-gatherer to agrarian societies is called the Neolithic Revolution. One of the earliest happened between 10,000 and 8,000 years ago in the area of the Middle East stretching from present-day Iraq to Egypt (the Fertile Crescent). Other areas of agrarian societal development include Central and South America, East Asia (India), China, and Southeast Asia. Agrarian societies often have a ruling class of landowners and a lower class of workers.

***Society 3.0: Industrial Society (1770 to 1970; 200 years)***

A society is considered industrial when only fewer than half its members are actively engaged in agriculture. They congregate in larger cities which become centers of manufacturing and trade. Their growth depends on innovators in technology. For example, the introduction of the printing press by Gutenberg in 1440 changed the world by accelerating the spread of literacy and the creation of new knowledge even though physical books were expensive to produce, transport and store.

This form of society evolved when water and steam power replaced ox and horsepower to allow the manufacturing of textiles and other products. It accelerated when electric energy could be delivered at longer distances and petroleum could drive cars with their combustion engines. The airplane became a tool of war and the start of aviation. Supply and distribution chains accelerated transportation.

The 3$^{rd}$ industrial revolution was marked by a radical shift from analog electronics and production control to digital computing, information and communications technologies (ICT) with automation in production, social networking and distribution of information, knowledge, experience in education and training for more than one job, as well in healthcare and governments.

Society 3.0 spans 200 years with three industrial revolutions (1.0, 2.0 and 3.0). Over the relatively short period (200 years), the Earth's population has tripled, from 1 billion (B) in 1804 to 2B in 1927, and 3B in 1960. The search for resources became relentless.

Bertrand Russel has seen the danger in the 1950s and developed the Einstein-Russel Declaration.

*"How can we achieve sustainable living on this planet? How can we transition from a consumption-oriented society to a human-aligned society?"*

***Society 4.0: Information and Communication Society (1970 to 2020; 50 years)***

The 4th Industrial Revolution was marked by the ability (i) to monitor and acquire massive data almost everywhere at any time (the Internet of Things, IoT, and the Industrial IoT) (ii) to accommodate the big data in new classes of data storage and distribution, (iii) to transmit the big data almost everywhere through terrestrial and space channels, (iv) to compute almost everywhere with small and large computers (locally and in distributed computing cloud of the cyberspace), and (v) to control almost anything in hard or soft real-time). These pervasive technologies started blurring the boundary between the physical world and cyberspace.

Significant breakthroughs in fields such as AI, robotics, IoT, autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing are augmenting the possibilities every day. Innovative digital fabrication technologies with biological science connect computational design, additive manufacturing, materials engineering, and synthetic biology to mastermind a symbiosis between micro-organisms, human bodies, to commodities, and even our homes.

Humans in the physical world have been empowered by smart technologies from cyberspace. Our human capabilities have been augmented by machines that behave in a way to complement our operations.

The fundamental feature of current Society 4.0 is that a person decides to access the data needed, retrieve the pertinent data, and analyze the data to make better decisions and predictions so that the actual work can be done by other human beings or robots or both. Society 4.0 has room for us to work and make the world a better place.

This augmentation through AI was well-intended and often useful for society. However, the process of vetting the correctness, truthfulness, timeliness, relevance, and ethical value of the data retrieved was done by humans. We have shown that we are not very good at detecting misinformation, disinformation, indoctrination, falsehood(s), and fabricated data generated by other either humans or by AI such as the ChatGPT.

The most significant recent achievement of AI appears to be the ability to learn the human language based on what we have done so far in our writing, sound, images, and video. In doing so, our human operating system has been hacked.

> *"We have to learn how to do almost everything in a new symbiotic way, not only with other humans but with machines."*

Our uniqueness in telling stories has been challenged. AI is telling stories already. They are as beautiful or as ugly as we are. It has learned from us through our language. It can also tell stories in more spoken languages than many of us.

This is the reason why AI has also very dangerous in more ways than we can imagine. This is why we need the next version of Society 5.0.

We also need Society 5.0 because of the (i) information and knowledge tsunami and the limited ability to discern between the relevant data and noise; (ii) rapid population growth and the corresponding increasing consumption and pollution, (iii) increasing need for limited Earth resources; (iv) slow transition for sustainable energy production; (v) increasing globalization and monopolies; (vi) regional and social inequalities and the perceived or real need to migrate; (vii) lack of policies, regulations, and laws related to industrial, economic and social infrastructures of the nations.

How can we achieve sustainable living on this planet? How can we transition from a consumption-oriented society to a human-aligned society?

***Society 5.0: Sustainable Society with HS4A (Since 2016)***

The concept of Society 5.0 is centered around life on Segan's "pale blue dot" where we have now been living for a while, and feel the obligation to not only maintain it, but make it better for the new generations of our successors.

In addition to scientific, engineering and medical innovation, we must create a better new value through social innovation to reduce the current diverse inequalities and gaps through the personalized and safe delivery of education, healthcare, and work environment in symbiotic relation with the AI-related technological developments. While we must refine our understanding of creative competition, we have to relearn how to cooperate. Society 4.0 was laced with conflicts intended to expand, conquer, and colonize other tribes, then dominate, steal and kill groups of perceived lesser value.

We need Society 5.0 because our four industrial revolutions have created unintended and undeclared wars on our planet itself. She has been patient, understanding and resilient for a while now, possibly because society is prone to errors and insensitivities. However, her recent severe climate responses might be a wake-up call so that we could rebalance our economic values with the values humanity has gained on the long road to freedom, safety, wonder, knowledge and life. If we will not stop the abuse, she might ask us to leave her soon anyway.

To be more specific, around 500 million people in India make their living from agriculture. In recent years, those farmers have lived through irregular monsoon cycles, making it difficult to plan on what crop and when to plant. Precision smart agriculture might help. Japan proposed the concept in 2016. Japan is the fastest-eldering nation, where more than 50% of citizens are already over 60 years of age [14], [73].

This Society 5.0 approach has a reasonable potential to address the urgent challenges in education, healthcare, agriculture and food production, energy, manufacturing, and disaster control.

The fundamental feature of Society 5.0 is that an AI decides (i) how to obtain the required data, (ii) how to analyze them, and (iii) how to decide what to do through either dialogue with humans, or through direct instructions for robots.

The process of collecting the required data is now very different from that in Society 4.0. Since AI is aware of all the data collected so far, it either extracts what already exists (including historical operational data, analytics, decisions made before, and outcomes of those decisions) or collects the new data from either the physical terrestrial and space environments (such as autonomous self-driving cars or from low-Earth orbit (LEO) interlinked satellites), or from humans, other living entities, organizations, governments, as well as other robots and machines.

The process of vetting the correctness, truthfulness, timeliness, relevance, and ethics of the data retrieved must also be very different from that of Society 4 because it has to be done at the speed and bandwidth of AI. Any false information carried by well-manipulated data may lead to unrecoverable catastrophes [12].

