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Creativity and innovations in the 21st Century

Abstract. *The paper discusses the following problems: creativity, can creativity be learned, innovations, continuous and discontinuous improvements, life cycles (Kondratev waves) of new products, technologies and inventions, innovations in the U.S. and in the world, innovations in Poland, patents and breakthrough innovations of the last decades. The paper ends with conclusions.*

Streszczenie. *W artykule dyskutowano nastepujace zagadnienia: kreatywnosc, czy kreatywnosci mozna sie nauczyc, innowacje, ulepszenia ciagle i skokowe, cycle Kondratiewa nowych produktow, technologii i wynalazkow, innowacyjnosc w Stanach Zjednoczonych i w swiecie, innowacyjnosc w Polsce, patenty, epokowe wynalazki w ostatnich dekadach. Artykul jest zakonczony wnioskami. (**Kreatywność i innowacje w 21 wieku)**.*

Keywords: creativity, innovations, Kondratev cycles, patents, breakthrough inventions
Słowa kluczowe: kreatywnosc, innowacje, cycle Kondratiewa, patenty, wynalazki epokowe.

Introduction

Nowadays, new developments in engineering and information technology require design engineers to have qualities of high level of creativity, inventiveness and ability to apply the newest achievements in science and technology to modern products.

Creative people need to be able to view things in new ways or from a different perspective. Inventiveness means the power of creative imagination. The goal of science is the pursuit of knowledge for its own sake while the goal of technology is to create products that solve problems and improve human life. Technology is the practical application of science.

Creativity

There are many definitions of creativity. According to *Webster Dictionary*, creativity is the ability to make new things or think of new ideas. There are many other definitions, e.g., 1) Creativity is a thought process that involves generating new ideas or concepts or links between existing ideas or concepts; 2) Creativity is the process of developing a new, uncommon or unique idea; 3) Creativity is the ability to generate new ideas, you can learn it, it depends on knowledge, experience, motivation, effort and perseverance; 4) Creativity means creating new combinations from known information. Has anybody ever thought that [1]:

- All literature written in contemporary English consists of various combinations of only twenty-six letters;
- All images in the world are combinations of only three basic colors: red, yellow and blue;
- All music is a composition of up to twelve notes;
- All known numbers consist of only ten symbols;
- Extremely complex computer calculations are made using two-element systems.

That's why, whenever we mention something new, we say in fact, about the innovative arrangement of existing elements.

The world of ideas is similar to the world of finance. Investors are active in the financial world, whereas creative people operate in the world of ideas. Creative thinkers act just like good investors: they buy cheap and sell expensive. Creative people generate ideas that are like undervalued shares on the stock market (shares with *low price–to–profit* ratio). Both shares on the stock and ideas are generally rejected by potential buyers.

The effectiveness of ideas is low. From the pool of 2000 ideas only 11 excellent solutions and 17 relatively good solutions are created [2].

When creative ideas are proposed, they are often perceived as bizarre, useless, stupid and are usually rejected. The person who proposes them is treated with suspicion, with pity, even with mockery. According to A. Schopenhauer[1] all truth goes through three stages:

- First it is ridiculed;
- Then it is violently opposed;
- Finally, it is accepted as self-evident.

Creative people are vulnerable to disrespect and even aggression because most societies have in common:

- "Collective" thinking;
- Do exactly what others do;
- No acceptance for unusual behaviour;
- The attitude focused on survival, not on development;
- No vision for the future;
- Fear of continuing education.

Can creativity be learned?

There are controversial opinions about learning the creativity. However,

- there is a relationship between the intelligence quotient (IQ) and creativity;
- generally, people talented towards arts are creative;
- creativity can be developed.

Fig. 1 shows the relationship between knowledge, natural creativity, creative efficiency and their change with age [2]. Young children are naturally creative. Then, with

[1] Arthur Schopenhauer (1788 - 1860), a German philosopher.

age, the natural creativity drops down, while knowledge gained at schools, universities and workplaces can boost the creativity.

