

To Err is Human, To Teach VR

Virtual Reality and Artificial Intelligence
in Medical Education



Maxim Gorshkov

EuroMedSim, 2024

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The book discusses the use of virtual patients, simulators, trainers, and artificial intelligence (AI)-based systems in medical education. It covers issues such as terminology, design and classification of virtual simulators, differences in training and assessment in the digital environment, benefits and potential threats of the training of health care givers using virtual technologies and artificial intelligence. This study is addressed to educators using digital simulation technologies, developers and manufacturers of virtual didactic equipment, and clinicians considering the possibility of integrating VR and AI technologies into the training of healthcare providers.



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Metalla ferri optumo pessimoque vitae instrumento est

Iron is good and at the same evil to life

Pliny the Elder (AD 23–AD 79)

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I express my deep gratitude to the employees of the organizations mentioned in this book – after all, it is thanks to their intelligence and hard work that these amazing digital devices were created, designed to make life easier and improve the quality and efficiency of the medical education. Special thanks to the creators of the search engine Google, life sciences and biomedical database PubMed, and the large linguistic generative model ChatGPT, with the help of which the information for this book was collected and summarized and without which effective academic activity is unthinkable today.

Abstract

The book discusses actual issues related to application of virtual reality (VR) such as simulators, virtual patients, and other digital educational aids and devices, as well as systems based on artificial intelligence (AI), in medical education. The principles of terminology, methodology design, technical construction, and classification of medical virtual simulators, the differences between training in a digital and virtual environment, the advantages and disadvantages of training medical specialists using digital technologies, potential hazards associated with virtual training and ways to combat them are considered. The paper contains the following original concepts:

- The original classification of medical virtual reality simulators has been formulated;
- The advantages and disadvantages of virtual simulators have been summarized;
- Medical education – and especially training in virtual environment – are reviewed from the perspective of Maslow’s Hierarchy of Needs;
- The possibility of VR systems to substitute the medical teachers performing 12 roles according to Ronald Harden’s classification, and the potential of AI and VRS for replacing humans in some of these roles are discussed;
- Requirements for the architecture of virtual reality medical training systems have been formulated;
- Approaches for the development of medical school curricula are proposed, where traditional and virtual teaching methods are combined and complementing each other;
- The benefits and potential hazards of using artificial intelligence in medical education are summarized.

This study is addressed to medical educators who integrate virtual simulation technologies into the educational process, as well as to designers and manufacturers of virtual medical training devices, clinicians who are contemplating bringing VR and AI tools into healthcare training programs.

Introduction

Fifteen years ago, when a small group of enthusiasts, including myself, founded the journal “*Virtual Technologies in Medicine*”, where I took the place of deputy editor-in-chief, the idea of writing a book on the use of virtual devices in medical education was born. Throughout these years, I used every opportunity to gather the necessary information, and yet, until a year ago, there was no chance that this book would see the light of day. At the same time, on the contrary – in just one year some of the data presented here will be outdated and of only historical interest. So now is just the right time to get together and write this book. At this moment, in 2023, we are experiencing another surge of “disruptive technologies”, generating tectonic shifts one after another, “tearing” the unhurried course of incremental progress and the gradual improvement of methods and technologies. It undermines the well-established principles, approaches and strategies of organizations and branches, literally turning entire industries upside down, overthrowing the ever-existing traditions and leaders from the pedestal and raising new idols to the summit. Even though discoveries have been made before, and in the old days there were brilliant scientists, engineers and doctors who transformed the humankind’s perception of the Universe, the current changes are incomparable with what happened in the past.

Although there have been no groundbreaking discoveries in the field of medical education comparable to those in practical medicine, a number of historical events not only brought about radical changes in approaches to patient diagnosis and treatment, but also had a significant impact on the development of the medical education system as we know it today.

One of the first breakthrough technology that seems to have left an indelible mark on medical education is the emergence of printing. The manuscripts of ancient authors were copied by hand, and hidden in monasteries, universities and papal libraries, were accessible only to a select few. However, this situation changed radically after the printing press was invented in the middle of the 15th century [Fig. 1]. The number of medical publications grew by leaps and bounds, and the number of readers increased by several orders of magnitude.

Although kept safely behind forged bars on the shelves of libraries (each one costing a fortune, and in those days there were many thieves everywhere, also in universities), books, textbooks, and atlases became accessible to a relatively wide range of educated people, including primarily students, teachers, and graduates of *alma mater* [Fig. 2]. This has contributed to the dissemination of knowledge, exchange of medical information and enlarged access to medical education. Since then, everyone who spoke Latin could independently study medical sciences (starting from the 16th century, they could study medical texts in their native language as well). Science-based medicine crossed the walls of monasteries and castles and invaded the streets of free European cities, gradually replacing barbers, quack healers, and imposter doctors.

The emergence of anatomical theaters, where public dissections of human corpses were allowed, enabled *Andreas Vesalius*¹ in the mid-16th century to draw the attention of scientists to the gross inconsistencies of Galen's ideas of reality [Vesalius A., 1543]. His book caused quite a shock in scholarly circles – after all, the monument to the immutable authority of the great Galen was rebuilt for fifteen hundred years by professors of all European universities without exception. However, this Flemish genius managed to discover more than two hundred errors in his *Opus Magna* and thus initiated a flood of studies in the field of anatomy and physiology that changed the understanding of the structure of the human body and how it works [Fig. 3].

Credit: Maxim Gorshkov



Fig. 1. Printing press. The Johannes Gutenberg's museum, Mainz, Germany

¹ Andries van Wezel (1514, Brussels – 1564, Zakynthos), AKA Andreas Vesalius, was professor of anatomy and surgery in Padua where he wrote in 1543 “*De Humani Corporis Fabrica Libri Septem*”, the cornerstone work of modern anatomy. According to many historians, Vesalius was forced to go on a pilgrimage to the Holy Land under the pressure from outraged professors, ostensibly as a sign of repentance in the dissection of a living body. On the way to Jerusalem, he passed away.

The development of network of medical schools in Europe in the 19th century, primarily in France, Great Britain, and the German-speaking states, attracted surgeons to universities – from that moment, in addition to barbers, wandering healers, bonesetters and stonecutters, graduates of medical faculties with the diploma began to treat injuries, wounds, hernias, amputate extremities and cut bladder stones. Surgery training was taken to the next quality level – capable “craftsmen” who had grown out of apprentices after observing a couple of “techniques” from their mentor, were left in the past. Surgeons began to study the same classical disciplines as their fellow internists in the systematic and structured way, receiving after graduation the degree of Doctor of Medicine that they had rightfully earned².

It is impossible for modern people to even begin to imagine what was a terrible norm for humanity less than 200 years ago, when any surgery became an excruciating ordeal that caused great suffering to the patient. The skill of the surgeon was measured primarily by how quickly he could act, reducing the operation to a few minutes. Through joint endeavors of *Horace*



Credit: Maxim Gorshkov

Fig. 2. University Library, Coimbra, Portugal. Books on the shelves of the lower tier cabinets are protected by massive forged bars

² In the UK, surgeons are traditionally addressed as “Mr.” rather than “Dr.” (or “Ms.” etc. for female surgeons), due to the tradition went back to the times when surgeons were members of the Guild of Barber-Surgeons. At the top of their careers, they could earn even more than university graduated “doctors” of internal medicine. In this way, they wanted to distinguish themselves from physicians with medical degrees. Even as the professions developed and merged, the tradition of titling persisted.

The Latin word *medicina*, meaning “the art” or “practice of healing,” is derived from the Latin term *medicus*, meaning “doctor” or “healer.” The word *medicina* itself, though it sounds differently, was borrowed from ancient Greek, coming from *ἰατρεία* (*iatreia*), which also denoted the art of healing and medical practice. *Iatreia* itself is a derivative of *ἰατρός* (*iatros* – “doctor” or “healer”). It is believed that this Greek word has Indo-European roots and is associated with the Sanskrit *āyurveda*, which still called the ancient Indian system of medicine.

*Wells*³, *William Morton*⁴, *Robert Liston*⁵ and many other scientists and clinicians, nitrous oxide, ether and chloroform came to be used in surgical practice, decreasing the priority of speed factor in surgical skill, which has led to dramatic changes in surgical training as well.

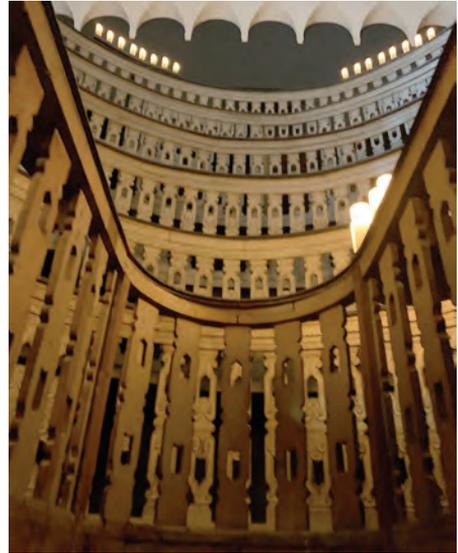
³ An American dentist Horace Wells (1815–1848) accidentally saw the use of laughing gas (nitrous oxide) during a traveling lecturer’s show in 1844. Following an idea of its medical usage, he performed a series of tooth extractions under anesthesia with nitrous oxide. After a while, he organized a public demonstration of tooth extraction at Harvard University, Boston. The attempt ended in failure – the volunteer patient screamed in pain. This fiasco so shocked Wells that he never returned to promote his idea. Deeply disappointed, depressed, and sinking to the social bottom, he went to prison and committed suicide in his cell by cutting femoral artery with a razor after inhaling an anesthetic dose of chloroform. However, his former student William Morton, on the contrary, was so enthusiastic about what he had seen that a year later he repeated the experiment, but with the use of ether.

⁴ William Morton (1819–1868), an American dentist and physician, demonstrated the world’s first successful public use of inhaled ether as a surgical anesthetic on October 16th, 1846, at Massachusetts General Hospital, in Boston. Now, this day is celebrated as “Ether Day” by anesthesiologists around the world. In an attempt to protect “his discovery” he filed a patent a month later for a so called gas “*letheon*”, but was booed by the medical community. The followed numerous efforts to earn some money out of it failed as well.

⁵ Robert Liston (1794–1847) brought anesthesia to Europe by performing the first public operation under ether narcosis two month after Morton’s demonstration. The surprise that the discovery was made not to Europe but to America was expressed in his historic phrase: “This Yankee dodge beats mesmerism hollow”.

*Ignaz Semmelweis*⁶, *Louis Pasteur*⁷, *Robert Koch*⁸, *Joseph Lister*⁹ laid the ground for the germ theory of infectious diseases, obstetric and surgical purulent complications, put their ideas into practice, which completely changed the architecture of the hospitals and operating rooms, design of the surgical instruments, and methodology of the training in medical schools.

-
- ⁶ Ignaz Semmelweis (1818–1865), assistant in the First Obstetrical Clinic of the Vienna General Hospital, noticed that mothers in labour who gave birth under the care of clean and tidy midwives had several times less postpartum fever incidence than in the neighboring clinic, where women in labor were examined by medical students participating in autopsies. Unfortunately, he was unable to establish good cooperative relations with his colleagues and his arguments about infectious origin of puerperal fever were never heard by medical society. Toward the end of his life, Semmelweis went mentally ill and died in a Viennese insane asylum.
- ⁷ Louis Pasteur (1822–1895), a French chemist, dean of the faculty of sciences at University of Lille investigated wine fermentation and hypothesized that the transformation of sugar into alcohol was caused by microorganisms trapped in the grapes from the air. Although the diseases of wine, milk, and beer interested him more than human pathologies, Pasteur's publications were the starting point for the invention of antiseptic techniques.
- ⁸ In addition to discoveries of tuberculosis, cholera and anthrax pathogens, Robert Koch (1843–1910) is considered the father of medical bacteriology for his famous four postulates – criteria of microorganism causes of a disease (presence of an infectious agent by diseased, and its absence by healthy; its isolation in pure cultures; inoculation recapitulates disease; re-isolation from the inoculated).
- ⁹ Joseph Lister (1827–1912), reflecting on the nature of purulent complications in surgical practice, carefully read the works of Louis Pasteur on the fermentation of wine. The Scottish surgeon's great merit was his guess that the source of microorganisms is not so much the atmosphere as contaminated surgeons' hands, instruments, and dressings. Another of his brilliant insights was the use of a chemical agent (carbolic acid) to disinfect wounds and everything contacted with them.



Credit: Maxim Gorshkov

Fig. 3. Amphitheater of the world oldest anatomical theater, 1490. University of Padua, Palazzo del Bo, Italy

The German physicist *Wilhelm Röntgen*¹⁰ (*Roentgen* in English spelling), having discovered the “unknown X-rays,” paved the way for radiology and instrumental diagnostics in general. This marked a new era not only in medicine, but also in medical education – in the clinical and academic study of injuries, wounds, and pathological conditions of internal organs.