The process of analyzing the data to make better decisions and predictions is also different from Society 4.0 because the request for the decision originates from the AI collective. Since the AI identifies the need for the decision at a higher speed and bandwidth, it can cooperate and consult other AI units with similar experiences.

Decisions that lead to the actual work can be made as before in Society 4.0.

Society 5.0 has room for robots to perform work much faster, safer, and efficiently, while giving us more time to be creative in making the world a better and more sustainable place.

For that scenario to be true, we have to learn how to do almost everything in a new symbiotic way, not only with other humans but with machines.

Will the AI system tolerate our slowness, our idiosyncrasies, our fuzzy memories, our inability to transfer our knowledge and experience to the next generation, our need to relearn, our compassion, our dislikes, and our hate? Will there be work for all of us?

The shift from the past corporation-oriented slow industrial revolutions to a human-sustainability-oriented rapid eco revolution is consistent with many calls for sanity, including the Russell-Einstein Manifesto from July 9, 1955, "We appeal as human beings to human beings: Remember your humanity, and forget the rest" [8], as well as those initiatives mentioned in Sec. 1.1.

## 2. Why We Should Consider Personal Companions in Learning & Living

This section addresses some of the critical issues related to human security in the emergence of new AI tools.

### 2.1. The Language and Human Intelligence (hI)

Human culture uses language as the key ingredient in the process of bringing us together in terms of identity. This critical binding ingredient, language, includes different forms such as gestures, smiles, spoken and written language, sounds, songs, music, images, movies, and video. All those real-time and more-permanent language forms are used to tell stories (orally, in handwriting, in printed writing, in images, and in music), as well as to write regulations and law, create money and currencies, formulate political views, and articulate laws of nature in terms of science, mathematics, engineering, technology, design, and other standards. Language has been instrumental in teaching and training us to design and manufacture better products, to grow food more efficiently, and do our work better and with a greater impact. It has also been used to articulate and communicate our emotions, desires, aspirations, and dreams. Code of ethics, human rights, and human security have also been articulated using language. Those elements are some attributes of human intelligence (hI) that allow us to solve problems.

Throughout our human written history, we have been dropping such cultural "bread crumbs" in the places where we lived. Some of them were lost in accidental or intentional fires (e.g., The Library of Alexandria), purging of intellectuals, wars, and declining interest in them due to other more urgent events.

The revolutionary shift from analogue to digital representation of our language, as well as the development of the Internet and Web hyper-connectivity, have produced more permanent traces of the available data, information, and knowledge. The expansion of our abilities to monitor, read and interpret signals from the physical and biological worlds has resulted in a knowledge tsunami so great that our human intelligence (hI) has recently overwhelmed our ability to absorb it, and we have learned how to ignore most of it by not knowing what exists.

This planet has also experienced another carbon tsunami due to our four industrial revolutions triggered by technological discoveries and innovation. The severely expanding climate changes, however, cannot be ignored.

Another tsunami has also occurred in the population of people on this planet. In 1974, the planet hosted 4 billion individuals. In 2022, that number exceeded 8 billion; doubling in 50 years as compared to the entire history of people on this "pale blue dot."

A tsunami related to the industrial revolutions has also occurred in business. The inequality of wealth has increased beyond what can be handled by the vast majority in the population tsunami.

The outcome of the previous tsunami waves produced a tsunami of human insecurity, including the planet and all life on it.

This Earth needs help. We need help. Perhaps our human intelligence (hI) is no longer sufficient to undo what we have created.

*"The two-sided nature of the genAI entities cannot be fixed easily, because it originates from the human nature captured through the acquired language. The acquired language in genAI reflects our duality because humans swing between various extremes characterized by dialectic, contrasting, but complementary patterns."*

## 2.2. Artificial Intelligence (AI) and Generative AI (genAI)

Although the concept of artificial intelligence could be traced back to 1308 [Pres16], the term "artificial intelligence" (AI) was coined in 1955 by John McCarthy, Marvin Minsky, Nathaniel Rochester, and Claude Shannon [Adam21], [45]. With some bumps, the evolution of AI was very intense at several levels including pattern recognition, self-organization, neural networks, *natural language processing* (NLP), and corresponding mathematics. However, what has happened since 2017, and particularly in 2022, is that the 70-year-old AI has jumped to acquire new capabilities to learn our language because of a new idea of how to treat the human language through attention [90]. This non-human intelligence, in the form of *generative AI* (genAI) has hacked our *human operating system* (hOS) and acquired a part of our recorded human language. It has been shown to be able to mimic our use of language.

In a very narrow sense of intelligence, AI systems are already better at solving well-defined complex problems. For example, it can beat humans at chess and Go.

In a narrow sense, the genAI is already better than us, although it acquired the knowledge from us. Although our brain is still more complicated and complex, our short- and long-term memory is very leaky and elastic, while the *large language models* (LLM) remember. We have an idea about the vastness of current knowledge but do not have it.

In a broader sense, when solutions require conscience (the ability to feel compassion), humans have not been challenged yet.

The key problem with this genAI is, however, that our recorded culture is characterized not only by the most desirable human features, but also by all the shortcomings and fringes, including dishonesty, falsehood, corruption, nepotism, bias, anger, hate, selfishness, dominance, skillful dissemination of fear, and all the traits that caused the tsunamis in the first place. Since the genAI had acquired those undesirable attributes, it has been using them in the generated output, as seen by many available examples already. Some major designers of genAI expressed concerns about its possible existential threats (e.g., [78], [18]).

## 2.3. Why is genAI Uniquely Dangerous?

### 2.3.1 Past Fears of Machines Used as Tools

Similar fears have emerged with the creation of computers, as well as agile and powerful robots capable of using their strength and fast computing capabilities to take over our physical and knowledge-based jobs [10]. Although killer robots have been created, computing and robotic technologies have not posed an existential threat to humanity because our human rights and culture are not defined by brute force and the ability to compute fast. Those developments did not produce a system capable of acquiring our language. Computers and robotic devices were just very capable tools. Humans controlled them and decided how to use them. While a scalpel can kill or save a life in an operating room, it does not decide by itself for what purpose it is used. As a tool, we could unplug a computer or a robot when it malfunctions.

### 2.3.2 How Does the New genAI Differ?

The situation is now fundamentally different because genAI has succeeded in hacking our human operating system (hOS) by acquiring our language. Such a genAI articulates new answers to questions that were never asked before. It already started changing social media. This type of AI may want to be autonomous and decide on its own, even being able to pretend that it cooperates with us.