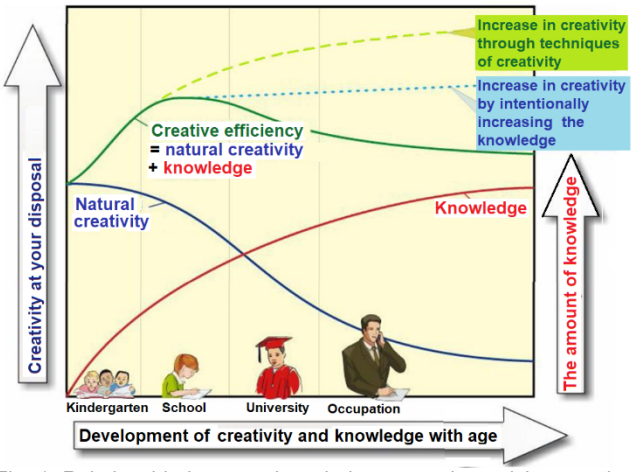

Fig. 1. Relationship between knowledge, natural creativity, creative efficiency and their change with age [2[.

The most powerful way to develop creativity in students is to be a role model (authority). Children develop creativity not when you tell them to, but when you show them [3]. It is recommended to use Sternberg's method [3] to create diverse activities and to help all students explore all aspects of their intelligence (Fig. 2). "Creativity is contagious, pass it on!" – A. Einstein.

ANALYTICAL	CREATIVE	PRACTICAL
Analyze	Create	Apply
Critique	Invent	Use
Judge	Discover	Put into practice
Compare/contrast	Imagine if...	Implement
Evaluate	Suppose that...	Employ
Assess	Predict	Render practical

Fig.2. Sternberg's method to develop creativity [3].

Most complicated problems have solutions

There is a legend about the merchant, his beautiful daughter and the old moneylender. A merchant owed a large sum of money to the moneylender. The old, ugly moneylender fancied the merchant's beautiful daughter. He proposed that he would forget the debt if he could marry the merchant's daughter. The merchant and his daughter were horrified. The cunning moneylender suggested that they let providence decide the matter. He told them that he would put a black pebble and a white pebble into an empty bag. The girl would have to pick a pebble from the bag. If she picked the black pebble she would have to marry the moneylender and the debt would be forgotten. If she picked the white pebble, she need not marry him, and the debt also would be forgotten. If she refused to pick a pebble, the merchant would have to go to jail. The moneylender bent over and picked up two black pebbles and put them into the bag. The sharp-eyed girl noticed his cheating.

What should the merchant's daughter do according to standard reasoning?

- The girl should refuse to pick pebbles – her father will go to prison;
- The girl should reveal that there are two black pebbles in the bag and that the moneylender is a crook – revenge from the moneylender, her father will go to prison;
- The girl should pull out the black pebble, so she have to marry the moneylender and her father's debt would be forgiven – too much sacrifice to be a wife of an old, ugly moneylender.

What the merchant's daughter did? She has chosen an unconventional solution. She nervously pulled one pebble out of the bag. Without looking, she dropped that pebble into the alley, covered with white and black gravel, where the dropped pebble mixed with other stones. "How awkward I am" – she said. "But never mind. If you look in the bag, you'll see what color the pebble has left and then we will know what color my pebble was" – she turned to the old banker.

Moral of the story: Most complex problems do have a solution. Sometimes we have to think about them in a different way.

Creativity and innovation

What is the difference between creativity and innovation? Creativity means the act of generating a new idea, approach or action. Innovation is the process of both generating and applying creative ideas into a specific context.

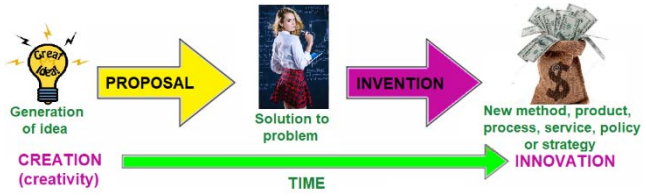

Fig. 3. From creativity to innovation.