Several years after the creation of an optical systems and instruments for endoscopic examination and surgical interventions on the bladder, Austrian urologist *Maximilian Nitze*, in collaboration with medical instruments manufacturer *Joseph Leiter*¹¹, presented a simulator for mastering the technique for performing this intervention – “cystoscopy”. *Kurt Semm*¹², inventor of numerous laparoscopic procedures in gynecology, during his workshops and lectures demonstrated extensive use of a plexiglass box which he had constructed to practice the challenging manual skills. Anesthesiologist *Peter Safar*¹³, the creator of the cardiopulmonary resuscitation, proposed to the Norwegian manufacturer of rubber toys *Åsmund Laerdal*¹⁴ to develop a doll for teaching chest compressions technique. Following this, simulation training methods began to penetrate gradually into various branches of medicine, today practically to all of them.

¹⁰ While investigating the permeability of the X-rays, Wilhelm Konrad Röntgen (1845–1923) discovered that they were slightly trapped by the bones of his own arm, showing up as shadows. When he purposefully took the famous radiographic picture of his wife’s hand with a ring on it, she exclaimed: «I have seen my death!»

¹¹ German urologist Maximilian Nitze (1849–1906) and Austrian instrument maker Josef Leiter (1830–1892) in close cooperation of medicine and technology created a whole range of innovative minimally invasive devices that originated entirely new clinical manipulations and disciplines – cystoscopy, laryngoscopy, and endoscopy.

¹² Kurt Semm (1927–2003), German gynecologist performed the world’s first laparoscopic appendectomy (1980), in the same year the first removal of an ovary with the Endo-loop and laparoscopic-assisted vaginal hysterectomy (1984).

¹³ Peter Safar (1924–2003) created ABC-scheme of cardiopulmonary resuscitation, later adopted by American Heart Association, created first in America Intensive Care Unit and developed standards for emergency medical technician education. His enthusiasm convinced toy-maker Åsmund Laerdal (1914–1981) to create CPR-mannequin Resusci Anne, that become “the world’s most kissed girl” due to mass saving-life trainings.

¹⁴ Åsmund Laerdal, a Norwegian toy maker, revolutionized medical training by creating Resusci Anne, the first CPR manikin, in the 1960s. His company, Laerdal Medical, became a leading provider of medical simulation and resuscitation equipment globally.

Nonetheless, the pace at which discoveries were made a hundred or two hundred years ago is incomparable with the fast evolving of technologies that we witness today. In the last twenty years, a real revolution in medical education took place right before our eyes, and it seems that it is far from over.

Rapid development of simulation techniques was underpinned by the reluctance of patients to serve as teaching aids for future doctors – all this has led to the development of phantoms, manikins, patient simulators, imitating the anatomical structure and physiological response, phasing out living people. Students tend to spend more time in the simulation laboratory, practicing their clinical skills and dexterity in simulated environment, which rules out any harm to patients, teachers, and the trainees themselves.

The incorporation of digital cameras into mobile devices and the emergence of online platforms, like a tsunami, brought powerful streams of medical videos onto the Internet. All components of the educational process, starting from anatomical dissection to the application of plaster bandages, explaining the principles of treatment of anaphylactic shock or teaching the peculiarities of coronary artery bypass grafting – all of these or any other video resources can be found today on field-specific free of charge or paid portals. For most people, the Internet has become the leading source of information.

This is relevant not only to videos – once transferred to the Internet, entire topics, separate chapters or textbooks evolve into the means of remote, distributional and personalized learning. Distance technologies allow students to attend lectures and communicate with their teachers despite their geographic remoteness and contact their mentors at the time which is most convenient for them, regardless of what time the clock shows.

Virtual reality (VR) and augmented reality (AR) allow to create immersive educational environments, where students can interact with three-dimensional models of organs, systems and diseases and fill in the shoes of members of medical teams, while feeling totally immersed in the medical diagnostic process. Although students are faced with emotionally charged situations demanding their personal participation, their performance bears no risk to the health of the participants whatsoever in these educational events.

Fig. 4. One of the first versions of the CPR manikin “Resusci Anna”, 1960s, Laerdal, Stavanger, Norway



Credit: Maxim Gorshkov

The artificial intelligence (AI) technologies are just making their first steps in the field of the clinical medicine – and yet they’ve already demonstrated very promising results in the training of healthcare specialists.

Artificial Intelligence (AI) is a field of informatics and computer science that deals with the creation of computer systems capable of performing tasks typically requiring human intelligence. AI seeks to develop computer programs that can analyze and generate data, learn from experience, make decisions, and recognize visual patterns and human speech (ChatGPT-3, July 2023).

(Please note that part of the paragraph above printed in purple. Similar fragments will appear in the book further on, highlighting texts generated by AI – the Large Linguistic Generative Model *ChatGPT*¹⁵. Guided by the color of the font, you can assess the degree of presence of AI in this book.)

¹⁵ ChatGPT is developed by OpenAI Corp., San Francisco, CA, USA.

The introduction of all these breakthrough technologies in medical education can boost the effectiveness of training, improve access to educational resources, enrich hands-on experience and enhance the quality of training of future medical specialists. And who knows, maybe one day AI systems will be able to substitute the doctor at the patient's bedside, or the teacher at the blackboard (sounds provocative, doesn't it? However, without such an intention).

However, while AI is causing surprise, delight and admiration in some people, others have developed mixed feelings of uncertainty, doubt and anxiety. Is it all as wonderful and promising as it might seem at the first glance? Is there any threat of the learning process getting out of control, if managed by the computer? Is there a possibility that the teacher will turn into a negligible appendage of the machine?

To be honest, we deserve it, it's the result of our own actions. For centuries we have been relentlessly pursuing this result. That's literally what we were aiming for! Dependency as a cost of progress. Wheel, plow, printing press, loom, photography, internet... Steam engine, diesel, electric motor, solar energy... In the old days, we used to listen to the news on the radio, watch it on TV – and now we are scrolling through the Internet and social networks... Opera performed on the stage came to be replaced by a collection of gramophone records, which, in turn, were replaced by a pile of magnetic tapes, a shelf of videotapes, a stack of DVDs – and now we have video portals, streams and podcasts, rare loners gather collections of audio recordings. Why, everything is available on the Internet, just a mouse-click or a tap way! On the other hand, it has always been this way – as soon as a new machine is created to make humans' life easier, people would start fighting for their rights that suddenly appear to be endangered by mechanisms attacking from all sides. A struggle immediately unfolded for the role of the creator of mechanized products. So, who serves whom? The machine serves the human, or vice versa? Slaves in Rome broke plows, English luddites smashed power looms, French saboteurs pounded their wooden clogs on the pavement in protest – today, environmental activists from the “Last Generation” glue their palms to pavement of highways or airport runways.

Many professions are rapidly dying out like dinosaurs after the fall of a giant meteorite – blacksmiths, travel agents, cashiers... They are being replaced

by new, even greater crowds of workers servicing the newly created mechanisms – a tractor driver instead of a plowman, a typesetter in lieu of a scribe, a taxi driver in place of a coachman, a programmer substituting a craftsman. So, who are they, slaves to the machines or inventors enjoying the results of the mankind’s collective achievements?

German photographer *Boris Eldagsen* submitted his work to the prestigious *Sony World Photography Awards 2023 (SWPA)* – a competition of the World Society of Photographers. His piece of work was evaluated by the jury among more than 200 thousand other photos. In April 2023, the winners were announced; in the “Creative” category, a monochrome photograph called “Electrician” won, which appeared to have been made using the century-old technique. However, the Berlin photographer refused to accept the honorary title and cash prize at the awards ceremony in London, much to the surprise of the presented public and jury members. He stated that he had no moral right to take the award, since the work chosen by the jury was not captured by the lens of his camera, and the two women depicted in it did not actually exist. The entire work, from head to foot, was created using the *Promptography* technique (English *Prompt* – hint; Greek *γραφία* – graphia, record) – that is, the image was obtained using an AI algorithm operating under the photographer’s guidance and based on his “prompts”. He said that the refusal to accept the prestigious award was not a promotion action, *épatage*, and



Credit: Boris Eldagsen, 2023

Fig. 5. The “Electrician”, an AI-generated “photo” based on Boris Eldagsen’s prompts

even less an affront, but an invitation to society to discuss the essence of this phenomenon and how it should be treated, how to get along with it, and whether the piece of work created by AI can be considered photography, or maybe we are seeing, in fact, the final nail in the coffin of this profession [Eldagsen B., 2023].

Believe it or not, the integration of virtual technologies into medical education is already a historical fact, and the integration of AI, although relatively recent, is also a fait accompli. No matter how we perceive it from emotional, political, or sociological point of view, there is no point in judging these events anymore. There's nothing left for us to do but to develop practical recommendations on how to incorporate them into medical education and understand the directions of growth of these phenomena.

Despite the exponential growth of studies confirming the undeniable benefits of virtual simulators in medical education, and noticeable progress and improvement of digital technologies, we cannot yet talk about their dominant use in this area. Even with the obvious advantages of virtual learning and teaching methods, their use in medical education was relatively limited until 2020, when the outbreak of the coronavirus pandemic led to a sharp surge in the use of digital technologies in medical education – this explosive growth was reverted to status quo.

Will the level of digital transformation in medical education return to the previous level that was observed before the pandemic, due to the disappearance of the epidemiological threat? Can we say that a natural process of gradual virtualization of learning is currently underway, accelerated by epidemic control measures, or was this surge misinterpreted by all of us and it was only a forced measure, not a progress?

Let's make a short consideration of the simulation, virtual and AI technologies from the perspective of the *Gartner Hype Cycle* [Fig. 6] – a methodology developed, used and branded by the American research, advisory and information technology firm *Gartner Inc.* (Stamford, CT, USA) for presentation and analysis of the life cycle of emerging technologies, products or concepts, understanding the phases of their evolution, representation of their adoption by society [Gartner Inc., 1995–2023].

The Gartner Hype Cycle is a graphical representation developed by research and advisory firm Gardner to represent the maturity, adoption, and social application of technologies. The cycle aims to provide a snapshot of the relative maturity of technologies in a particular domain, helping decide when and how to adopt a technology. The cycle consists of five phases:

1. Innovation Trigger: This is the phase where a new technology is introduced, and initial interest is generated, often because of media coverage. There’s often no usable product at this stage, but there’s potential.

Credit: gartner.com

Hype Cycle for Emerging Technologies, 2023



gartner.com

Source: Gartner
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Gartner.

Fig. 6. Gartner Hype Cycle of emerging technologies, August 2023

2. Peak of Inflated Expectations: At this phase, there's a lot of buzz and excitement around the technology. Some early adopters might have success, but there might also be many failures. Media coverage is usually at its peak.

3. Trough of Disillusionment: The initial excitement fades as implementations fail to deliver. The technology is criticized, and some companies may choose to abandon their efforts.

4. Slope of Enlightenment: Businesses start to understand the technology better, figuring out how to use it effectively. Best practices emerge, and more companies find success.

5. Plateau of Productivity: The technology becomes mainstream. Its benefits and value become widely recognized, and it sees widespread adoption.

The Gartner Hype Cycle is used by businesses to gauge where a technology stands and whether it's the right time for them to adopt it. It's a tool to help avoid the pitfalls of adopting a technology too early or too late. [ChatGPT-4, October 2023]

The Peak of Inflated Expectation according to Gartner Hype Cycle published in August 2023 has been reached already by numerous AI-related innovations like Generative AI, AI-Augmented, AI-TRiSM with prognosis of reaching of Plateau of Productivity in 2 to 5 years, whereas AI Simulation and Casual AI are on the first rapid rising part with a promise to reach productivity stage in 5 to 10 years. Interesting to compare their positions and forecasts with the previous year issue. The version of the hype cycle edited in 2022, AI systems (Casual AI, Code Generation, Generative Design AI, Digital Humans, etc.) were at the very beginning of their popularity with no prognosis under 5 years.

An attempt to locate on the Gartner hype cycle curve the physical simulation models, virtual reality simulators and artificial intelligence systems can help to understand and predict the phase of the technology development and its life cycle part. The physical models, phantoms and box trainers have been used in medical training over centuries and have reached the Plateau of Productivity long time ago among our grandparents. Today, their application extent is determined by general factors like convenience, realism, economic

feasibility. Virtual reality medical training platforms have been used for only a few decades, with VR-helmets even less. However, they have already disappointed many learners and educators with their cartoonish images, lack of haptics, dizziness in users wearing VR glasses – the list of complaints will be continued (see Chapter 6). However, one thing is clear: although these technologies are currently located somewhere around disappointment and disenchantment, their real success is still ahead of them – the slope of enlightenment and the plateau of productivity are surely coming. As for AI systems, they are at the beginning of soaring popularity, at the top point, where the growing counter stream of criticism will soon throw them into the Trough of Disillusionment. However, the period of soured dreams won't last long, and will soon be replaced by slow but steady growth towards the Plateau of Productivity.

Having determined the position of the digital education technologies on the public adoption graph with the help of Gartner's consultants, let's try to find out what exactly is the cause of the dissonance between obvious advantages of digital technologies and their limited application in medical education? Low realism, "toy-like" nature of virtual teaching aids? Inadequate quality of the available software solutions? The high price of the teaching aids (which, by the way, is largely explained by low production volumes)?