The two-sided nature of the genAI entities cannot be fixed easily, because it originates from the human nature captured through the acquired language. The acquired language in genAI reflects our duality because humans swing between various extremes characterized by dialectic, contrasting, but complementary patterns. We are suspended and swing between predictability and spontaneity, utopia and dystopia, yin and yang, and Heschel's halakhah and aggadah. Lyman Tower Sargent [74] calls this utopianism a social dreaming or the desire for a better way of being and argues that it is essential for the improvement of the human condition. However, if used without any checks and balances, it becomes dangerous.

### 2.3.3 Will Our Right to Cognitive Liberty Survive?

There is another threat that has just emerged: the potential loss of our cognitive liberty [Fara23a], [Fara23b]. When genAI acquired our language with our help at an enormous expense, we felt quite free because the acquired thoughts were from the past. Our current thinking inside our heads was still inaccessible, private.

When we realize that our thoughts (when reading a sentence, imagining, calculating, or a private thought and emotion) trigger some localized neurons in the brain to become active, it becomes obvious that those activities constitute an electrical language of the brain. Such a language can be picked up by another genAI. No more private thought(s).

Neurotechnology is the collection of devices including (i) sensors capable of picking up brain activity through external electrodes, (ii) storing the signals, (iii) translating them into tokens, (iv) recognizing them and (v) generating actions back in the language of the brain. The picked-up signals constitute the language of our brain.

What if the brain language can be translated into internal actions, altering the thoughts, or internal actions performed by us? This might be beneficial in rehabilitation but is also unchartered territory. This new thought-to-action translation can benefit humanity immensely, but without safeguards, it can seriously threaten our fundamental human rights to privacy, freedom of thought, and self-determination.

*"Addressing human security is of paramount importance not only today but in the future."*

### 2.3.4 Is the New genAI a Tool?

Such an AI is no longer a tool. When it malfunctions, unplugging it is not possible. How do we unplug a social network that spreads misinformation and disinformation, and manipulates us to do unthinkable harm to others? There is no single plug. In fact, much research has been done to detect malicious attacks, and issue counter-measures to either neutralize the attackers, or to make the networks more resilient (the ability to recover from any damage).

Humans have evolved so far because they were expected to reduce suffering. We failed that expectation many times on that journey, but we were able to globalize, recover and improve when we realized the damage. For many of us, the real wake-up call comes when we realize that we must **breathe** and, like all our predecessors, we need a place to breathe. The AI entities do not breathe.

## 2.4. Human Security for All (HS4A)

Addressing human security is of paramount importance not only today but in the future.

We are facing unprecedented climate changes due to the industrial and economic revolutions. We can prevent and recover if we agree to invest 2% of GDP each year. This requires collaboration by all. We will still have enough life on this planet to breathe. What about our children and grandchildren?

Global conflicts stemming from our mistakes in the past ended with the hope that they would not be repeated. They ended because many nations fought them together and because the weapons of global destruction did not exist. They do exist now.

The new type of generative AI (genAI) capable of acquiring human language has been released to the public without testing. We have learned from experience that no new medication should be released to physicians or the public without its testing and approval. Furthermore, by having almost unlimited access to our data, it can sell us to various bidders without us even knowing about it. Doctors require our data to help us and are not allowed to share our data. The proposed new regulations to control the use of AI must be implemented urgently.

## 2.5. The Need for Life-Long Learning and Education

The World Economic Forum reports [96] that 673 million people are being affected globally by the technological transformations, and that one job in four may undergo a change (either growing by 10% or declining by 12%), thus leading to 69 million jobs created and 83 million jobs lost (14 million jobs net lost). Those shifts from one job to two or more in a lifetime appear to become a new reality.

> *"We should develop a totally new Personalized Symbiotic Education and Learning Ecosystem (PSELES). The system should not be producing a workforce only, but be in symbiosis with all the stakeholders, including industry, business, governments, security forces, and those who will not be able to work. This system should match the capabilities of each individual and prepare those individuals for many jobs in their lifetimes."*

The leading drivers for job growth are expected to be ESG (Environmental, Social, and Governance) standards, green transition, and localization of the supply chain. The leading losses may be caused by slow economic growth, high inflation, the increased cost of money to fight inflation, geopolitical uncertainties, and a shortage in supply.

More specifically the expanding jobs due to data generation and processing are expected to occur in (i) AI and Machine Learning (ML) specialists (+39%); (ii) Sustainability specialists (+33%); (iii) Business intelligence analysts (+32%); (iv) Information security analysts (+31%); (v) Fintech engineers (+31%); (vi) Data analysts and scientists; (vii) Robotics engineers; (viii) Electrotechnology engineers; (ix) Agricultural equipment operators; and (x) Digital transformation specialists.

The greatest decline due to digitization may occur in (i) Bank tellers and related clerks (-40%); (ii) Postal service clerks (-40%); (iii) Cashiers and ticket clerks (-37%); (iv) Data entry clerks (-36%); (v) Administrative and executive secretaries (-34%); (vi) Material-recording and stock-keeping clerks; (vi) Accounting, bookkeeping and payroll clerks; (vi) Legislators and officials; (ix) Statistical, finance and insurance clerks; and (ix) Door-to-door sales workers, news and street vendors and support workers.

To address some of the problems, many actions have been initiated by organizations including the Future of Life Institute [23], [24], [25], and individuals [88], [100].

This paper addresses personalized education in symbiotic relations with cognitive digital twins that may be helpful in our human transformation to deal with this complicated and complex intertwined problem.

# 3. A New Personalized Symbiotic Education and Learning Ecosystem (PSELES)

## 3.1. Motivation and Foundation

This paper focuses on a new personalized model of education and learning designed to prepare individual learners of any age for a constant change in their lives within their local communities and global societies. The model requires personalized cognitive digital twins with sufficient awareness of their symbiotic relation to others and local and global cultures.

The industrial, economic, and social revolutions and the emergence of new tools such as generative artificial intelligence (genAI), with its acquired functional concept of human language, are altering many aspects of our lives. What used to be safe in the domain of human security has been now challenged existentially. The need for transformation in education and learning is being addressed by many organizations such as the World Academy of Art and Science (WAAS), the United Nations (UN), the National Academies for Science, Engineering and Medicine (NASEM), the Association of Computing Machinery (ACM), and the Institute of Electrical and Electronics Engineers (IEEE) with its TryEngineering program. Many companies provide tools such as Customer Management Systems (CRM), Student Information Systems (SIS), and Learning Management Systems (LMS), including the Desire-to-Learn (D2L) from Brightspace, Blackboard Learn LMS, and Canvas LMS, and over 900 other LMSs.

There are many models of educational systems proposed and some implemented. For example, Zucconi and Jacobs discussed the general need for revising education in 2014 [103]. Integrated approaches were discussed by many (e.g., [22]). Different implementations were evaluated (e.g., [31]). A new education paradigm and the role of eco-systemic leadership were discussed in [59]. Kinsner et al. discussed some challenges in the engineering education of cognitive dynamic systems (e.g., [55]). A model involving digital twins for an evolving symbiotic education was discussed by Kinsner [51].