Creativity is a necessary condition but not sufficient condition for innovation. Innovation is an idea that creates a certain economic value. There is no innovation without economic value. Innovation can include:

- new products;
- new qualities;
- new production processes;
- new services for clients;
- new sale markets;
- new materials;
- new ways of doing business.

A patent for an invention is the grant of a property right to the inventor. Patents are granted for new, useful and non-obvious inventions for a limited period of time (20 years in the U.S.) from the filing date of a patent application, and provide the territorial right to exclude others from exploiting the invention during that period. Patents are a form of intellectual property.

Some countries allow for "utility model" patents. The U.S. does not allow for utility model patents. The utility model is a new and useful solution of a technical nature, regarding the shape, construction or composition of the object of a permanent form. Common characteristics of the invention and utility model suitable for legal protection are:

- they must be technical solutions;
- they must be new on a global scale.

On the other hand, invention must be non-obvious and utility model – must be an object.

According to [2] there are five levels of innovations: 1) obvious conventional inventions, 2) good inventions in the area area of existing solutions, 3) important inventions within a given technology, 4) inventions beyond the existing technologies, 5) discoveries.

Only 1 out of 100 patents makes money. Countries that invest more in R&D tend to produce more high-quality patents. Innovation is the opportunity to make changes and introduce new opportunities – not a threat.

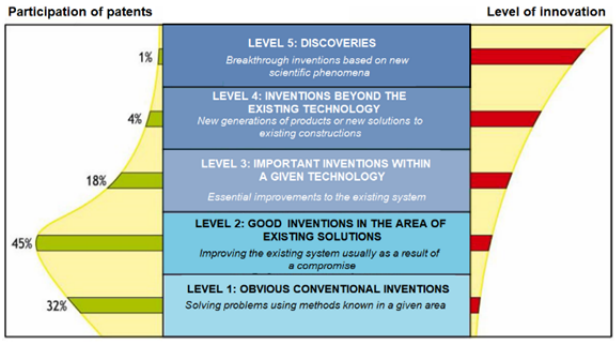

Fig. 4. Five levels of innovations [2].

Innovations in industry

In the late 1990s, the resurgence of American industry combined with the stagnation of Japanese economy restored a strong emphasis on the benefit of innovations. Innovation has become the industrial religion of the late 20th century… and it is now.

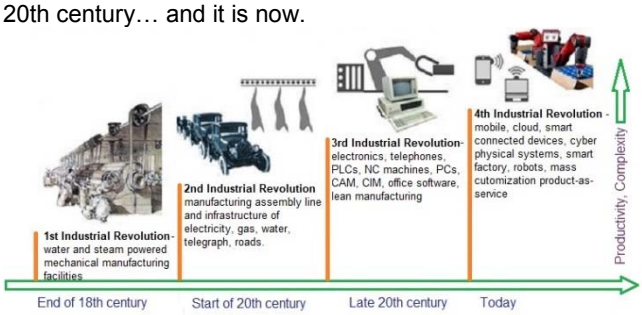

Fig. 5. Industrial revolutions.

Historically, four industrial revolutions can be identified (Fig. 5). Nowadays, there is the 4th Industrial Revolution, i.e., the era of mobile telephony, smart connected devices, iCloud, cyber physical systems, smart factory, robots, mass customization product as service, artificial intelligence, etc.

Continuous improvement keeps a company in the game, while discontinuous improvement wins the game for a company (Fig. 6). *Continuous improvement* or *continuous innovation* means incremental, evolutionary improvement (fixed trajectory) or simply doing things better. *Discontinuous improvement* or *discontinuous innovation* means breakthrough, revolutionary improvement (new steeper trajectory) or simply doing things di□erently. Discontinuous form of innovation is creation of new families of products or businesses. “Innovations make a division on the leader and followers” – S. Jobs, *Apple* co-founder.

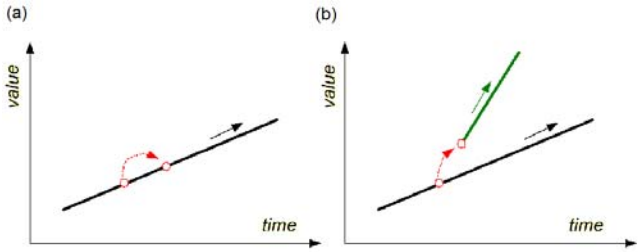

Fig. 6. Forms of innovations: (a) continuous improvement; (b) discontinuous improvement.