Or maybe the reason lies in the teachers themselves? In their excessive conservatism, zealous defense of traditional approaches and classical methods? In their reluctance to master new technologies which appear challenging for them? A banal fear of finding themselves "on the sidelines," pushed aside by a more efficient computerized piece of hardware? Or is it all about the students and their desire to learn at the patient's bedside, to observe real surgeries and real patients instead of looking at virtual organs on the computer screen and studying medical histories invented by computer brains? Do students dream of electric patients?

What place do digital teaching aids take in the educational process, what are the prospects for their implementation, what performance features the digital products must have, how to develop a learning curriculum featuring convenient and effective use of digital teaching aids, what are the advantages and potential threats of their use and the challenges that they pose to the modern teacher – this book aims to answer these questions.

Errare humanum est, perseverare autem diabolicum (To err is human, but to persevere, in error, is diabolical) – this phrase of *Seneca* inspired the English writer *Alexander Pope* when he wrote in 1711 the now famous line, *To err is human; to forgive is divine*. In turn, the 1999 *Institute of Medicine (IOM)* book *To Err is Human: Building a Safer Health System* brought widespread attention to the prevalence of medical errors in the U.S., highlighting that preventable medical errors contribute to an estimated 44,000 to 98,000 deaths each year. The publication had a bombshell effect on the health care and medical education communities, was quoted in numerous articles, and served as a catalyst for further, more extensive research on patient safety and the development of strategies to reduce errors. Today, medical errors are often cited as the third leading cause of death in the United States, after



Generation: DeepAI, prompt: Maxim Gorshkov, 2023

Fig. 7. This is the way how AI visualizes a virtual patient

heart disease and cancer. The book spurred hospitals, healthcare providers, and researchers to explore and implement evidence-based safety practices. Following the book's publication, numerous quality improvement initiatives and patient safety movements were launched, including the creation of the *National Patient Safety Foundation* and the *Agency for Healthcare Research and Quality's* focus on patient safety research.

Another important consequence of the data published in this report has been a significant impetus to increase the use of simulation methods in health care training, because it is modeling that allows training to be conducted without risk to the patient, doing so effectively and ensuring that the appropriate level of competence is achieved.

But what about educational mistakes? How many preventable medical errors are pre-programmed by the gaps in the learning process? Failings determined by a human factor? Tired tutor, overloaded teacher, distracted instructor... Nowadays, digital technologies have taken over the baton from simulation methods. It is learning in a virtual environment that, while having all the advantages of simulation training, adds a whole host of other benefits to the medical education system. A virtual assistant, especially when using artificial intelligence systems, can successfully fulfill most of the 12 roles of a medical educator. The willingness of a digital system to tirelessly explain material to a student time after time, to provide an unlimited number of repetitions of an exercise, along with unbiased, objective assessment of performance, opens up exciting possibilities for healthcare training that we don't even realize yet.

To err is human. To teach... is VR?

1. Medical virtual simulators

The advent of computers in everyday life has enriched our familiar physical environment with digital objects, virtual phenomena, and entire digital worlds. Virtual reality simulators (VR simulators, VRS) are now extensively used in medical training. These devices are presented in a wide variety of models and versions, distinguishing significantly from each other in design, functionality, dedicated educational tasks, the cost of acquisition and operation. They can fit in the smartphone lying the palm of your hand or take up an entire room to create an immersive mixed reality environment.

In 1968, *Ivan Sutherland*, with the help of his student *Bob Sproull*, introduced what was considered the first head-mounted display system capable of three-dimensional movements tracking, called the *Sword of Damocles*. This pioneering system included a stereoscopic display that presented visual output from a computer program that dynamically adapted to the user's movements. However, if we consider the term "virtual" in a general way (this will be discussed in more detail later), then a VR helmet is not necessary to perform a simulation in a virtual, i.e. computer-generated, environment – the screen of a regular desktop is quite sufficient.

Virtual simulators have been used in medical education for more than twenty years. The first encouraging evidence of successful implementation of virtual simulators in training of laparoscopic skills was published at the end of the last century [Wilson MS, 1997]. In 2001, a group of researchers from the *University of Washington* led by *H. A. Schwid* published the proceedings of the experience of using virtual simulators to practice clinical reasoning skills. The paper "Screen-based anesthesia simulation with debriefing improves performance in a mannequin-based anesthesia simulator" convincingly demonstrated the superiority of the group trained in 10 anesthetic emergencies using the screen-based anesthesia simulator program and received written feedback on their management, whereas the traditional (control) group was asked to study a handout covering the same 10 emergencies. According to the authors "all residents then were evaluated on their management of 4 standardized scenarios in a mannequin-based simulator using a quantitative scoring system. The average point score for the simulator-with-debriefing

group was 52.6 +/- 9.9 out of 95 possible points. The traditional group average point score was 43.4 +/- 5.9, $p = .004$. Residents who managed anesthetic problems using a screen-based anesthesia simulator handled the emergencies in a mannequin-based anesthesia simulator better than residents who were asked to study a handout covering the same problems.”

For more than twenty years, virtual models have been used in the Old and New Worlds for testing and exams, including end-of-year and graduation exams. For example, over a two year-period, more than 50 thousand tests of the 3rd stage of the *USMLE*¹ exam were conducted using *Computer-based Case Simulations (CCSs)*, as reported by American authors [Dillon et al, 2002]. In Europe, pilot testing with *Interactive simulation of patient cases (ISP)*, presented on the computer screen, was for the first time described by researchers from the *Karolinska Institute*, one year after the event [Bergin and Fors, 2003].

As digital technologies blend in with the educational process in medical schools, the debates concerning their strengths and weaknesses are getting louder. Still, those concerned voices warning against the obvious or possible negative consequences of the virtualization of medical education, although clearly heard, are doomed to remain a minority from the start, since not only it is impossible to stop progress in general – it cannot be done in one single industry. The introduction of digital technologies appears to be very alluring and promising, so they will inevitably be gaining momentum. The range of practical skills, manipulations, theoretical knowledge of preclinical and clinical disciplines mastered using virtual simulation technologies, is constantly growing. The more complex the educational task, the higher the level of virtual simulation technologies used to effectively solve it.

¹ USMLE (The United States Medical Licensing Examination) is a three-stage exam program for obtaining a medical license in the United States, which is passed by graduates of American and international medical universities

1.1. Terminology related to virtual learning

Due to the variety of virtual simulators available, which vary widely in design, application, and learning objectives, it is necessary to discuss the basic terms, concepts, and to propose a classification of VRSs used in medical education. The second revised and expanded edition of the Dictionary, released by the *Society for Simulation in Healthcare (SSH)* in September 2020, provides several definitions of virtual simulation [Dictionary of Simulation in Healthcare, 2nd ed., 2020]:

- The recreation of reality depicted on a computer screen [McGovern, 1994].
- A simulation involving real people operating simulated systems. Virtual simulations may include surgical simulators that are used for on-screen procedural training and are usually integrated with haptic device(s) [McGovern, 1994; Robles-De La Torre, 2011].
- A type of simulation that injects humans in a central role by exercising motor control skills (for example, flying an airplane), decision skills (committing fire control resources to action), or communication skills (as members of an air traffic control team) [Hancock et al, 2008].

Unfortunately, these are not definitions – rather, they are descriptive explanations, narratives. All of them were formulated quite a long time ago and therefore cannot any more correlate to today’s rapidly developing environment. Thus, it is necessary to provide up-to-date definitions of terms that are used in the field of medical virtual simulation.

To better understand the connotation of the word *virtual*, one needs to trace its etymological trajectory – what historical roots and meanings the term had. It all started from antique Latin “*vir*” that had a meaning “*a man*” with further derivative “*virtus*” – “*strength, valor, ability, quality*”. Then, in the Middle Ages professors and scholars started to use “*virtualis*” in the meaning of “*possible (admissible), capable*”. Thus, after having come to spoken French of the 15th century the word “*virtuel*” completely lost its component of “*power*” and has shifted into the elucidation of “*invented, non-existent*”. It subsequently was borrowed by the English language in the meaning of “*imaginary, fictitious, unreal*”. This transformation remained unchanged till 1980s when scientists

and fictionists brought second (sic!) interpretation as “*computer-based, created with the help of computer technology and not existing in the real world*”. It is worth noting that cognates words with the root “*virtu*” remain in the Romance and Germanic languages to this day (*Werte, Værdier, Virtud*), retaining the former meaning of *value, dignity, virtue* or even *virile*.

Virtual reality is a computer-generated digital model of an environment, existing or non-existing, simulating an experience where users can interact with its components, producing and observing changes caused by their actions to the model.

Generalizing term “**Virtual Reality Simulators**” refers to a large group of digital devices consisting of a software application running on a microprocessor and one or more peripheral devices (UI, User Interface) enabling interaction between the doctor’s hands, medical instruments or electronic devices with the patient and his/her organs. VRS can replicate not only pathological states of the patient but also clinical and organizational processes in the healthcare. VRS provide an opportunity to practice a variety of skills, such as clinical reasoning, communication with the patient or health care team, honing specific skills, manipulations, as well as carrying out objective assessment of the level of proficiency achieved. This group also embraces cross-functional solutions ranging from screen-based simulators to VR Task-Trainers and designed to practice manual or surgical interventions in virtual reality (for example, laparoscopic simulator LapSim¹ with haptic feedback systems). Based on the above, we propose the following umbrella definition for this group of devices:

Medical virtual simulators are devices consisting of software and hardware components designed to simulate in a virtual environment interactive medical conditions, processes, conditions, objects, and subjects used for the purposes of education, assessment and research.

Simulators that imitate patients and their conditions – so-called *virtual patients* – are often recognized as a separate **VRS group**. They are designed for case-based learning, including the acquisition and practice of various medical competencies, such as professional communication, history taking,

¹ LapSim is a trademark of Surgical Science, Gothenburg, Sweden.

diagnosis, treatment prescription, teamwork, decision making and other clinical activities, as well as for formative and summative assessment of acquired competencies.

However, it is important to highlight that this term is used in various fields, without limitation to education only. For example, in a literature review of 2015, dedicated to virtual patients, 60% of the 536 articles fall into the category of medical education, 25% pertain to clinical research, and the rest to clinical practice, planning of surgical interventions, and writing patient record notes in electronic format [Kononowicz et al., 2015]. Some authors tend to group computerized mannequins and high-fidelity robotic patient simulators into the same category as far as their important component is a computer. Therefore, an accurate definition of the term is of paramount importance.

According to the *American Association of Medical Colleges (AAMC)*, a virtual patient is “A specific type of computer program that simulates real-life clinical scenarios; learners emulate the roles of healthcare providers to obtain a history, conduct a physical exam, make diagnostic and therapeutic decisions” [AAMC, 2006]. Another definition given in 2007 by *Kenny P. et al.*, offers the following description: “Virtual interactive agents that are trained to simulate a specific patient’s particular clinical presentation with a high degree of consistency and realism” [Kenny P. et al., 2007]. The Society for Simulation in Healthcare (SSH) defines it as: “A computer program that simulates real-life clinical scenarios in which the student acts as a healthcare provider collecting a history, performing a physical exam and making diagnostic and therapeutic decisions” [Healthcare simulation dictionary, SSH, 2020].

As we see it, none of these definitions reflects all key features characterizing this type of teaching aid, which prompted us, taking into account the need for generalization, to formulate the following definition of a virtual patient:

Virtual patients are a specific subset of virtual simulators, interactive digital models of patients, simulate subjective and objective signs of a disease, including physiological parameters, laboratory, and instrumental diagnostic data, primarily for educational and assessment purposes.

In the above definition, we did not mention some other frequently encountered features such as 3D-image of the patient [Fig. 8], speech generation to develop communication skills, or a computational model of patient physiology. Thus, after some thought the part “interacting with user’s actions or simulated medicines” was excluded as not mandatory, though the word “interactive” remained, while this is the key feature of any simulation. For example, if the case represents a dermatology clinic, visual features of the skin will be the most



Generated by: Crayon. Prompt: Maxim Gorshkov, 2023

Fig. 8. AI-generated image (Crayon) representing a virtual patient, based on the prompt “virtual patient old female”

important; if the patient has cardiology problems in stable condition and the purpose of the training is to practice diagnosis skills, realism in auscultation, ECG and instrumental data will come to the first place; while in an emergency care training, highly dynamic physiological parameters that quickly respond to the trainees’ actions come to the fore. The most common areas where virtual patients may be used in medical education are summarized in Table 1.

Screen-Based Simulation is an umbrella term covering various types of simulation displayed on the screen of a mobile or desktop device and interacting with the user via standard user’s interface (keyboard, mouse, touchscreen). Even though the first articles on the computer simulators were published at the end of the XXth Century [Christensen UJ, 1997; Bosse G,

Table 1. Virtual patients' application domains in medical education

- Communication skills
- Physical examination, including visual examination and auscultation
- Clinical reasoning, interpretation of the laboratory and instrumental data (“slow” clinical cases)
- Diagnostics and treatment strategy in emergency conditions (“rapid” clinical cases)
- Teamwork, leadership, interdisciplinary and interprofessional interaction
- Organizational and management decisions in healthcare, including triage of patients or casualties

1997] the term itself is relatively young, it was first mentioned in PubMed² in 2001 [Schwid HA, et al, 2001].