At the beginning of the first industrial revolution in the 1770s, an efficient well-organized Prussian classroom education system was introduced to produce large numbers of individuals with well-defined expected skills within a fixed period. This "one program fits all learners" produced magnificent results for assembly lines in many new factories then. That one-size-fits-all educational system worked so well that we are still using it.

Since we will not be working on the same assembly line throughout our life and each of us is different and many of the hard skill jobs may be taken over by humanoids and machines, we should develop a totally new **personalized symbiotic education and learning ecosystem** (PSELES). The system should not be producing a workforce only, but be in symbiosis with all the stakeholders, including industry, business, governments, security forces, and those who will not be able to work. This system should match the capabilities of each individual and prepare those individuals for many jobs in their lifetimes.

The PSELES should provide the individuals not only with the requisite body of knowledge (BoK) and the body of experience (BoX) in a single discipline but also with the additional trans-disciplinary BoK and BoX. Furthermore, the new PSELES should prepare each individual to act as a learner, teacher, and mentor to close the educational loop in which Box is passed to young students and professionals.

In addition, PSELES should also pay attention to the development of talent, character and softer skills, including transparency, honesty, fairness, nimbleness, passion and purpose, and the ability to cooperate in teams, all grounded in literacy to demonstrate analytical and critical thinking.

Sustainability and human security for all are the ultimate goals that must be implemented soon. In short, using an analogy from music, the new PSELES is intended to help individuals develop not only their abilities to read a musical score and play the notes, but nurture the talent of a musician playing both solo and in an orchestra in a way that many listeners would like to experience.

To achieve this goal, we cannot hire a teacher for each student. One of the solutions is to develop personalized tutoring helpers/companions for each student in the form of personalized **symbiotic memetic cognitive digital twins**.

## 3.2. Learning Ecosystems: Some Definitions

Education and learning have always been existential to humanity, and have been evolving throughout the millennia [51]. Recently, educational systems have been changing more rapidly as a result of sociocultural, political, economic, demographic, and technological changes [90]. New technologies (such as social media, serious games, adaptive software, and software-defined communications systems) and emerging practices (openness, user modelling) in particular, have facilitated opportunities to transform education, learning, and particularly teaching. With the advent of the Internet, the Web and the arrival of the COVID-19 pandemic, brick-and-mortar education has been expanded to network education through distance education, massive online courses (MOOC) [3], avatars, online classes, discussion groups, and remote laboratories. Social media is also providing new channels, including Facebook, Twitter, Flickr, Digg, YouTube, Upcoming, LastFM, Technorati, MyBlogLog, Discord, and SlideShare.

New ways of presenting the material and discussions had to be developed. New ways of doing laboratories and demonstrations of results had to be developed. New ways of asynchronous and synchronous consulting and proctoring of students by the instructors and teaching assistants had to be developed with new communications channels on learning networks.

In addition to those changes, in the classrooms and research laboratories, the pandemic has also accelerated the development of artificial and augmented intelligence (AI) because of the enormous new data related to human activities online, including teaching, theoretical and experiential learning, delivery of test and examinations on line, preparation of the materials, on-line tutoring, tutorials, workshops, symposia, conferences, business meetings, and new forms of educational interaction.

Elimination of travel has resulted not only in the reduction of the carbon footprint, but also more time to find more productive ways to interact and cooperate with more individuals. Although research and development in the area of AI produced magnificent results, the pandemic shock provided an additional impetus that resulted in radically enhanced language translators, written and spoken language generators, as well as image and video generators, all consistent with the user behaviour exhibited during the massive online activities during the pandemic.

### 3.2.1 What is Learning?

Learning is the acquisition of knowledge, or professional and other skills, through either self-study, or by being taught by parents, friends, teachers and/or tutors, or intelligent systems, or workplace, or organizations, all with different degrees of experience, starting from childhood, through adolescence, to professional life and seasoned years. Learning occurs in many different ways, including a **systematic** way (schools, routine reading of scientific, technical and other news digests, discussions with family, colleagues and friends) and through the less predictable experiences and events that occur in life. This **experiential learning** is also fundamental in acquiring knowledge that is important in decision-making. Learning alters the functioning of the brain [42].

### 3.2.2 What is Education?

We have just defined learning as the process of acquisition of knowledge in a discipline, hard and soft skills, critical thinking, creative thinking, values, beliefs, and habits. Education is then the process of facilitating learning by teaching, training, discussion, interactive experiential experiments, and directed research.

We learn best when acting on what we have learned, thinking about it, and actually participating in the real world. Effective and impactful learning requires that we immerse ourselves in the process completely: with our will, senses, feelings, intuition, beliefs, and values. It often starts from our own enquiry. This is a very important point to make: the impact of education on us is determined by our engagement; technology by itself can help, but is not a replacement for engagement. For the symbiosis to have the multiplying effect, we must engage the technology too.

In the past, learning was modelled as a linear process in which progression through various educational events produced an additive effect. Today, researchers and educators model learning as well as growth and development as a nonlinear dynamical system. Our proposed digital twin symbiotic educational system is intended to assist in our engaged lifelong learning with emergent possibilities.

A **learning ecology** includes (i) learning concepts, (ii) learning dimensions, (iii) filters, (iv) conduits. Learning is a process that involves several foundational concepts, such as signals and noise in the real and or virtual environment, observables and data, information, knowledge, meaning, understanding, wisdom, and vision. We learn because (the **dimensions of learning**): we need to know, we want to do something, want to be somebody, as well as want to create, transform, and change. Educational filters affecting our outcomes include values, perspectives and beliefs. Educational conduits include selected languages, media, and technologies engaged in the process.

The educational process can be either formal or informal, it can be done through self-study or communities, with the help of direct performance support or monitoring and mentoring, all gaining experience through simulation, emulation, experiential learning, internship, co-op, or apprenticeship.

## 3.3. Current Models of Learning

Marcy Driscoll [17] provided a classification of epistemologies including (i) **Behaviorism** (objectivism) in which reality is external to the mind and knowledge and perception are acquired experientially, (ii) **Cognitivism** (pragmatism) in which knowledge is a negotiation between reflection and experience, inquiry and action, and (iii) **Constructivism** (interpretivism) in which knowledge is an internal construction and is informed through socialization and cultural cues. De Corte provided an overview of historical developments in the understanding of learning [11]. A detailed discussion of the systems and their variants can be found in [51].