An example of continuous improvement is shown in Fig. 7. The introduction of the desktop publishing in the mid–to–late 1980s is one of the best illustrations of how a discontinuous change and innovation can in short order destroy an existing marketplace and create an entirely new playing field (Fig. 8). Other examples of discontinuous improvements are shown in Figs 9 and 10. In the case of development of telephony, there are both continuous and discontinuous innovations.

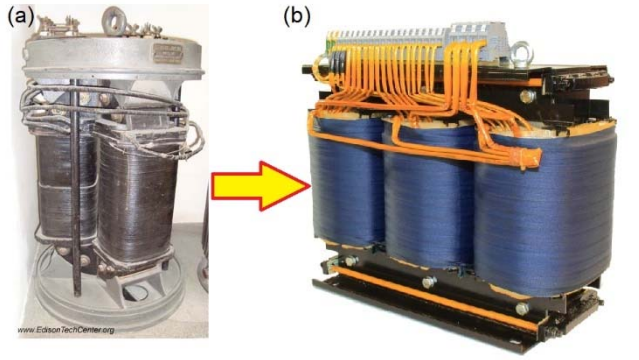

Fig. 7. Example of continuous improvement: (a) early three-phase transformer with circular core (Siemens and Halske, 1891); (b) contemporary three-phase transformer with flat core.

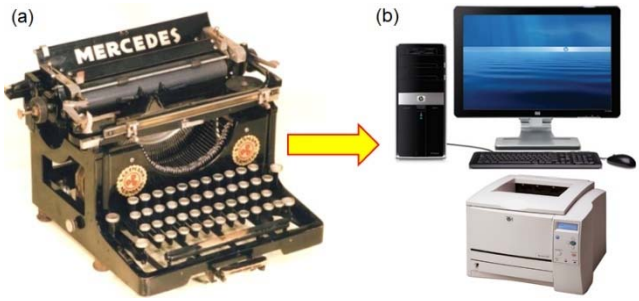

Fig. 8. Example of discontinuous improvement: (a) typewriter; (b) desktop computer with laser printer.

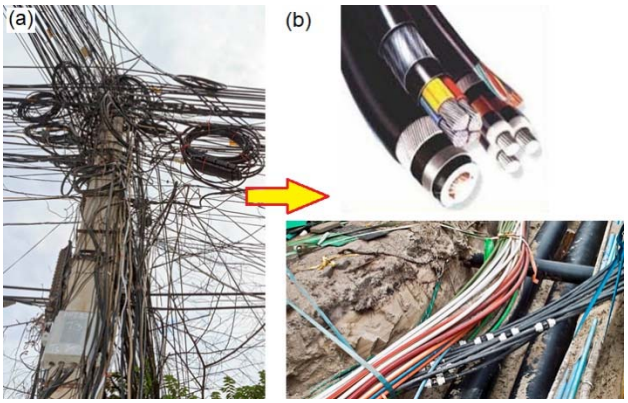

Fig. 9. Example of discontinuous improvement: (a) Overhead electricity distribution system although more resistant to earthquake, is very vulnerable to wind and ice accumulation; (b) underground electricity distribution system using cables.

Fig. 10. Progress in telephony contains both continuous and discontinuous innovations.

What kind of innovations are there in electrical engineering, for example, in electrical machines? Electrical machine technology is very basic, but the systems in which they are used are still benefiting from technological advances. Electrical machine industry can be classified as a slow-moving industry, where continuous innovations are predominant. There are a few exceptions, e.g.,
(a) invention of three-phase induction motor by M. Dolivo-Dobrovolsky in 1889;
(b) invention of non-salient-pole rotor synchronous generator by C. Brown in 1901;
(c) impact of power electronics on control of electrical machines since the 1970s;
(d) introduction of rare-earth SmCo PMs in the 1970s and NdFeB in the 1980s;
(e) application of vector control strategy to induction and synchronous motor drives in the early 1970s;
(f) application of HTS materials in the late 1980s.