Virtual Reality Trainer (box trainer) is a firmware unit consisting of software, computer and peripherals (user interface) imitating medical instruments as well as the patients or their organs and intended for deliberate practice (training) and objective assessment of specific manipulations. Unlike a virtual simulator, the term “trainer” or “training device” usually refers to a training aid for the development of technical skills, i.e. a consciously distributed in time, repetitive performance of individual movements, actions, manipulations or exercises in order to acquire sustainable practical, manipulative ability.

Virtual clinic is a computer-generated model of a medical institution or its unit, designed for training in making clinical, epidemiological, economic, administrative, and other managerial decisions, as well as objective assessment of these skills.

² PubMed is a free search engine with access to the MEDLINE database containing references and abstracts related to biomedical and life sciences and administered by the US National Library of Medicine (NLM).

1.2. Teaching formats and models

Since the introduction of digital innovations into full-time-presented and distance learning has significantly changed the existing educational formats, let us review them briefly in this section of the present chapter.

Face-to-Face Education (in-person, in presence) is a set of educational activities – lectures, tutorials and workshops – conducted in a traditional format in a real, physical environment where educator and learners are presented in the same room. All of these require dedicated educational premises (classrooms, laboratories, lecture halls), simultaneous physical presence of the teacher and students in the same room, with their number being limited, while creating certain logistical hurdles and significant financial costs. As a matter of fact, this format has been there for no less than a thousand years – this is exactly how students have studied since 1088, the year when the *University of Bologna* was founded.

E-Learning, electronic learning (from the Greek *ηλεκτρον*, *ēlektron* – “amber”) is the umbrella term for the type of education, where traditional educational activities (lectures, tutorials) and teaching aids (books, posters, slides, films) are delivered in electronic format. The discovery of static electricity when rubbing amber paved the way for the development of the electrical theory; nowadays, the term “electronic” refers to educational methods involving the use of electronic circuits, computers, smartphones and chips – e-books, video lessons, interactive quizzes, computer tests, virtual simulators. E-learning can be conducted face-to-face, via computer devices installed in classrooms, or remotely, through remote access to digital materials. It’s important feature is the flexibility in the timing and location of lessons, allowing for self-directed learning. Some authors use letter “E” to differentiate this type from traditional activities carried out in real environment – “*R-Learning*” (Reality Learning).

Distance learning, DL or remote learning (from the Latin *distantia* – *remoteness*, *distance*) is the successor to the correspondence course, a learning format where the student and teacher can be remoted from each other not only in space but can be separated also in time. Historically distance learning was performed through written correspondence courses sent via postal mail or television lessons. In distance learning, not only conversion of teaching aids into electronic format is required but it is also necessary to use telecom-

munication technologies to connect participants located far away from each other. DL activities can be carried out synchronously (at the same time), asynchronously (at different times), or be distributed. In distributed learning, the student and the teacher are not only located remotely from each other but are also distributed over time and space – such format is devoid of a centralized structure, fixed learning schedule, or a precise timetable. The comparison between real, distance and e-learning is shown in Table 2.

Table 2. R-learning, D-Learning and E-learning

Feature	Face-to-face (RL)	E-learning (EL)	Distance Learning (DL)
Key feature	Direct contact. Educator and learners are in the same room, communicating face-to-face	Technology (electronic). Often, educator does not even exist	Location (Geographical remoteness). Student/teacher interaction occurs at a distance through telecommunication
Distance	Not distant – face-to face, presence	Both distance and face-to-face	Participants are in different locations, at a distance
Types of learning activities	Lecture, seminar, colloquium, workshop, lab session, simulation, skills training, clinical round, in situ training	Entire spectrum of self-paced learning and assessment modalities	Teleconferences, video-lectures, webinars, group activities, access to online-courses and other educational materials
Medium	Traditional materials like books, lecture handouts, slide-presentations	Both content like classic PDFs, videos and web pages to more dynamic such as interactive modules, quizzes, and simulation	Printed materials, radio broadcasts, television, teleconferencing, online platforms
Flexibility	Low, normally based on learning schedule, timetable	Flexible, learning at any time, with some deadlines, self-paced	Rather flexible, however, can be based on online-lectures timetable
Modelling, simulation	Normally not. During learning activities in a simulation center an educator can supervise and facilitate the learning process	Often but not mandatory. By usage of virtual simulators	Rare

Feature	Face-to-face (RL)	E-learning (EL)	Distance Learning (DL)
Technology	Not mandatory. Can be used physical models and simulators, videos, slides, or other technical teaching aids	Computer-based technologies as by definition	Not necessary e.g., can be provided by classic post. However, modern distance courses are based on internet connection and communication technologies
Interaction with teacher	Direct interaction, non-verbal cues, body language. However, interaction is not obligate, depends on type of activity (at the lecture interaction is minimal)	Usually there is no direct interaction with an educator, who is substituted by e-learning devices (simulators, smartphones, etc.)	Indirect interaction, sometimes timely distributed. Its type and level depend on the medium (by written correspondence courses might have minimal interaction)
Social interaction	Directed and spontaneous social interactions, group work, and collaborative projects in a physical setting	Some opportunities, however, less organic. Requires more structured digital platforms to facilitate	Very rare. Contacts can be limited to computerized systems only. Students often create informal social interaction through chats, groups, channels
Work with educator	Synchronously	Synchronously, asynchronously, distributed or self-learning without educator	Synchronously, asynchronously or distributed
Cost for learners	High. Learner needs to be presented in a specific location, which can be time-consuming and costly	Middle. E-learning brings education directly to the learner; however, e-learning programs and devices can be expensive	Low. DL saves time needed for travel and potentially money
Cost for institutions	High. Institution has higher organizational expenses for premises, equipment, salary of educators and axillary personnel	Middle. E-learning has multiplication effect, allows to copy lessons and educational materials; however, e-learning programs and devices can be expensive	Low. DL allows to broadcast and repeatedly copy lessons and educational materials, saving personnel, time, and cost

There are two educational formats falling into the category of distance learning: hybrid and mixed learning. Both of them involve a combination of offline and online learning but differ in some aspects.

Hybrid learning (from the Greek *ὑβριδικά* – a “combination of heterogeneous elements”) is an educational approach combining presence and distance phases of learning. Hybrid learning divides the educational process into two distinct formats: in-person sessions and online sessions. Students might attend classes in person some days and complete the rest of their coursework online. It offers more flexibility in terms of where learning takes place while the students might attend fewer in-person classes, making it more suitable for those who might live far from the educational institution or have other commitments.

Blended learning has its focus on integrating digital resources into the traditional classroom setting. It’s more about enhancing and personalizing the in-class experience with online tools and activities rather than replacing any portion of the in-person instruction. It requires more consistent attendance of face-to-face sessions that are enhanced with digital tools and online activities.

When it comes to **virtual learning**, lot of educators do not bother themselves with “categorizing” individual concepts and, not seeing the differences between electronic, distance and virtual types of learning, often confuse these terms or use them as synonyms. Likewise, ChatGPT, which is based on the generation of arrays of texts – both correct and not quite correct, claims that:

Virtual learning, also known as online learning or e-learning, is a form of learning delivered remotely or via the Internet. It involves the use of digital technologies such as computers, the Internet and various software applications to provide educational content and facilitate the learning process [generated by ChatGPT on 11 of July 2023].

Moreover, many authors understanding “virtual reality” as a digital space that can be accessed with VR helmets only, make difference between virtual learning and virtual reality learning. They describe “**VR learning**” as use of virtual reality technology to create immersive educational experiences in VR – a computer-generated, three-dimensional environment where they can interact with objects, scenarios, or simulations in real-time.

1.3. Discussion of the term “Virtual education”

As described above, the term “virtual” has become so popular in recent years, and its meaning is so vague that in some cases it is used inaccurately. The *Cambridge Dictionary* defines virtual learning environment as a “system for learning and teaching using the internet and special software” – that’s it! It seems that this defining is given too broadly. What does it mean, then, that every time we switch on a computer and open a software or load an Internet site while learning, we can call it “virtual education”?

Thus, one can read at *Coursera*¹ that “Virtual learning refers to an environment where students study a digital-based curriculum taught by instructors that lecture online via video or audio. This instruction can take place either in a self-paced (asynchronous) environment or in a real-time (synchronous) environment.” The definition given by Coursera is much better, on the contrary suffers from excessive narrowness, being limited to lectures recorded by actual teachers. At the same time, there are many examples where human participation is not foreseen in the delivery of educational material. *Anki* cards² are presented as texts or simple images. The delivery of material in *Amboss*³ is more like a *Wikipedia*⁴ specialized in medical issues – texts, illustrations, diagrams, and no people at all. So, what if there are no educators presented in the education system? What if the lectures are written by artificial intelligence and presented by generated avatars?

Another consideration can be addressed to the nature of “virtuality” described. When reading a paper dedicated to virtual learning, the reader needs to ask himself “Is this actually about learning in virtual environment?” If the answer is positive, the following thing needs to be clarified: “What kind of virtuality are

¹ Coursera Inc. is a massive open online course provider. Mountain View, CA, USA.

² Anki was made by Damien Elmes in 2006, is an open-source flashcard system, apps. ankiweb.net. Be aware of copies!

³ Amboss is a medical knowledge platform for doctors and students, by Amboss GmbH, Berlin, Germany.

⁴ Wikipedia is a free-content online encyclopedia launched in 2001 by Jimmy Wales, Larry Sanger. It has now over 110 million registered users, the content in over 300 languages is written and maintained by a community of about 300 thousand volunteers.

the authors talking about?” The use of the word “virtual” does not necessarily imply that a VR helmet is utilized in a virtual reality experience described in the paper – rather, it is about exploring an online-course, cross-platform technology, or interactive virtual patient on the screen of mobile device!

In the past decade, the term *vOSCE* (other variants are *VOSCE* and *virtual OSCE*) has become widely used to refer to the remote delivery of an *Objective Structured Clinical Examination (OSCE)* in which the examinee and a standardized patient communicate online via video link. For example, educators from the *School of Medicine, Dentistry and Nursing, University of Glasgow* described the *VOSCE* as follows: “We conceived, developed and then successfully implemented a novel Virtual Objective Structured Clinical Examination (*VOSCE*) using videotelephony through a cloud-based peer-to-peer software platform *Zoom*⁵ [Boyle et al, 2020]. A similar meaning is attached to the concept of “virtual OSCE” by dozens of other authors (Craig et al, 2020; Pante et al, 2020; Donn et al, 2022 and many more).

This type of remote OSCE conducting, where the examinee and the SP are located at a considerable distance from each other, has been used for more than twenty years [Lentz et al, 1999; Novack et al, 2002]. Since the same technical Internet solutions were used for its implementation as for telemedicine (“via a teleconferencing program designed for the World-Wide Web”), at the dawn of its development, this method of conducting the exam was called *teleOSCE* or *webOSCE*. However, over time, the term *vOSCE* has begun to be used more and more often, which, in our opinion, is terminologically inaccurate. In the modern life not a single process of data transmission can do without computers – be it a communication via telephone, fax, radio- or TV-broadcasting, internet, or satellite communications – all of them are governed by computers and can be classified as digital technologies. However, all types of data transfer are seen to preserve their old names, while our interlocutor, though communicating with us via *Skype*⁶, *Zoom* or any other messenger or teleconference app, is perceived by us as real a person, not a virtual character.

⁵ Zoom Video Communications Inc., San Jose, California, USA.

⁶ Skype is a trademark of Microsoft Corp., Redmond, Washington, USA.

Alongside with this, a technology for using virtual and digital models in OSCE has been around for just as long – for over twenty years – where virtual models can be uploaded to a remote computer, located in another campus or in the cloud. As it has been mentioned above, in November 1999 and 2000, American researchers piloted the *USMLE* Step 3 exam using virtual clinical cases, where these types of OSCEs were referred to as “Computer-based Case Simulations (CCSs)” [Dillon et al., 2002].

A European training system for interactive simulation of clinical cases, including for assessment purposes, was described by the authors from the *Karolinska Institute* (Bergin, Fors, 2003). The examination was based on videotaped interviews with patients but was supplemented by interactive physical examination and tests. Computer simulation-based examinations in students of different semesters (n = 70) were conducted in three research control trials during 1999-2001. Last but not least, in step with the times, as technologies evolve and change, screen simulators are being replaced by immersive technologies, which are being developed and implemented in virtual augmented reality. To illustrate, an example of using mixed reality technology is the use of *HoloLens*⁷ to conduct extended Objective Structured Clinical Examinations at *Imperial College London* [Minty et al., 2022].

What should we call such methods, where virtual characters act as the object of examination – even though the name “virtual OSCE” has already been taken, although not entirely fair? Computerized OSCE? Digital? Virtually enhanced? OSCE in augmented reality?