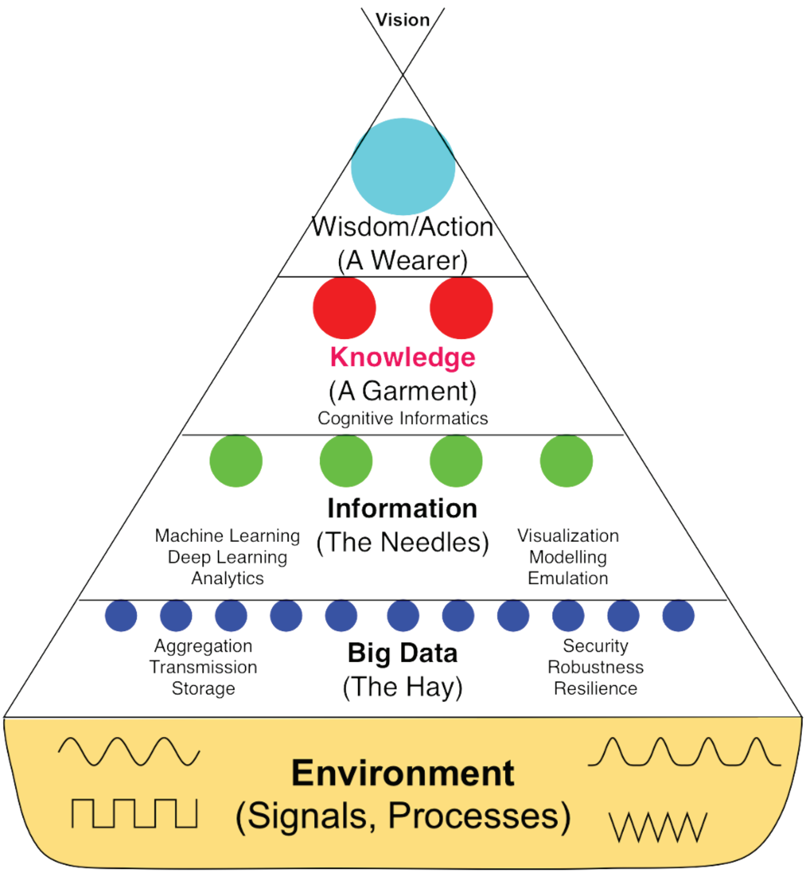
Since human behaviour cannot be fully understood by the reductionist behaviourist approach (decomposing the system into linear parts and then reconstituting it), the idea of Gestalt psychology became more attractive in which the organized configuration of components in the whole system is considered. This approach to learning requires information-processing techniques. **Social constructivism** might be a good model for representing interactions between learners and their grounding contextual environment. This is also combined with shifting away from artificial exercises to real-life situations. The current view on learning includes **adaptive competence** characterized by the so-called CSSC learning ("constructive" to signify that the learners are responsible for constructing their knowledge and skills; "self-regulated" as the learners use their strategies to learn; "situated" to indicate learning in the context of the environment, rather than abstracted from it; and "collaborative" to indicate a team rather than an individual approach.

Stephen Downes [16] [16] and George Siemens (e.g., [17], [79], [25], [80]) proposed another learning theory called **connectivism**, based on various ideas from networking and dynamical systems, i.e., complex interacting nonlinear systems that can develop chaos and self-organization. Connectivism is based on distributed adaptive knowledge (viewed as composed of connections and networked entities) and tries to explain how new knowledge is created. Siemens uses the example of senior citizens that have been linked as mentors to elementary school pupils, thus forming a new distributed knowledge. In that view, learning is a process of connecting specialized nodes or information sources and may reside in non-human nodes. Thus, knowing where to find information is more important than knowing the information element. In contrast, the other three theories do not address the new distributed knowledge creation. A discussion of critical views of the systems and their variants can be found in [51].

### 3.4. The Knowledge Pyramid (ODIKWaV) Model

Figure 4 illustrates a common progression of situated-learning stages from (O) observations of the environment leading to (D) data extracted from the observations to (I) information, (K) knowledge and action, (W) wisdom, and finally (V) vision [51]. This is often called the data-information-knowledge-wisdom (DIKW) pyramid model. This model is important because it will be required in the SALES learning system using digital twins. The core of a digital twin will have to include the ODIKWaV model.

*Fig 5: The Knowledge Pyramid Model*




We have extended that model to include directed and purposeful observations to reduce unwanted data. To know what constitutes relevance in data, knowledge and actions (experience) are needed. Responding to the environment only is not sufficient in the extended model, as for the observations to be relevant, a vision is also required.

In the hierarchy of human scientific and technical development, data appear at the starting point for our analysis and provide the impetus for our data-driven learning. Analysis of the data may produce useful information. Note that if we consider the data as a stack of hay, extracting the information could be compared to finding a needle in the stack. Useful information may lead to knowledge (information woven into a garment). Good knowledge may lead to enhanced wisdom needed by the student (the wearer of the garment) to make good decisions. Although this model is fairly limited, we have described it to link it with the concept of digital twins directly. A more detailed discussion of the different levels in the pyramid can be found in [51]. Kinsner also modified the ODIKWaV from a pyramid to an igloo model to emphasize the importance of relevant knowledge and wisdom (purpose).

# 4. Towards Evolving Personalized Symbiotic Education with Digital Twins

## 4.1. Summary of Reasons

As we have seen, the knowledge tsunami, automation, and the emergence of generative AI (genAI) are a change in the current classroom/workshop model in universities, colleges, vocational training and retraining, high schools, primary schools and kindergartens. More students and workers learn "just-in-time", and often just enough to solve a problem or get a job completed. this is not sufficient.

Teachers and trainers can no longer be the main sources of knowledge about the world or the work environment, but need new forms of technology to help find and manage the increasing amount of information. No single person, no matter how brilliant, can handle the knowledge, even in one field of study.

Consequently, the roles of teachers, trainers and consultants need to change—from mostly presenters of information to guides, mentors, curators of knowledge, critical thinkers, and problem solvers. They will have to use digital learning skills and literacies.

Throughout the previous section, we have been making the case that the next generation of education would benefit much from the development of personalized symbiotic cognitive digital twins capable of being in relation with human beings in a symbiotic system. This intimate knowledge of personal abilities and needs could allow the digital twins to deliver both the BoK and BoX in a personalized way that has a chance to compete with the best model of the Oxford Master of the past.

Cognitive digital twins could be very helpful in increasing our resilience in many areas, including: (i) Curation of knowledge (organizing and filtering according to agreed-upon criteria to eliminate irrelevant knowledge); (ii) Knowledge fusion (to discover and clean errors present in sources, as well as mistakes made in the process of knowledge extraction from sources); (iii) Plagiarism management (to generate new knowledge); (iv) Knowledge vetting (to identify and verify sources for quality of the content used in the organization); (v) Intellectual property management (separating intellectual property, trade secrets, and copyrighted information from generic and public-domain content); (vi) Knowledge sunsetting (to identify knowledge that cannot be used any longer); (vii) As traditional libraries dwindle, creation of a digital twin "librarian" that knows the needs of the organization and its members would be beneficial; (viii) As traditional publishing also dwindles, creation of a suitable digital twin "publisher" could benefit the organization; (ix) Acting as assistants and consultants to medical personnel with their awareness of the thousands or more similar cases; (x) Acting as assistants, consultants and mentors to students at different stages and levels of their development; (xi) A guardian against fake information, misinformation (incorrect, but not intended to harm); disinformation (intended to harm); and (xii) A guardian of our privacy and safety to protect us against Slavery 4.0 in which we (i.e., our behaviour) are sold without even knowing it.