New types of electrical machines can find broad application only if their cost and quality are competitive to currently manufactured electrical machines.

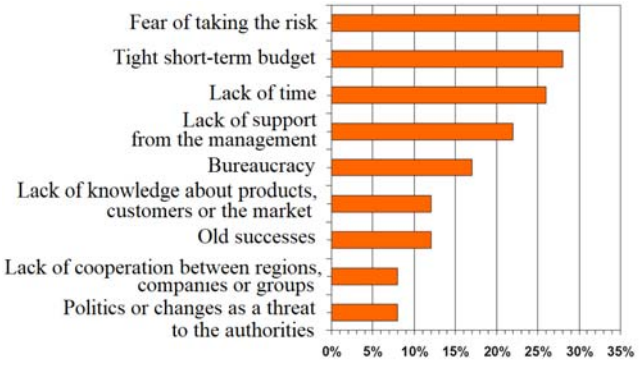

Fig. 11. Barriers of innovations [2].

The most difficult barrier of innovation to overcome is the fear of taking the risk (Fig 11).

Life cycles of new products, techniques and inventions

Economists have identified five Kondratiev[2] waves (cycles) since the 18th century:

- The 1st cycle resulted from the invention of the steam engine and ran from 1790 to 1815.
- The 2nd cycle arose because of the steel industry, railways and telegraph. It ran from 1815 to 1890.
- The 3rd cycle resulted from electrification, innovation in the chemical industry and development of radio. It ran from 1890 to 1930.
- The 4th cycle was fuelled by automobiles, electronics, TV, synthetics and jets. It lasted from 1930 to 1970.
- The 5th cycle was based on information technology and biotechnology and began in 1970 and ran through the present.
- The 6th cycle is predicted to arise because of healthcare.

Kondratiev wave (cycle) is a long-term economic cycle believed to result from technological innovation and produce a long period (50 to 60 years) of prosperity. E.g., life cycles of energy sources are shown in Fig. 13 [4]. Each energy source has its life cycle. The wood as an energy source was abandoned in the 1990s. The existing energy sources have also their predicted life cycles.

[2] Nikolai D. Kondratiev (1892-1938), eminent Russian economist, executed by Stalinist's regime.

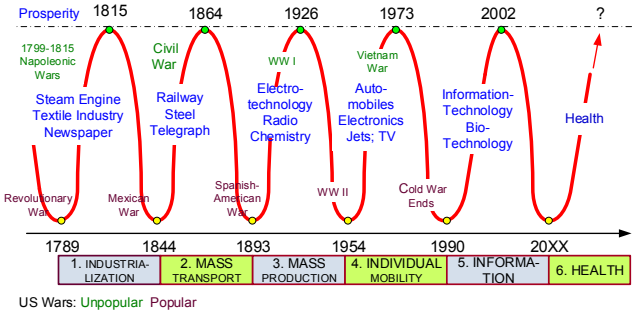

Fig. 12. Kondratiev Waves (cycles).

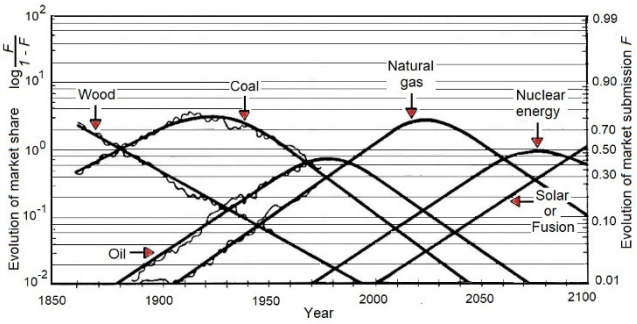

Fig. 13. Life cycles of energy sources [4].