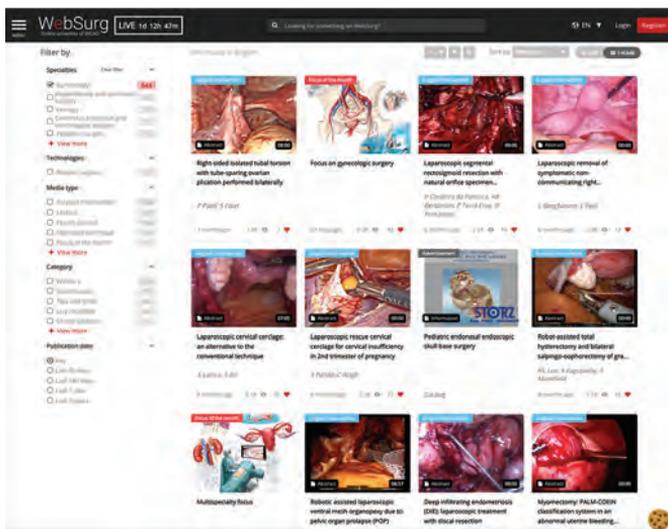
Of course, as virtual technologies develop, sooner or later there will be a specific term for conducting exams with the help of virtual patients. For now, we do not have an answer to this question – only a modest attempt to draw attention to the existing terminological confusion, when the use of the name “virtual OSCE”, in our opinion, is not entirely accurate.

So, and what is the situation with teaching aids? Are there fundamental differences between “e-learning” and “virtual learning”? If during cardiopulmonary resuscitation an electronic stopwatch is used to determine the correct procedure execution, will such training become electronic? And if

⁷ HoloLens is a trademark of Microsoft Corp., Redmond, Washington, USA.

not, how should one categorize the light indicator built into the mannequin that lights up when the chest compressions are performed at the proper depth? Obviously, the presence of electrical devices in itself is not enough. It should also be noted here that textbooks, atlases and other printed teaching aids, digitized and translated into electronic format (E-books, web-atlas, etc.), should not be classified as virtual simulators, but rather as a group of “electronic teaching aids” (e-learning devices), since the real environment cannot be simulated in the virtual world, it cannot be modified, but only copied and displayed on a technologically different, electronic medium instead of a physical one, and it does not have interactivity – it is not able to interact with the user.

The same is true for the video materials posted on specialized portals [Fig. 9] and streaming servers like *YouTube*⁸ or *Vimeo*⁹. Founded 17 years ago, YouTube service has become one of the leading educational tools for students and doctors around the world [Frongia G, 2016]. However, just like electronic textbooks, video materials are not interactive models, generated solely by a computer microprocessor, so distance or e-learning based on watching videos on the Internet, although supported by electronic/computer technologies, cannot be classified as virtual simulation [Table 3].



Credit: website websurg.com

Fig. 9. Video portal websurg.com where educational video content provided by world-renowned experts in all fields of minimally invasive surgery is provided. Powered by IRCAD

⁸ YouTube is a trademark of Google LLC, Mountain View, CA, USA

⁹ Vimeo is a trademark of Vimeo LLC, New-York, NY, USA.

We believe that some of the definitions used today will soon be phased out or acquire a different meaning. For example, the term “screen simulator” was widely used in 2000s, when users ran educational programs on personal computers and the screen was the only means of interaction. These applications can now be presented on embedded in teaching aids or stand-alone screens of mobile devices – tablets and smartphones, as well as seamlessly integrated into immersive environments using virtual reality goggles. This creates a unique meta-universe, distinct from the real world and containing many virtual worlds and applications that interact with each other, allowing the user to move freely between them, just as we move between different sites on the Internet. The same simulated case can be presented on a smartphone, tablet, 60-inch screen, in a VR helmet or mixed with real world through AR-glasses. Can all these devices still be referred to as a “screen” and can we still call these apps a “screen application”? Moreover, screen simulators have acquired many additional functions that users couldn’t even think of ten or twenty years ago, such as vibration of the screen when palpating for pulse or wireless collection of physiological parameters of a trainee using external sensors and their integration into a virtual clinical case.

While modern e-learning encompasses a broad range of educational content on the Internet and can be either self-paced or live, synchronous and asynchronous, virtual learning specifically refers to real-time education conducted in a virtual environment, mirroring the interactivity of a traditional classroom – and is not conducted by humans but computers, otherwise it could be called distant learning. This communication in digital space with machine not human is the key feature and main difference to e-learning or distance education. Paying special attention to the interaction of the user with the computer-steered learning environment, wide usage of modelling methodology and taking into account another above-mentioned consideration, as well as echoing David Gaba’s famous definition of simulation [Gaba D., 2004], we would like to propose the following definition of virtual medical education:

Virtual medical education is a technology-enhanced approach – not a technique – to transfer education or assessment activities into computer-generated virtual environment filled with digital models of medical processes, procedures, conditions, statuses, subjects, and objects interacting with learners, to replace physical presence in a traditional classroom or real clinical setting.

Table 3. Comparison between E-Learning and VR-learning

<i>Feature</i>	<i>E-Learning</i>	<i>Virtual L.</i>
Key feature	Digital technology	Virtual reality, digital environment
Educator as a real person	Not mandatory but is presented by distance learning	There is no real educator
Technology	Is an instrument used by educator or learner	Is a key point of the learning process – it is object, media and environment where learning occurs
3D images	Not mandatory	Specific to VR learning
Interaction between learner and learning media	Not necessary. Can be passive reading or watching.	Interaction in VR with virtually simulated objects and subjects as well as with didactic materials and LMS
Immersion	Usually, cognitive immersion only	Any type of immersion including cognitive, emotional, sensorimotor, spatial

1.4. VR simulator design and features

Let's dwell more on the devices of virtual training systems – VR simulators. Any virtual simulator (trainer) consists of the following main components:

- a) a software application that creates an interactive model of reality experiences in a virtual environment,
- b) a computing device for data processing (in situ or in cloud), and
- c) a peripheral device (user interface) for user interaction – input of external commands and output of processed results in virtual reality.

Let's take a closer look at each of these components.

1.4.1. Data input

To interact with the virtual simulator, the user can enter commands via the following devices:

- Keyboard, other devices for entering text, numbers or images.
- Microphone (voice commands based on speech-recognition).
- Mouse, trackpad, touchpad, touch screen or another coordinate device.
- Joysticks, sensors, gloves, suits and other sensory and haptic devices: ultrasonic, microwave, tomographic (electromagnetic) sensors for analyzing spatial coordinates, movement, pressure, tension (*Wii U*¹,



Credit: Surgical Science

Fig. 10. Haptic feedback system allows to feel the resistance of modelled tissues when performing simulated surgeries on a virtual simulator

¹ Game console, Wii U is a trademark of Nintendo Co., Ltd, Kyoto, Japan.

*SimBall*², *Polhemus*³, *Sensable*⁴). Some of them realistically reproduce parts of the human body, such as a robotic arm for intravenous injections. Such interfaces can be of interactive type not only carrying out input commands, but also providing counteraction, a physical response – tactile feedback.

- Optical devices, including laser detectors, mono- and stereoscopic video cameras detecting in the visible or infrared band the position of the object in space (special coordinates), gestures, hands position, eye movements, recognizing and analyzing events. Examples of such devices include *Leap*, *Kinect*⁵. Another example of breakthrough in the development of the human-machine interface is *Apple Vision Pro*⁶ device. Numerous patented technologies for transmitting commands to the computer, such as zooming in on an area where your gaze has been directed for a long time (“looks”), controlling glasses using a combination of blinking, looking at a specific point, gestures, voice input and other actions promise to revolutionize the way how we interact with machines.
- Devices for recognizing mental commands, which is technologically possible today, but so far has only been implemented in medical devices, for example, bionic prostheses [Fig. 11].

Credit: Johns Hopkins APL



Fig. 11. Bionic prosthesis that moved by the “power of thought,” 2015, Johns Hopkins University Applied Physics Laboratory

² Coordinates tracking device, *SimBall* is a trademark of Surgical Science, Gothenburg, Sweden.

³ *Polhemus Inc.*, Colchester, Vermont, USA.

⁴ Haptic feedback device, *SenceAble* is a trademark of Surgical Science, Gothenburg, Sweden.

⁵ *Kinect* is a trademark of Microsoft Corp., Redmond, Washington, USA.

⁶ *Apple Vision Pro* is a trademark of Apple Inc., Cupertino, California, USA.

1.4.2. Elements of virtual environment

One of the first classifications of virtual simulation proposed in 1997 by Meller identified three types of virtual simulation elements: passive, active and interactive [Meller G, 1997]. However, the modern level of technological development allows us to introduce another type of elements, which we suggest calling “hyperactive”. On this basis, one can speak of four types of elements of the virtual environment:

1. Passive or Inactive elements remain unchanged during the simulation and do not interact with the trainee. User can only watch or hear them, for example, images of the environment, instruments and equipment, medical personnel or sounds of cries or ambulance sirenes. These elements are auxiliary objects and subjects that are used to “enhance the realism” of the simulation, create nice general fidelity of the virtual environment.

2. Active elements change throughout the simulation process to prompt the learner to take action; the script, not the user, governs them. The script changes their characteristics during the simulation according to a predetermined script and at a specified time, for example, on the bedside monitor screen, a drop in pressure to 90/60 mm can be seen within 5 minutes; or, after specific triggering events, e.g. following defibrillation, sinus rhythm is restored. Such changes are standardized and preset.

3. Interactive elements are based on a complex mathematical model or script in which parameter values change in response to the learner’s actions, and the degree, level or area affected by such response depends on the intensity of user activity. Examples: individual, dose-dependent changes in physiological parameters after drug administration; the intensity of bleeding from an organ is determined by the location and depth of injury caused by the trainee’s surgical instrument; the level of saturation correlates with the quality of cardiopulmonary therapy or oxygen flow rate and concentration; stopping or continuing blood loss and its volume is associated with the correct application of the tourniquet.

4. Superactive (or hyperactive) elements not only demonstrate parameter changes in response to learner’s actions, but also produce feedback on him/her actions or on the real environment. For example, virtual intestine tissues will push back on the endoscope shaft if it hits the inner wall of the organ, and the resistance will further be transmitted to the student’s hand holding device.

1.4.3. Immersion

“Immersion” in its classical natural science meaning implies the process of transition across media state boundaries, as a rule, from gaseous to liquid. In the digital world, the concept of immersion (or “immersion effect”) refers to the state of an individual who plunged down into the virtual world and perceives the virtual reality as if it was real. Psychologists distinguish several types of immersion (I.) – cognitive, sensorimotor, emotional, spatial, and some of them do not require immersion in a virtual environment to occur.

The **cognitive** (or **strategic**) immersion is a condition of deep involvement or absorption by a certain activity or experience, when all person’s attention, focus and mental resources are concentrated on finding a solution to a specific task or situation, causing him to “freeze”.

Cognitive Immersion refers to a state where an individual is deeply engrossed in an activity, whether in a virtual environment or in the physical world. It often occurs during tasks that demand intense mental focus, such as solving intricate problems, engaging in creative endeavors, or reading a captivating book. In this state, a person’s thoughts and emotions become profoundly intertwined with the task at hand, pushing distractions to the periphery. This heightened concentration not only boosts productivity but also elicits a sense of pleasure. [ChatGPT-4, October 2023].

A classic real-life example is the focused state of grandmasters during an intense game of chess. Similar cognitive immersion can be observed in medicine, when performing a complex manipulation, making a diagnostic decision during an ultrasound examination, or developing a treatment strategy for a real or even virtual patient (e.g., on a smartphone screen).

Sensorimotor (or **tactical**) immersion involves interaction of sensory organs and body parts in a virtual, augmented, or real environment; it manifests itself during practical skills training, when the student is required interact to quickly and skillfully with the virtual environment. In some situations, where the learning objective is to practice a complex skill, such as endosurgical intracorporeal suture or abdominal palpation, all attention may be absorbed by the physical interaction with the virtual object. The learners may even close their eyes to shut out the surrounding reality which is not part of the simulation

scenario, or their gaze freezes as if following their fingertips down in the depths of the patient's abdomen.

There are two types of **haptics** feedback used in VR simulation: passive and active tactile interaction. The passive option is provided by a physical phantom, the position and structure of which is selected so that when touching tissue on the screen, this would also happen inside the simulator.

Active feedback is a more complex engineering solution implemented with the help of a computer program and a sophisticated electronically driven device – the program calculates the position of the virtual device relative to the tissues and uses servomotors to simulate their resistance to pressure or stretching [Fig. 12].



Credit: Maxim Gorshkov

Fig. 12. The immersive effect is achieved primarily due to the use of a virtual reality helmet. However, physical reality can be compromised by the use of additional sensors, joysticks, etc.

Sensorimotor immersion in the real-life results from the harmonious integration of tactile sensations and corresponding motor actions. This deep synergy between sensory organs, physical movements, and the surrounding environment is evident when musicians play instruments, dancers move, or athletes, like basketball or football players, engage in complex maneuvers. These individuals depend on sensory cues, including visual hints, auditory feedback, and proprioception (body position awareness), to guide their actions and make instantaneous decisions. Achieving an impressive performance in these activities requires meticulous coordination between sensory inputs, like auditory, tactile, and visual cues, and motor reactions. Such synchronization establishes a seamless link between one's physical state and motor activities, especially in virtual settings.

Sensorimotor I. integrates both sensory and motor signals, striving to forge an unbreakable bond between the user's actual body and the digital or augmented realm. This fusion intensifies the user's sense of presence, self-awareness, and self-control, amplifying immersion and fostering more organic and instinctive interactions. Modern virtual reality systems equipped with Sensorimotor AI utilize motion detectors, tactile feedback (haptics), and other advanced sensors. For instance, a person donning a VR headset and operating hand controllers can walk, grasp items, and manipulate them within a virtual domain. [ChatGPT-4, October 2023].