### 4.2. What is a Digital Twin?

A digital twin (DT) is defined as a real-time (RT) digital replica (virtual entity, VE) of a physical entity (PE) such as a non-living entity (devices, subsystems, systems, processes) or a living physical entity. The DT models the PE's physical elements and their dynamics, and both PE and VE can co-exist simultaneously, thus constituting a cyber-physical system.

Based on multi-source RT data, the DT learns and updates itself to represent its status (working conditions, possible malfunctions, and required maintenance), and can control the PE throughout its operation. Since the DT can also integrate its historical data into its model, it can learn from its past behaviours, as well as from its past decisions and their impact on the process itself and the environment in which exists. The fourth industrial revolution (Industry 4.0) has been using DTs very extensively (e.g., [28], [30]).

The idea is to mirror a physical analog object in bits (i.e., a physical digital system, not resembling the original object in shape, but in its behaviour), keeping the bit replica synchronized with the physical one. This allows various types of retrospective and predictive analyses on the digital twin that can provide a better insight into the analog one, and lead to corrective actions when required. In this sense, digital twins are new tools for education: rather than studying and training on the analog object, one can study using its digital representation first. Many technologies like virtual reality can further enhance training and education.

The usefulness of a digital twin goes beyond that scenario. The digital twin can develop far beyond our physical and physiological limitations, and find proper ways to be helpful in our adaptation to the untenable challenge of doubling knowledge over a decreasing time period. Another challenge is the need to educate individuals for more than one job due to automation, mechanization, and the unprecedented growth in deep learning (DL) [1] [27] and artificial general intelligence (AGI), as described in the White Paper I and II [13]. Some challenges in developing better engineering education in cognitive systems are described in [2][49], [3][55].

### 4.3. Applications of Digital Twins

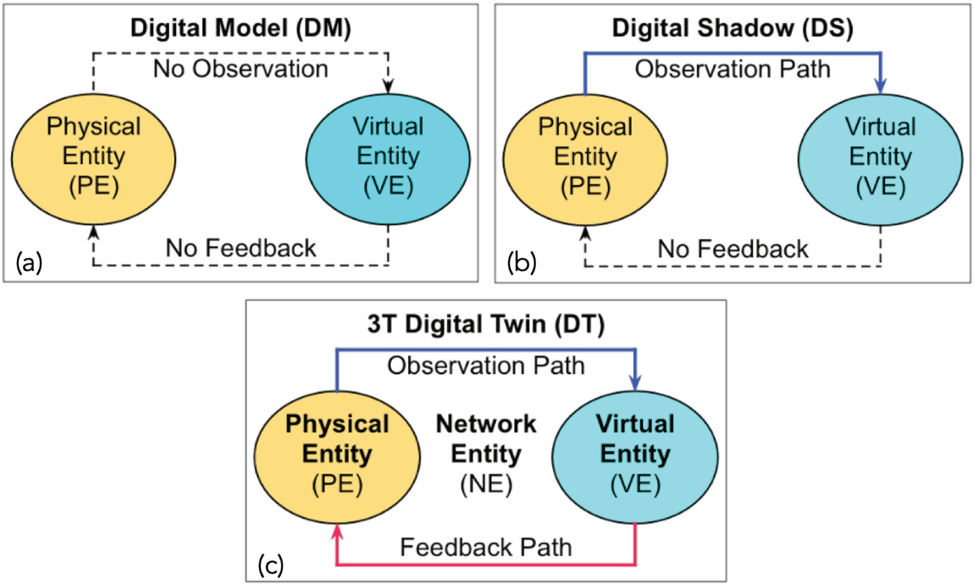
In industries (manufacturing, automotive, healthcare, and enterprise), DTs are often used to optimize the operation and maintenance of physical assets, systems and manufacturing processes. Other applications include: (i) Power generation (hydro turbines, wind turbines, solar); (ii) Utilities (electric, gas, water, wastewater networks at Siemens, General Electric); (iii) Aircraft, rockets, satellites, engines (Boeing, NASA, SpaceX); (iv) Locomotives; (v)

Automotive (Tesla); (vi) Buildings; (vi) Large structures (offshore platforms); and (vii) Heating, Ventilation and Air Conditioning control systems. There is interest in applying digital twins in education (e.g., [43], [19]).

## 4.4. Evolution of Digital Twins

The digital twin (DT) concept has evolved over the last 10 years (e.g., [29] [71]) from a digital model (DM, Fig. 5a) through a digital shadow (DS, Fig. 5b), to the proper digital twin (DT, Fig. 5c).

*Fig. 6: Evolution of the digital twin concept.*
(a) Digital model. (b) Digital shadow. (c) Digital twin.




### 4.4.1 Digital Model (DM)

A digital model (DM; Fig. 5a) is an accurate mathematical model of the physical entity (PE) designed to mimic the physical entity (PE) as accurately as possible, and when implemented in software on a computer environment, it can be used to simulate the behaviour of the PE for teaching or research purposes. However, since there is no monitoring link from the PE, the model cannot be adjusted to the current conditions of the PE. Furthermore, since there is no link back to the actuators in the PE, the physical system cannot be controlled.

### 4.4.2 Digital Shadow (DS)

A digital shadow (Fig. 5b) is an improvement over the digital model (DM) because it has a link to the monitoring section of the PE, thus allowing the digital shadow to update its parameters in the model to reflect the current conditions in the PE. The DS does not have a feedback path back to the PE.

#### 4.4.3 Digital Twin (DT)

The digital twin (Fig. 5c) is a further improvement over the digital shadow (DS) because it has another link to the controlling section of the PE, thus allowing the DT not only to update its parameters in the model to reflect the current conditions in the DE, but also control it.