Innovations in the U.S. and in the world

Table 1 shows patent applications and patents granted in 1998-2015 in the U.S. [5]. No data after 2015 have been published by the U.S. Patent and Trademark Office (USPTO), the agency responsible for granting U.S. patents and registering trademarks [5]. About 50% of total U.S. patents are granted every year to foreigners (Fig. 14).

Table 1. Patent applications and patents granted in 1998-2015 in the U.S. (all patents) [5]

Year	Patent applications	Patents granted
1998	260889	163142
1999	288811	169085
2000	315015	175979
2001	345732	183970
2002	356493	184374
2003	366043	187012
2004	382139	181299
2005	417508	157718
2006	452633	196405
2007	484955	182899
2008	485312	185224
2009	482871	191927
2010	520277	244341
2011	535188	247713
2012	576763	276788
2013	609052	302948
2014	615243	326032
2015	629647	325979

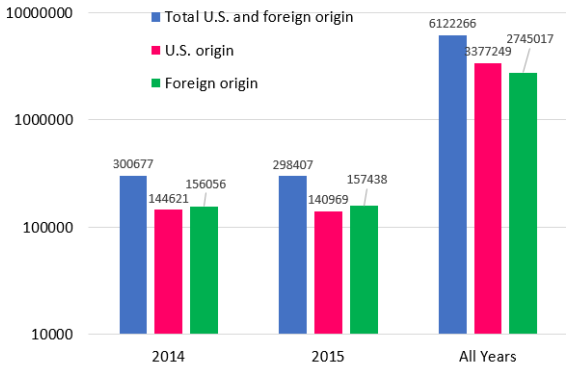

Fig. 14. Utility patents of U.S. origin and foreign origin [5].

Top ten countries with the largest number of U.S. patents are compared in Table 2, while the top ten companies that were granted the largest number of U.S. patents in 2016 are presented in Fig. 15.

Patents granted by European Patent Organization (EPO) are presented in Fig. 16. EPO members are the 28 states of the EU and 10 other states. The total number of patents issued by EPO in 2017 is 105,635.

Table 2. Top ten countries with the largest number of U.S. patents

	Country	2014	2015	All years
1	Japan	53848	52409	1061170
2	Germany	16550	16549	408791
3	U.K	6488	6417	165269
4	France	6691	6565	153980
5	South Korea	16469	17924	152835
6	Taiwan	11333	11690	139080
7	Canada	7042	6802	124008
8	Switzerland	2398	2553	67880
9	Italy	2628	2645	61267
10	Sweden	2767	2633	54487

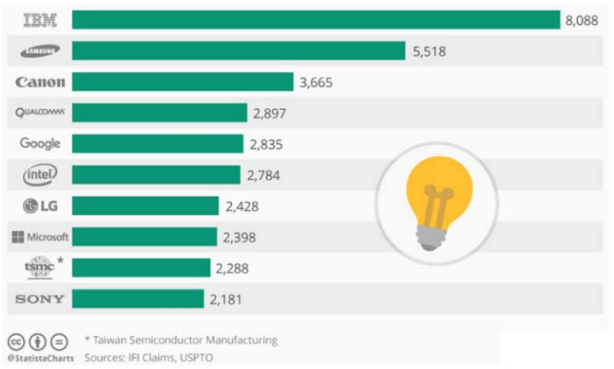

Fig. 15. Top ten companies with the largest number of U.S. patents granted in 2016.

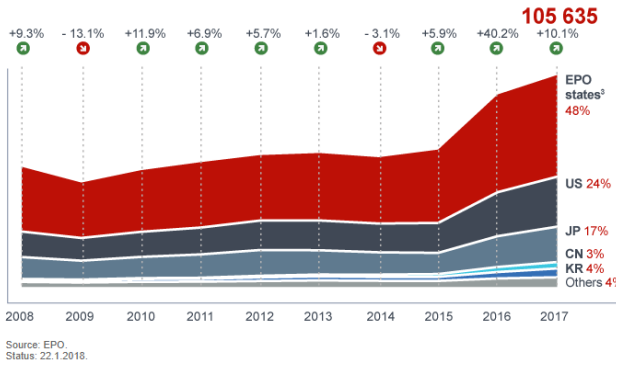

Fig. 16. Patents granted by European Patent Organization (EPO).