Sensorimotor immersion is a typical feature for virtual simulators designed for training practical interventions – laparoscopy, endoscopy, angiography. This type of immersion places very high demands on the technological level of the simulator design. Fidelity is immediately lost if the simulated tissues unrealistically respond to the touch or the screen is “lagging behind” and does not coincide in time with the movements of the student.

Today, haptic devices for the virtual environment, including those integrated in medical virtual simulators, are high-tech electromechanical devices which appear as something innovative, entangled in wires, equipped with sensors and servomotors. Integrated into a VR system, they always turn the latter into a more technologically sophisticated and therefore expensive unit; despite all, the developers use them whenever a hands-on training of complex sensorimotor skills is required, for example, when honing intricate surgical interventions.

Emotional (or descriptive) immersion means psychological, emotional involvement and connection with the phenomenon or the events that are unfolding before the person's eyes, in the real or the virtual environment, and with what is happening around him and with him.

In this state, an individual's emotions and feelings are deeply shaped by their surroundings and the circumstances they are in. Experiences like watching a captivating film, witnessing a mesmerizing landscape, attending a top artist's concert, or celebrating weddings or holidays can evoke profound emotional and sometimes physiological responses. Emotional immersion in the tangible world means not just observing or participating but truly sensing and being moved by its emotional facets. This heightened emotional bond

enhances the individual's experience, fostering a more profound sense of presence and engagement with the real world. [ChatGPT-4, October 2023].

An individual's emotional immersion can be so deep that they become literally "overwhelmed with feelings." Internal excitement splashes out the feelings beyond the edge of everyday life, breathing and heartbeat become faster, cold sweat appears, pupils dilate – vegetative reactions are so deep and pronounced that they may not disappear immediately, lingering for some time, leading to a serious psychosomatic illness. Following the sentimental shock, a phase of exhaustion (suppression) begins, the residual effects of which can persist for a long time. Depending on the factors that caused this condition, it can be given different names: *Stendhal syndrome* (also known as "Florentine syndrome"), a long-term condition he described after his trip to picturesque Florence in the 19th century, characterized by constant dizziness with fainting and rapid heartbeat. Between 10 and 20 such incidents are recorded in Florence every year, some people lose their temper, crying, at least once an epileptic seizure and one myocardial infarction were observed; *Paris syndrome* – a psychological breakdown in tourists, mostly Japanese, deeply disappointed by the dissonance between romanticized notions of Paris and the unpleasant reality of visiting the real capital of White France, characterized by depression, anxiety, hallucinations and even acute psychosis; *Jerusalem syndrome* characterized by intrusive thoughts of religious themes, hallucinations and even the notion of possessing seemingly divine or prophetic powers, occurring in some people (regardless of their religion – in Jews, Christians and Muslims) when visiting the city of Jerusalem; *post traumatic syndrome*, which can be caused by direct participation in a terrible event – war, accident, sexual violence, tsunami, or earthquake; *post-partum depression*, occurring in women in the first weeks or months after childbirth, induced by hormonal changes, characterized by deep sadness, anxiety, sleep disturbances, feelings of hopelessness and helplessness that do not correspond to the real situation.

Spatial immersion manifests itself in a feeling of complete, global merging with the simulated world, a feeling of physical transition from the physical reality to the virtual world, like Alice who one day found herself in Wonderland. Similar to sensorimotor, the spatial immersion is achieved rather through the quality of simulation than through the content, and this directly depends on the level of complexity of technological solutions used: virtual reality helmets, haptic devices, interactive gloves, entire suits. The user needs to sense the

environment, feel the resistance when intruding. In the real world, spatial immersion occurs when riding a motorcycle, jumping from a cliff into water, immersing oneself in a warm bath, sledding down a mountain – the sense of the body’s position in space, the force of gravity, temperature, gushes of wind force all sensory systems that are normally snoozing, to turn on. By adding spatial immersion to other hi-tech solutions, developers of VR systems open opportunities for using a limitless number of training applications of different levels of realism, including large-scale team trainings based on specific scenarios, such as “Cardiac arrest during transportation in an ambulance.”

As can be seen from the above, the more different immersion options are combined in virtual reality, the greater will be the “depth of immersion,” and the degree of immersion in virtual simulation [Fig. 13].



Fig. 13. The immersive effect is achieved primarily due to the use of a virtual reality helmet. However, physical reality can be compromised by the use of additional sensors, joysticks, etc.

Credit: Maxim Gorshkov, 2019

1.5. Classification of virtual simulators

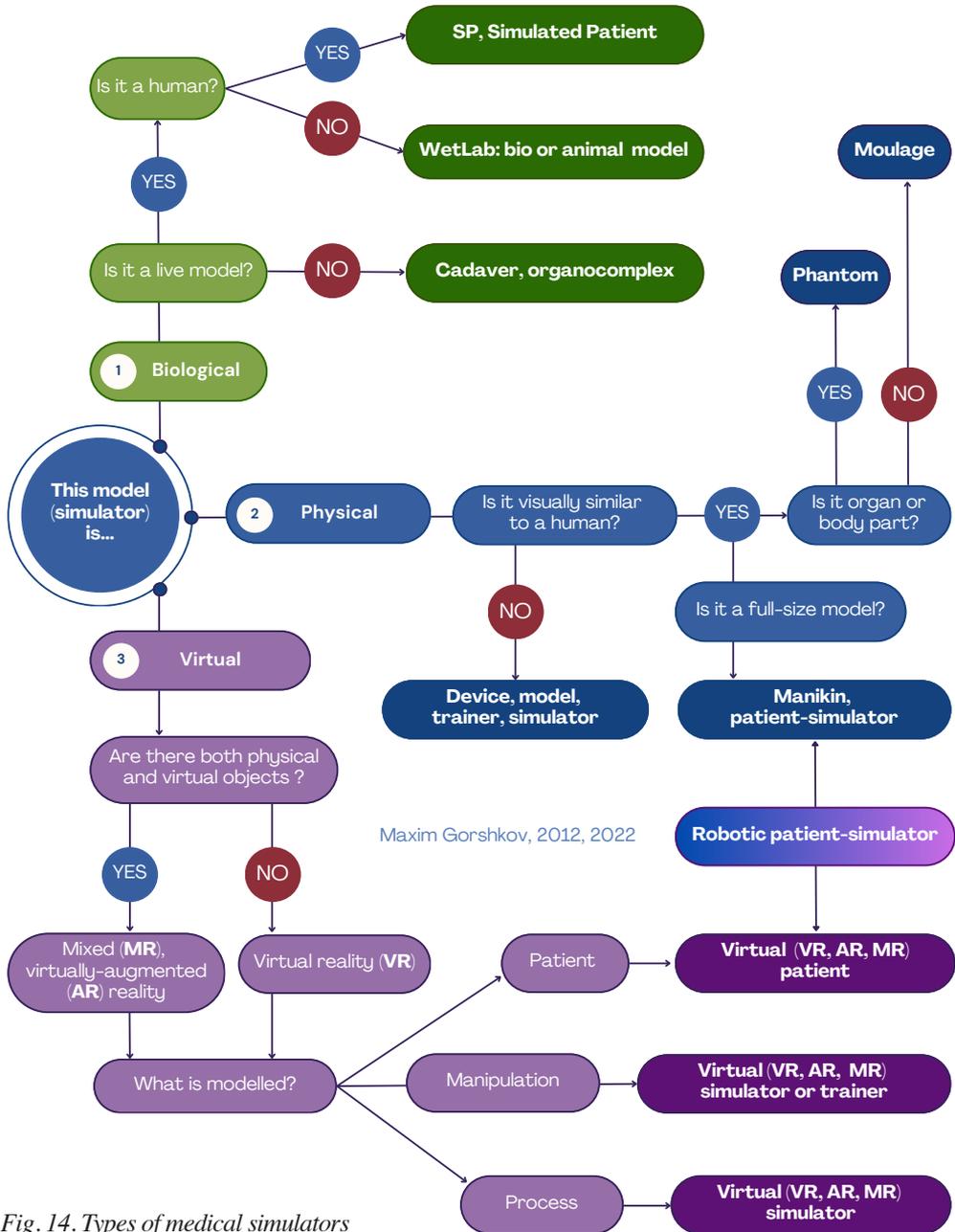
As mentioned above, the variety of virtual reality medical simulators is extensive, owing to the large number of different manipulations, skills, techniques, operations, tissue types, pathologies, critical conditions, medical specializations, learning objectives and training levels to be replicated. This current section – Classification of virtual simulators – is dedicated to bringing some systematization in finding common features and functionalities. Following the description of groups of devices with similar features, several typical examples from the field of medical education are given. First of all, medical simulation devices were divided into the several traditionally named groups of products with characteristic attributes and functional features:

- Live model (simulated patients, test animals);
- Biological model (cadavers, organ complexes, organs);
- Moulages of body parts and organs;
- Phantoms of body parts and organs;
- Full-body mannequins (manikins, dummies, robotic patient simulators);
- Trainers, models, devices for manual skills training;
- Screen-based simulators;
- Virtual reality or mixed reality simulators;
- Models (imitations) of medical equipment, consumables and medications.

The flowchart “Types of the medical simulators” given below illustrates this division and the algorithm according to which medical simulators are classified, helping to assign this or that unit to the right group [Fig. 14].

In addition to these historically established types, a few contemporary authors proposed original taxonomies, many of which mention virtual simulators as well. For example, the pioneer of the methodology of simulation training Prof. *David Gaba*, Director of the *Center for Immersive and Simulation based Learning (CISL)* at *Stanford University School of Medicine*, proposed in 2004 eleven dimensions of simulation application. As a part of the classification

Types of medical simulators



Credit: M.D. Gorshkov, 2012, 2022

Fig. 14. Types of medical simulators

of simulator based on technology applicable or required for simulations, five groups can be distinguished [see Table 4, left column]. Except of first two groups based on humans playing role, all three remaining groups include VRS [Gaba D, 2004]. Another well-known classification was proposed three years later by Prof. *Guillaume Alinier* [Table 4, middle column]. It compares the functions of simulators and the degree of instructor involvement in training, as well as the realism of the experience that can be obtained through them [Alinier G., 2009]. Virtual reality simulators in this classification are assigned to the second group only – “screen-based products”.

We have offered in 2012 a new classification of medical simulators featuring seven levels of fidelity [Table 4, right column, and Fig.15] and presented it at several scientific research conferences (Surgicon, Gothenburg, 2012; SESAM-2013, Paris, 2013). This classification is based on the defining characteristic of simulators – the level of didactic fidelity, how realistic are their properties, features, reactions and interactions with the user, their visual, tactile and functional similarity to real life in terms of learning objectives [Maxim Gorshkov, 2012].

However, as virtual simulators have evolved and improved, they have developed a number of properties of their own that were not previously present in physical and mechanical simulation models. As can be seen from the table of three classifications below, these features were not taken into account in the original taxonomies of medical simulators. In this regard, the need for its own classification of devices, which applies only to simulators that model objects exclusively in a virtual environment, has matured.

Table 4. Three classifications of medical simulators

David Gaba, 2004	Guillaume Alinier, 2007	Maxim Gorshkov, 2012
1. <i>Verbal Role playing</i>	<i>Level 0. Written simulations include pen and paper simulations or “Patient Management Problems” and latent images</i>	1. Visual appearance of a person, organs, tissues are reproduced only
2. <i>Standardised patients (Actor)</i>	<i>Level 1. 3D models which can be a basic mannequin, low fidelity simulation models, or part-task simulators</i>	II. Tactile Besides visual, tactile characteristics of the object are imitated also
3. <i>Part-task trainer: Physical; Virtual reality</i>	<i>Level 2. Screen-based simulators. Computer simulation, Simulation software, videos, DVDs, or Virtual Reality (VR) and surgical simulators</i>	III. Reactive The model has the simplest feedback, reacts to the trainee’s typical actions with standardized reaction(s)
4. <i>Computer patient — Computer screen; screen based “virtual world”</i>	<i>Level 3. Standardized patients. Real or simulated patients (trained actors), Role play</i>	IV. Automatic The programmed manifold reactions to various external influences and manipulations. Response is scripted (standard), not calculated (e.g. doses-dependent, etc.)
5. <i>Electronic patient Replica of clinical site; mannequin based; full virtual reality</i>	<i>Level 4. Intermediate fidelity patient simulators Computer controlled, programmable full body size patient simulators not fully interactive</i>	V. Technical Besides of above features simulation device can be “treated” and /or inspected with real medical technic, clinical equipment
	<i>Level 5. Interactive patient simulators or Computer controlled model driven patient simulators, also known as high-fidelity simulation platforms</i>	VI. Interactive Bilateral interaction with a trainee and medical equipment in the form of autonomous individual response to their actions, including haptic (tactile interaction) or doses-dependent calculated physiological changes
		VII. Integrated Complex interaction as a whole system of several simulators of the highest, VI level with each other, trainees, medical equipment, pharmaceuticals and other elements of the external environment