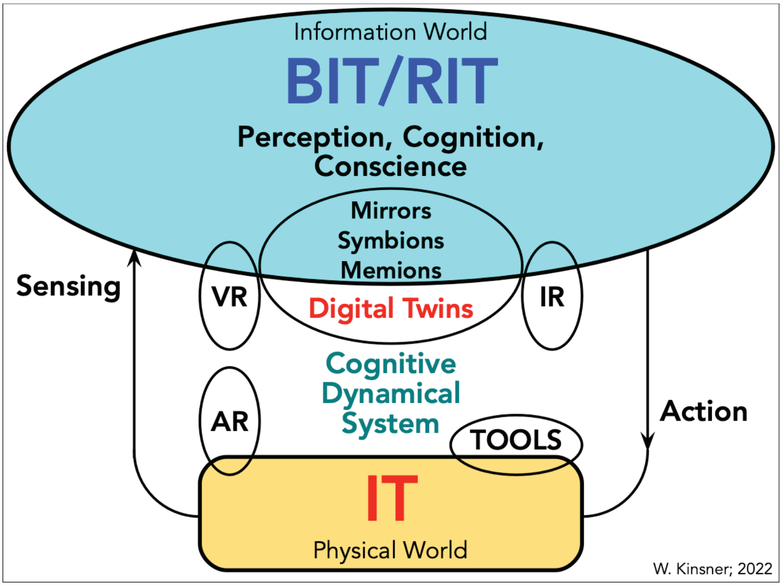
### 4.5. Attributes of Digital Twins

Digital twins have several essential attributes. They are well connected to the physical entity (PE) using many forms, including the Internet of Things (IoT) and the Industrial Internet of Things (IIoT). They utilize Artificial intelligence extensively for reactive and predictive analytics. They often utilize holarchy (a structure of multi-agent holons where each holon can be not only a part, but a whole). This is in contrast to the hierarchy (with a separate top and bottom) used by hierarchical systems with a central dominant control centre. Another attribute is homogenization in which data are unconstrained by physical location or time. DTs also have digital real-time traces to have a sense of real-time evolutions of events. Modularity is also an important attribute of DTs for debugging and maintenance.

### 4.6. Bit/Rit from It or It from Bit/Rit/Qbit?

Figure 7 illustrates the linkage between physical reality (IT) and digital reality (BIT) and relational reality, RIT) with the help of the digital twin, virtual reality (VR), augmented reality (AR) and intelligent reality (IR).

*Fig.7. The digital twin ecosystem and links between physical and digital realities.*



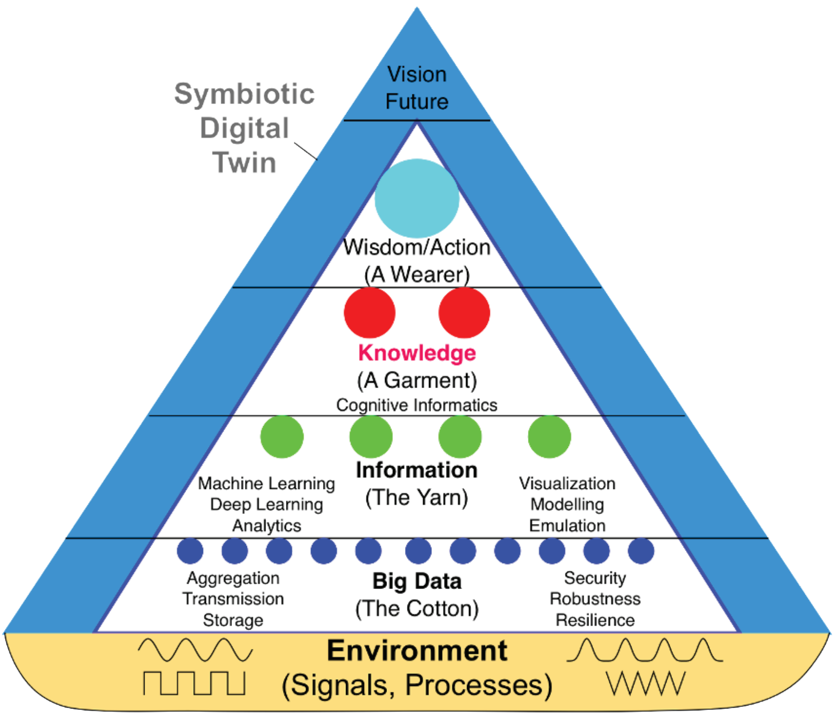
The concept of a digital twin resembles the famous John Archibald Wheeler's observation "It from Bit" and the other direction from Julian Barbour's "Bit from It" [2]. Today, we still have mostly "Bit/Rit from It," but with the advances in technology, the "It" is affected increasingly by "Bit/Rit and Qbit." Wheeler's observation may also be the source of one of the greatest dangers when we could become separated from the real "It." The current misinformation, disinformation and fake visual and audio "realities" generated by genAI have done much damage already.

## 4.7. Symbiotic Digital Twin (Symbion)

Recall that a digital twin (DT) is a replica of a physical entity (PE). If the PE is a person whose current state of learning is described by the knowledge pyramid/igloo model (ODIKWaV), then the personalized digital twin is called DT1.

Since the DT1 is intended to interact with the PE and the environment by monitoring not only the person but the environment, then analyzing both continuously, while advising mentoring, and learning, the DT1 expands to form a digital twin DT2, as illustrated in Fig.8. The relation between the person and the environment is designed to be symbiotic; i.e., all partners benefit from the relation. To distinguish between the previous models DT, DT1 and DT2 or SDT1, the new digital entity DT2 is called symbiotic digital twin or a **symbion** for short.

*Fig. 8: A Symbiotic Digital Twin (symbion).*



In a formal way, our digital twin could come to represent both our skills, knowledge, and wisdom. It can also be flanked by applications taking into account the fading away of skills (what we lose when not practising) and knowledge (when we forget). This information about our degrading skills/knowledge can be the starting point for a proactive education program.

*"The proposed Personalized Symbiotic Education and Learning Ecosystem (PSELES) has the promise of great impact on how we study, learn, acquire skills, interact with people and machines, discover new things, learn how to operate new things, and how to perceive and see reality much deeper."*

Writing an article and presenting it at a conference, or attending a conference to listen to colleagues presenting their papers can also be mirrored by our digital twin. The same applies to the process of reviewing papers.

Many publishers allow ongoing discussion on their published papers that could be monitored by our digital twin.

Educational institutions, including IEEE, could contribute to the mirroring of their "students", and "members" into digital twins. These might be very useful in creating customized and personalized education programs.

An example of such a program is the personalized system of instruction (PSI) by Fred S. Keller (1899-1996; 97) [4] [47]. Since the manual administration of Keller's PSI is very tedious, we have developed a Computer-Aided PSI (CAPSI) that has been running at the University of Manitoba, Canada for many years [5] [54].

Our system is a **digital shadow** of an individual student, with the feedback provided to a struggling student by a human proctor (also a student) who has advanced through the material and is qualified to give assistance to the struggling student as assigned by CAPSI.