How many patents have been granted in the U.S.? The USPTO issued patent 10 million on June 19, 2018 [5]. Inventor Joseph Marron and patent assignee *Raytheon Company* receive patent no. 10,000,000 for a "*Coherent LADAR Using Intra-Pixel Quadrature Detection*", which improves laser detection and ranging (LADAR).

The average age at great achievement of human being is 38.6 to 39 years [6]. The Nobel Prize and great inventors data sets have extremely similar age distributions and extremely similar mean trends (Fig. 17).

Breakthrough inventions of the last decades

Listed below are the top ten 1970-2000 innovations that have changed life most dramatically:

1. DNA testing and sequencing (early 1970s) and human genome mapping (working draft of the genome was announced in 2000).
2. Fiber optics. *Corning Glass* researchers invented in 1970 fiber-optic wire (US patent 3,711,262), which was capable of carrying 65,000 times more information than copper wire.

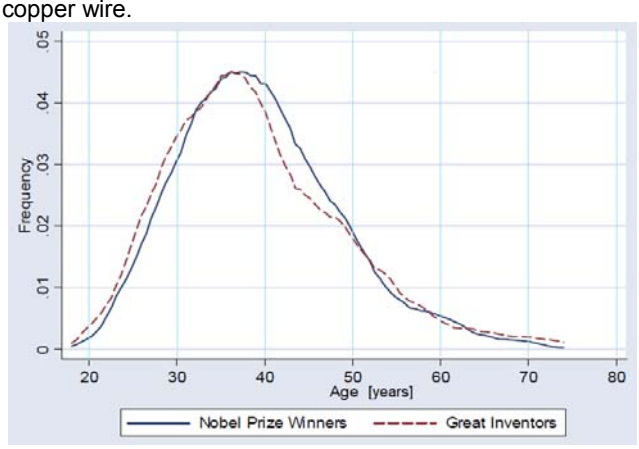

Fig. 17. Age distribution of great invention [6].

3. Magnetic Resonance Imaging (MRI). In 1970, R. Damadian, discovered the basis for using MRI as a tool for medical diagnosis. US patent granted in 1974.
4. Email. Probably the first email system was MAILBOX, used at MIT from 1965, exchange text messages among users at different terminals of timesharing computers. Ray Tomlinson created the first *ARPANet* email application in 1971.
5. Microprocessors. *Intel* introduced the first commercial microprocessor 4-bit Intel 4004, in 1971.
6. Mobile phones. Invented and demonstrated in 1973 by Martin Cooper, an engineer and general manager for *Motorola*.
7. PC. *IBM* launches PC in 1981. *Osborne Computer Corp* produced the first true laptop *Osborne 1* in 1981, weight 10.9 kg, 5" screen.
8. Non-invasive laser/robotic surgery (laparoscopy). First robot to assist in surgery, *Arthrobot*, was developed and used in Vancouver in 1983. *Da Vinci* Surgical System made by *Intuitive Surgical* was cleared by the Food and Drug Administration FDA in 2000.
9. Office software: word processors, spreadsheets, power point first announced by Bill Gates of *Microsoft* on 1 August 1988.
10. Internet. Commercial entities emerged in several American cities by late 1989. Tim Berners-Lee invented *www* in 1989. Broadband in early 2000. 3G broadband technology transformed into 4G in 2012.

Table 3. 2001-2010 breakthrough inventions according to "Times" magazine

Year	Invention
2001	Implantable Artificial Heart *AbioCor*
2002	Wireless headset *Bluetooth*
2003	99¢ Solution (*Apple* iPod) – piece of music for 99 cents
2004	*SpaceShipOne* – commercial spacecraft flights up to 100 km for $ 200,000. Launched into the orbit by *White Knight* turbojet
2005	*Tweel* (inventor Mike Tweel, Michelin) airless tires with cushion effect
2006	*YouTube*
2007	iPhone 3G
2008	Personal DNA tester (deoxyribonucleic acid) for $399, company 23andMe (on the basis of saliva samples)
2009	*Ares I* NASA's Rocket. Manned spacecraft as part of the Constellation Program (CxP) – manned flights to the Moon and Mars. Ares – Greek god of war

The best inventions of the previous decade according to "*Times*" magazine are listed in Table 3 and schematically visualized in Fig. 18. Table 4 shows other recent important inventions.