Classification of medical simulators by fidelity levels

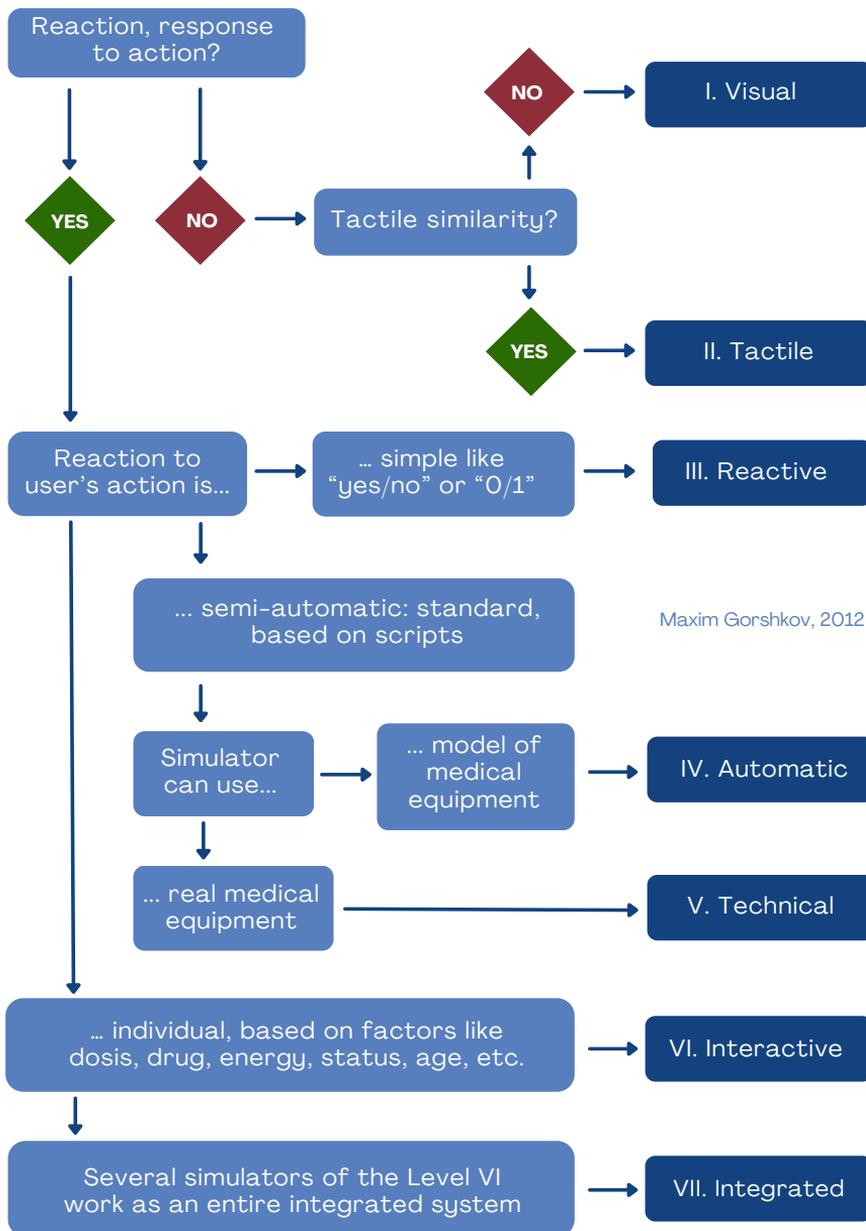


Fig. 15. Classification of medical simulators by fidelity levels

1.6. Classification of virtual reality medical simulators

Virtual simulators can also be characterized by changes in one key property – the degree of interaction with users, their involvement in the virtual world. Taking into account the growth of modeling fidelity, the training tasks grade to be solved, the complexity of the technological solutions used, and most importantly – the degree of the trainee’s involvement in the simulated virtual environment and the level of interaction with its elements, virtual simulators can be divided into the following four or, if we consider the initial zero level, into five levels [Gorshkov, 2017].

Level 0. Devices with passive VR elements

Although the “zero” level is described in this book as part of taxonomy, devices falling into this group are not considered as virtual trainers, but rather as their ancestors. Imitated images, sounds and vibrations can be assigned to this level. There is no interaction between the simulated environment and the user whatsoever. The integrated sensors are of passive type, there is no interaction with the user’s sensory organs; the only thing the user can do is passively observe and hear virtual objects. User’s actions are not logged, and therefore not assessed. The reason, why this group is mentioned in VR simulator classification at all, is the presence of formal signs and attributes of a simulated environment – digital replicas of “medical statuses, processes, conditions, objects, and subjects used for the purposes of education” – as per the definition of the “medical virtual simulators” term provided in “Terminology” section above.

Medical virtual simulators are devices consisting of software and hardware components designed to simulate in a virtual environment interactive medical conditions, processes, conditions, objects, and subjects used for the purposes of education, assessment and research.

So, why can’t we refer audiovisual records to the VRS group? The reason is the lack of the key feature – “interaction and response”, which makes us consider the digital audiovisual teaching aids as forerunners of virtual simulation devices, but not full-scale simulators. Videos and Co. are not interactive – they do not

change under user actions and do not affect the users themselves in any way. In medical education, this level comprises electronic (distance) learning courses with no active or interactive components, which are intended to assist in assimilation of theoretical materials and do not require user interaction with simulators. Examples include video tutorials complemented with comments, flowcharts, 3-D models, and other virtual objects demonstrating the algorithm of the forthcoming procedure or manipulation and hosted on a dedicated or a normal server. Below are the examples of “zero” level learning platforms:

- *YouTube* ([youtube.com](https://www.youtube.com)) is a free video hosting platform that provides users with services for storing, sharing, and playing of videos of various types, length and theme. YouTube has become the most popular video hosting service and the second most visited website in the world. Besides the media for the general public, it also hosts field-specific resources, which makes it one of the most powerful instruments in medical video-based education – over 2.5 thousand medical research articles are dedicated to the usage of this platform in medicine and 1.131 contained the word “youtube” in its title according to the PubMed search on 28 July 2022. It is interesting that the search according to the same criteria, carried out only a year later, showed a significant increase in research publications: 3.107 results are related to Youtube, and 1.422 have this word in the name (July 15, 2023) – within just a year it has grown by 26%.
- *MEDtube*¹ ([medtube.net](https://www.medtube.net)) is a social eLearning platform which hosts industry-specific medical video resources which are free to health care professionals worldwide. In addition to videos, Medtube provides others hi-tech tools for medical education and communications, such as a multimedia library, platforms for collaboration and electronic training, electronic books.
- *WebSurg*² ([websurg.com](https://www.websurg.com)) is a free of charge web-platform, specialized in minimally invasive surgery and dedicated to the promotion of medical and surgical skills training. It was launched by Professor Jacques Marescaux and his team at the *L’Institut de recherche contre les cancers de l’appareil*

¹ MEDtube is a trademark of MEDtube sp. z. o., Warsaw, Poland.

² WebSurg is a trademark of IRCAD University, Strasburg, France.

digestif (IRCAD) in 2000 in Strasbourg and nowadays is the world's oldest and probably most popular online source of endovideosurgical video tutorials, lectures and other educational materials.

- *CSurgeries*³ (csurgeries.com) is a platform specialized on surgical videos, physician owned and operated company that publishes high-quality surgical content that is open to students, residents, surgeons, and patients and covers both basic routine as well as advanced surgical procedures.
- *GibLib*⁴ (giblib.com) is a paid educational, streaming media platform offering an extensive library of medical lectures and surgical video tutorials of 4K in 360 degrees. While viewing a video, the user can change the viewing direction in the 360-degree range, using the cursor, so that not only the operating field, but also the actions of the surgery team could be observed [Fig. 16]. The majority of educational videos show interventions performed by the specialists of *Mayo Clinic*, Rochester, Minnesota, USA. The educational content is addressed to students, physicians, surgeons, physician's assistants, and nurse practitioners.



Credit: Maxim Gorshkov, 2019

Fig. 16. Video streaming educational platform GIBLIB seeks to “modernize surgical training”

³ CSurgeries is a trademark of CSurgeries Inc., North Little Rock, Arizona, USA.

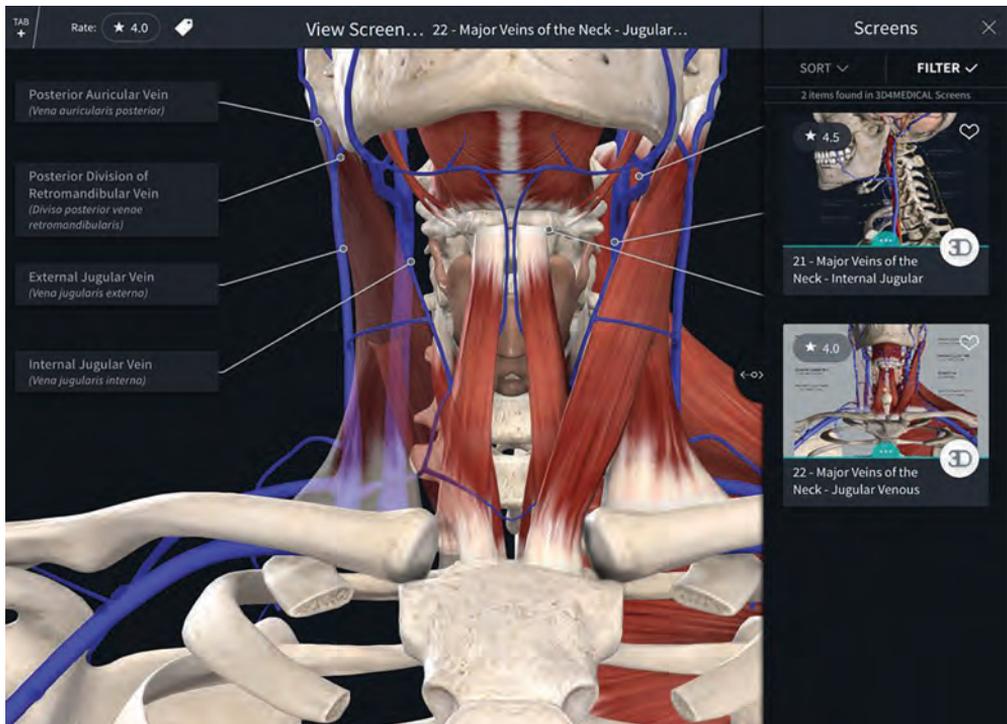
⁴ GibLib is a trademark of GibLib Inc., Los Angeles, California, USA.

Level 1 – Active

Virtual simulators of the first level contain active elements in addition to passive ones. The virtual environment equipped with such elements encourages students to act, while the environment itself remains unchanged. Visual images and acoustic signals are dynamically generated, the system responds to user actions. This is the key property of this level: on the one hand, the system is active, it addresses the user, for example, with questions or offers to choose a variant of further development of events. On the other hand, although the user can control the system e.g., rotating the 3D model to get a better view of it, turning off some of the anatomical layers – the student does not introduce any changes to it. At this level, simulations of pre-clinical and clinical subjects are presented, encouraging the trainee to perform elementary actions that can be assessed. The presence of the scoring system for evaluating the actions of the student is possible feature, but not the necessary one.

Some forms of immersion – cognitive and emotional – can be observed starting from this level already. Such immersion however cannot be regarded as “complete immersion in virtual reality”, rather, it is a kind of “presence effect”, affective participation. There are many examples of virtual simulators with active elements, so below are given just a few of them. They will be discussed in more detail in the next chapter, “Using Virtual Devices in Medical Education.”

For example, the *Complete Anatomy “3D4Medical”* application from Elsevier (Amsterdam, the Netherlands) offers a series of 3D models of both sexes that allow the user to virtually peel off layers and tissues, select thousands of structures of gross anatomy across twelve systems – from the main musculoskeletal and connective systems to the central and peripheral nervous system, as well as conduct transverse topographic sections. A special feature of the system is the presence of interactive functions that help visualize and remember key concepts [Fig. 17]. User can provide the pictures with their own annotations, labels, and sketches, simulate injuries and pathologies, animate pathological areas on it. Another useful feature of the system is the availability of interactive radiology images that can be matched with 3D anatomical models for a deeper understanding of both normal and pathological anatomy and radiology.



Credit: <https://3d4medical.com>

Fig. 17. Complete Anatomy 3D4Medical, interactive training program in anatomy

Level 2 – Interactive

As in the previous group, virtual simulators of the Second Level can reproduce images and sounds and feature both active and passive elements – and also interactive elements that are added to passive and active ones. It affects not only the virtual environment, but also the virtual objects and processes undergo changes caused by the students' activity.