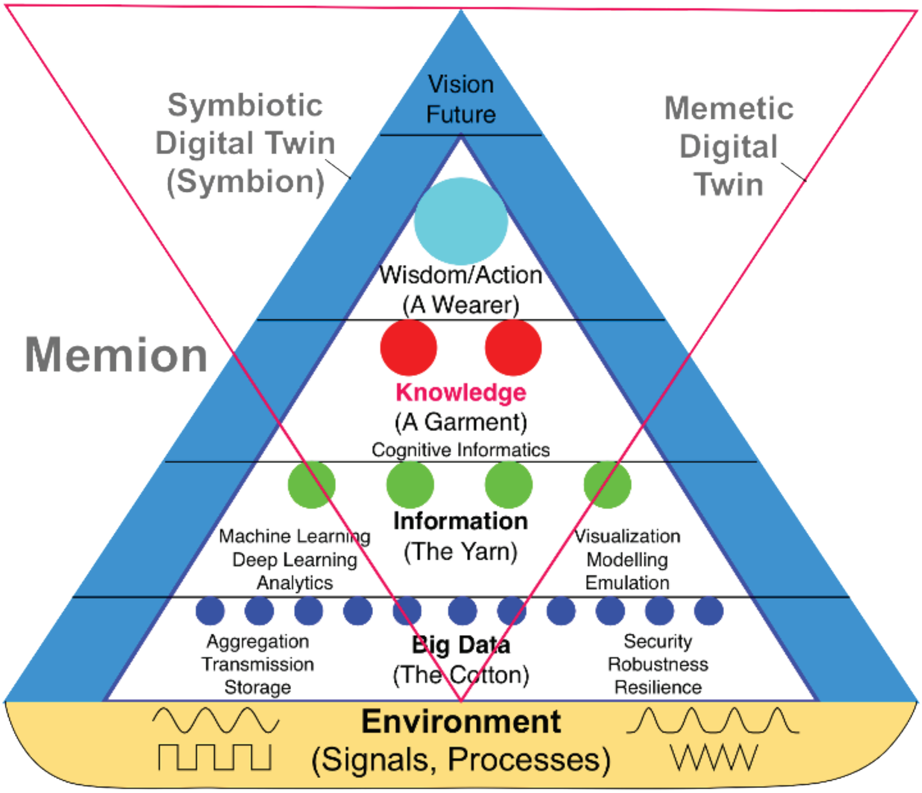
In a symbiotic autonomous system (SAS), the skills, knowledge and wisdom should be shared among its component subsystems to enhance the overall performance of the system.

Furthermore, the digital twin could start increasing (or decreasing) interaction between its parts. Notice that in dynamic complex systems, the whole is not necessarily the sum of its part. Through such nonlinear interactions, an emergent quality may appear that may not be found in any of its parts.

## 4.8. Memetic Symbiotic Digital Twin (Memion)

A memion is a symbiotic digital twin (SDT1≡DT2) combined with a memetic DT (MDT2≡DT3). It has the intertwined knowledge of the individual with the knowledge of a project team, work environment, community, organization, society and culture. Figure 9 illustrates a memion schematically.

*Fig.9: A Schematic Representation of a Memion*




## 4.9. Emergent Behavior of Symbions and Memions

Since sybmions and memions can interact with their twin, the person, and with one another, their interactions may lead to emergent behaviour, producing new behaviours that may be beneficial. This is an area of research.

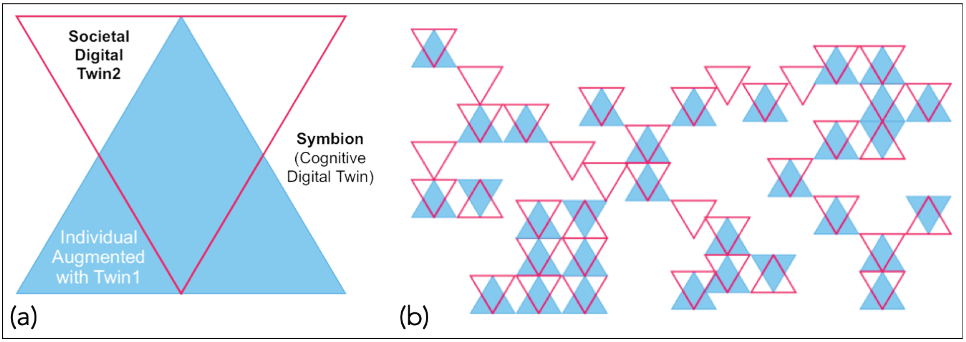
Learning through the symbiotic relationship between an individual and a digital twin is potentially much more beneficial to the individual than alternative learning methods.

The symbiotic pair (the individual and the digital twin) is called here a symbions.

It should be very clear that such individual symbions are connected with other symbions through the fundamental construct of a digital twin.

The individual symbions can enter into symbiotic relations with other symbions, forming teams, communities, and societies, as shown in Fig. 10.

*Fig.10: A schematic representation of (a) a memions and (b) its self-affine stochastic groupings (communities).*




## 4.10. Implementations of Digital Twins for Education

To succeed, this personalized symbiotic education must use sophisticated algorithms available today and might accelerate the development of better algorithms including:

- Machine learning and deep learning [6], [27];
- Cognitive systems [94], [Wang02];
- Generative and other appropriate AI [];
- Web intelligence [Deva11986], [26], [101], [71];
- Higher-order (HO) statistical signal processing [35];
- Intelligent signal processing [50], [36]];
- Compressive sensing [5];
- Fuzzy and granular computing [68];
- Multiscale (wavelet) analysis [98], [92];
- Polyscale measures and fractal signal processing [48], [53], [52]. [101], [Verh06];
- Long-range-dependence patterns in the data [53], [46], [78];
- Nonlinear time series analysis [35];
- Sifting our relevant information and knowledge [85]; [76], [Wolc17];
- Emergent dynamical systems concepts [83], [Deva1986]; and
- Dynamical systems and complexity measures such as learning entropies [7], [48].

## 4.11. Implementations of Digital Twins in Industry

Industrial digital twins have been implemented by many companies such as Siemens, Boeing, and NASA General Electric. New implementations are growing in numbers around the globe. One of them is intended to provide knowledge-as-a-service (KaaS) to members of an organization [51]. Other examples include [61], [58], [20], [21], [44], [57], [60], [99], [4], [84], and [71].

## 5. Closing Remarks on Personalized Symbiotic Education

The proposed Personalized Symbiotic Education and Learning Ecosystem (PSELES) has the promise of great impact on how we study, learn, acquire skills, interact with people and machines, discover new things, learn how to operate new things, and how to perceive and see reality much deeper. This personalized symbiotic education can open up a new landscape for exciting new concepts and research projects.

We already know how to compete. Symbiotic education might help us learn how to compete fairly. While competition could improve fairness, we might also learn how to cooperate to the benefit of all involved.

Another important outcome of developing personalized cognitive digital twins is that they might help increase human security not just for the few who can afford them, but for all. Personalized cognitive digital twins may actually enforce the ethical use of the entire ecosystem by operating ethically in symbiotic relations with us.

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