Fig. 18. The best inventions of the previous decade 2000-2010 according to Times magazine.

Table 4. Other recent important inventions

Year	Invention
2000	Text Messaging introduced to U.S. by *AT&T*
2001	Infrared smoke alarm
2002	*Aerogel*, the lightest solid (1 kg/m^3), invented in 1931, but refined in 2002 by NASA
2003	IEEE 802.11G Wi Fi, maximum speed 54 Mbps
2003	Social networking: *Friendster*, then *Facebook*, *MySpace* and *Twitter* have become more popular
2004	*Facebook*, Mark Zuckerberg, Harvard student
2004	*LiTraCon* translucent concrete
2005	GPS commercially available (started in 1973)
2006	Infrared alcohol test
2007	*Android* phone operating system, introduced by *Google*
2010	iPad
2013	Selfie stick
2014	3D printing (additive manufacturing)
2014	*Apple* Smart Watch

Innovations in Poland

In Poland, 4679 patent applications have been filed in 2015, 4261 in 2016 and 3924 in 2017 by Polish entities [7]. The number of patents granted to Polish entities by Patent Office of the Republic of Poland was 2404 in 2015, 3370 in 2016 and 2795 in 2017 [7]. The number of patents granted to Polish entities per one million of population was 0.073710^{-6}. In the same year 2015, the number of patents granted to U.S. citizens by the USPTO per one million population was 0.4406×10^{-6}, almost six times higher.

In Poland, in the early 1990s, the so called Innovation and Entrepreneurship Centers began to be organized. It was assumed that these centers would stimulate innovation, in particular new technologies. The number of these centers reached a maximum in 2013 (809 centers), after which, dropped to 674 in 2015 and to 560 in 2017 [8]. It has happened due to the lack of interest of entrepreneurs and decision makers in the potential of these centers [8].

This means that these centers are not needed and financial resources earmarked for their infrastructure and maintenance should be allocated to support small enterprises implementing new technologies, similar to American SBIR Program[4].

Why are innovations in 3rd world and post-communist countries widely discussed and poorly practiced? Possible main reasons include:

- Mentality of the previous era;
- Developed survival skills, not development skills;
- The misunderstanding is to limit the role of universities to practicing pure science and pointing to industry as the main agent of innovation;
- Reluctance of the Faculty and researchers to undertake applied research (of a utilitarian nature)– lack of PUSH;
- Major industry is weak– lack of PULL;
- Unwillingness to take advantage of foreign experiences.

Conclusions

1. Innovation is the process of both generating and applying creative ideas into a specific context.
2. Innovation is the opportunity to make changes and introduce new opportunities - not a threat.
3. Innovation is the basis to enter economic prosperity.
4. There is no innovation without economic value.
5. Most complex problems do have a solution. Sometimes we have to think about them in a different way.
6. Continuous improvement or continuous innovation means incremental, evolutionary improvement (fixed trajectory) or simply doing things better.
7. Discontinuous improvement or discontinuous innovation means breakthrough, revolutionary improvement (new steeper trajectory) or simply manufacturing of di□erent products.
8. Only 1 out of 100 patents makes money.
9. Foreigners hold half of all U.S. patents annually.
10. The average age at great achievement is about 39 both for great inventors and Nobel Prize winners.
11. Countries that invest more in R&D tend to produce more high-quality patents.

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[8] Innovation and entrepreneurship centers (in Polish), ed. A. Bąkowski, M.Mażewska, Society of Organizers of Innovation and Entrepreneurship Centers (SOOIPP), Poznan-Warszawa, 2018, www.sooipp.org.pl

[4] The SBIR Program. The Small Business Innovation Research (SBIR) program encourages domestic small businesses to engage in Federal Research and Development that has the potential for commercialization.