Such transformation of virtual objects and other elements of simulated reality due to students' actions is observed both at the current (the Second) and at the two subsequent levels. In addition, a mandatory evaluation system is available starting from this level and higher. All actions of the students performed in virtual reality are logged, analyzed and assessed. This level includes a number of devices intended for solving clinical cases – virtual patient-based systems

for practicing diagnosing, clinical decision-making, and dynamic assessment of the patient's condition. One can mention the *BodyInteract*⁵ system [Fig. 18] – a platform for the development of clinical reasoning skills, well-known in the educational community concerned of virtual patients. Developed in 2012, this virtual patient simulator was presented to the international medical simulation community in 2016 at the IMSH conference in San Diego, and soon started to be used in the medical schools world-wide. In its first version, the simulator was presented on a horizontal



Credit: Maxim Gorshkov, 2016

Fig. 18. Discussion of a clinical case, presented on a BodyInteract virtual patient

touch screen, simulating a bed with a patient lying on it. Currently, mobile versions of the application are available, provided with physiology models and allowing the students to solve several hundred clinical cases in dozens of specialties. Virtual patients are described in more detail in the next chapter. Apart from virtual patients, this level also features “virtual simulators” – firmware solutions for practicing algorithms for various procedures and manipulations, and “virtual clinics” for making management decisions, inventing strategies for administering healthcare facilities.

Level 3 – Immersive

In this group of VR simulators, in addition to images and sounds, signals recognized by tactile and proprioceptive organs, are reproduced. In combination with 3D images, these features increase the degree of student involvement in the virtual reality to the degree where an “immersion effect” occurs. Techni-

⁵ BodyInteract is a trademark of Take the Wind Lda., Coimbra, Portugal.

cally, this is achieved through the use of a more sophisticated user interface for data input and output (using gestures, speech, motion sensors, pressure, stretching) and realistic virtual environment (3D screens, virtual reality and augmented reality glasses, haptic effectors). Just like at the previous levels, here simulator capabilities are also represented by passive, active and interactive elements. In addition to these elements, “superactive elements” are available here, which are not only subject to changes throughout the simulation session, but also counter-react and affect the user or the real environment. At this level, virtual simulators for training complex practical skills are widely represented. Some of them are equipped with haptic devices – manipulators with tactile feedback. The microprocessor-controlled simulator recognizes the interaction of a simulated instrument with a virtual organ and calculates tissue resistance and other physical parameters, which have to be met through the use of mechanical joysticks with servos. Some of them are made as surgical instruments fitted with real instrument parts – handles, control elements, etc. Students not only see the instrument contacting the tissue on the screen, but also get a realistic feeling of their hand interacting with the organ. For example, when trying to pass an instrument through a virtual liver, they would feel the resistance from simulated tissues, and when pressing hard on the bone, the cutter is

blocked until it stops completely due to simulated “friction.” A specific example of such a simulator with superactive elements is the LapSim laparoscopic virtual simulator with tactile feedback, which realistically reproduces the course of endosurgical interventions. Its curriculum offers the students to begin with the training of basic endosurgi-



Credit: Maxim Gorshkov

Fig. 19. Interaction of haptic gloves with a VR helmet and hand positioning cameras

cal skills, such as bimanual coordination, laparoscope navigation, handling delicate tissues, clip application, and finish with a course of surgical interventions in abdominal and bariatric surgery, urology and gynecology. When performing simulated interventions, instruments that tighten endoscopic nodes or stretch the intestinal mesentery encounter a noticeable tension on a non-existent thread or virtual tissue.

Another option for simulating tactile sensations is a high-end mechanical device in the form of gloves equipped with sensors and servos – simulated interaction of hands with the patient's body or instruments is accompanied by 3D images displayed in VR glasses [Fig. 19].

Level 4 – Global, the highest

Due to the involvement of all sense organs without exception, the immersion should be achieved by almost 100%. During the simulation session, the student is completely disconnected from the outside world, which is replaced by virtual reality. None of his sense organs, not a single receptor system, including thermoceptive and equilibrioceptive, receive signals from the real world. Everything that happens around – visuals, sounds, noises, taste, color, smell, touch, and movement – all environmental signals are generated by a computer processor. The reality around ceases to exist, and instead of the “immersion effect”, we can talk about the effect of “global dissolution”, when a person feels his presence in the virtual world only. With due realism in the development of didactic content and its virtual implementation, practical experience and emotional experiences obtained in a global virtual environment should correspond as much as possible to real practical experience. Interaction with virtual reality is carried out using the same interfaces as in a real environment, for example, a conversation is conducted with a virtual patient (voice commands), virtual medical equipment is controlled by buttons or from a touch screen, and tissues are sutured using a virtual needle and needle holder (reproduced using haptics with feedback).

Such systems are already used in military, aviation, and space industries, but in medical education they are just making their first steps and exist as pilot projects or beta versions only. An example of such a system is the TraumaVR simulator demonstrated by Surgical Science at “the hottest SESAM conference”



Credit: Maxim Gorshkov, 2022

Fig. 20. Immersive system for practicing manipulations on a trauma patient in a combined physical and virtual simulation environment (Surgical Science booth, SESAM-2022)

in over 40°C Sevilla in 2022 [Fig. 20]. The platform consists of the following components: a torso and head with realistic airways to interact with the user and provide passive haptic feedback; virtual reality glasses; a set of video cameras for tracking the user's movements from different angles, as well as medical instruments and accessories in the user's hands; a computer and additional monitors; electromagnetic tracking system for auxiliary devices; simulated laryngoscope, endotracheal tube, stethoscope, suction tube, breathing bag. The combination of a physical simulator and virtual reality environment gives the users an opportunity to gain psychomotor skills and cognitive competencies as well as master airway management procedure – all while being in a stressful situation, in a highly realistic virtual environment.

This is an example of a qualitatively new level in the training of paramedics and intensivists. The global level simulators would perfectly fit in comprehensive training programs with a stronger emphasis on non-trivial situations and environments, requiring lots of movement, since they enable the students to practice various professional activities, such as clinical decision-making, performing manipulations, managing resources in a crisis, interacting with the team members – all at the same time. The main features and characteristics of virtual reality simulator levels are summarized in Table 5.

Table 5. Classification of virtual reality simulators

<i>Level, Interface</i>	<i>Elements</i>	<i>Immersion</i>	<i>Simulated</i>	<i>Interaction</i>
0. Passive Input: keyboard, mouse, touch screen Output: Screen	Passive	No	Image, sound	No interaction with user – it is not a simulator
1. Active Input: keyboard, mouse, touch screen Output: screen	Passive, active, interactive	No	Image, sound	Virtual environment reacts to the actions of the learner but remains unchanged
2. Immersive Input: keyboard, mouse, touch screen, voice, gestures, motion and pressure sensors Output: 2D and 3D screen, virtual glasses/helmet, haptic devices	Passive, active, interactive and superactive	Cognitive, emotional, sensorimotor	Image, sound	The virtual environment is dynamic and interactive – not only responsive to the learner, but also transformed by the actions of the learner (2, 3, 4). At this level and higher, the evaluation system is mandatory
3. Immersive Input: keyboard, mouse, touch screen, voice, gestures, motion and pressure sensors Output: 2D and 3D screen, virtual glasses/helmet, haptic devices	Passive, active, interactive and superactive	Cognitive, emotional, sensorimotor	Image, sound, tactile and proprioceptive signals	Change of virtual objects as a result of the student’s actions and reciprocal effect of the virtual environment on the real one. The effect of immersion in the virtual environment is observed
4. Global Input: devices for recognition of speech and movement commands and manipulations performed Output: virtual reality helmet, complex haptic devices, proprioceptive simulators, odor generators	All four types of elements provide 100% substitution of real environment with the virtual one	Cognitive, emotional, sensorimotor, spatial	Simulated signals are perceived by all human senses	In sensations of the learner the real environment ceases to exist, and immersion in the virtual environment is replaced by dissolution, total fusion with it

2. Application of VR in Medical Education

In the previous part, constructional design, classifications, and applied use of virtual reality simulators in medical education have been reviewed. This section aims to provide a systematic review of the aforesaid, discuss the principles and recommended practices for the application of virtual reality devices in medical education and to define the advantages and disadvantages of the associated processes.

Like any other learning technology, virtual reality medical training using screen simulators, virtual simulators, interactive digital patients, has its own peculiarities. Digital devices may vary greatly in terms of technological capabilities determined by their design, and methodological characteristics, especially in the context of various preclinical and clinical disciplines.

The development of a virtual reality lesson using a VR trainer or a digital patient for training clinical reasoning skills, consists of the following steps:

1. Determining learning objectives and lesson goals
2. Defining assessment criteria and competence levels
3. Reviewing, piloting, audit of the VR lesson
4. Curriculum integration
5. Teacher training, induction course
6. Feedback, correction work

Learning objectives and lesson goals. The first step in the development of a lesson using VR devices is to define learning objectives and goals of the virtual lesson, clarify and discuss the reasons behind the choice of a particular digital simulation technology. Learning objectives determine what is to be accomplished through the training, what knowledge, skills, and competencies

students have to master and how they will be assessed upon completion of the training process, for example, “Mastering the diagnosis of pneumonia” or “Practicing endosurgical suture skills.” Educational goals set to students represent specific activities or competencies that students must complete or achieve to acquire the necessary knowledge and skills; they are a means of achieving learning goals and provide a structured approach to learning. Educational goals are essential for guiding both teaching and learning processes, offering a clear pathway toward achieving desired educational outcomes. Examples of the lesson goals are: “Collect anamnesis; conduct a physical examination of the patient, including percussion and auscultation; make a preliminary diagnosis” or “Develop bimanual coordination while placing intracorporeal knot sutures with two endosurgical needle-holders; learn fast and secure suturing; regard the safety of surrounding tissues.”

Defining assessment criteria and competence levels, as well as quality of assimilated knowledge is a crucial component in the development of a lesson or an entire educational program. In the formation of competencies, criteria for achieving learning objectives and a given level of competencies should be provided or developed. For students, the highest degree of mastering a skill is practical mastering of the procedure, which implies a conscious demonstration of its proper form to solve a specific professional task (“shows” according to Miller); for practicing specialists it can and should be not only practical mastering, but also application of the mastered skill in practice (“does” according to Miller) and improvement of outcomes – clinical indicators (“results” according to Kirkpatrick) [Kirkpatrick DL, 1959; Miller G, 1990].

Defining key indicators allows the trainee to understand what is expected of the lesson, what means will be used to monitor the progress, and what is meant by successful accomplishment of educational goals. This allows, if necessary, to adapt the learning material and adjust the pace of increase in difficulty levels of the task. One cannot overestimate the importance of knowing evaluation criteria from the point of view of the andragogy principles. If well understood, they motivate the students to consciously and purposefully pave their way for better results, to improve competencies, consciously focusing their efforts on key aspects of the lesson. Defining criteria helps to make the assessment process more objective and structured and therefore more fair and reliable. Understanding educational goals and criteria for

achieving them helps to better organize and structure the theoretical material and practical tasks, thus contributing to the effective implementation of the task.

Criteria of educational goal achievement should be objective and measurable through suitable evaluation methods. For instance, students' knowledge can be gauged through computer MCQ tests, whereas their cognitive abilities can be evaluated by having them run through clinical scenarios using virtual simulation technology. Additionally, one can assess students' skill level by observing their practical demonstrations either at the bedside in real-life clinical settings or within virtual and physical simulated environments.

Modern digital technologies enable implementation of all these options using a single device, a unified platform, including assessment of knowledge through testing, assessment of cognitive and manual skills, including communication,

diagnostics, and treatment, performing medical manipulations – through the execution of virtual cases, tasks, exercises. Target indicators and assessment activities, as a rule, are already included in the simulator software, e.g. “during the execution of the scenario in a precisely specified sequence, conduct a patient interview, examination, physical examination, accurately describe the identified symptoms, locate auscultatory noises, select the correct treatment options” or “make an interrupted surgical suture in a secure manner, causing minimal trauma to the tissues.” Upon completion of the simulated case,



Credit: Maxim Gorshkov

Fig. 21. Manipulators that are capable of transmitting hand movements into a VR environment suggest quantitative measurement of movement parameters, enabling therefore the creation of a system of objective assessments of task performance

the student receives a detailed report indicating incorrect actions, errors, inaccurate answers, or assignments, untimely or unnecessary steps. Of course, this report is also available to his teacher. In this case, the teacher must decide whether the assessment system embedded in the virtual system meets his requirements and whether it needs to be complemented or modified.

The review, piloting and audit of the virtual clinical case begins with the previous two steps. Here it is necessary to obtain the approval of experts who confirm the reliability and plausibility of the case (so-called *expert validity*), to obtain confirmation from reviewers that the created scenario corresponds to authoritative sources – generally recognized protocols, clinical guidelines (*content validity*). Often equally important will be the question of whether the materials that form the basis of the scenario are consistent with those accepted by the institution. If this is not the case, the developer should be contacted with a proposal to make appropriate changes to the program – failure to do so may result in objections and appeals in examinations.

In general, the issue of comprehensive validation of both the virtual teaching aid itself and the assessment system embedded in it should not be underestimated. High-tech virtual systems are developed by large teams, most of which are programmers, roboticists, engineers, 3D-modellers, and computer scientists, who do not have proper medical competence. Any mannequin or virtual simulator is doomed to be wrong at first and only later, through multi-stage refinement, are the noted deficiencies and mistakes eliminated. Medical institutions pay great attention to the issue of validation – proving the effectiveness and practical value of using a simulator or methodology that plausibly models the patients and their pathology within the framework of the training task and the reliability and accuracy of the assessment made with their help. An improperly trained physician and unfairly admitted to medical practice can do more harm to the patient than a merely inexperienced one.

In 2005, the *European Association of Endoscopic Surgeons (EAES)* commissioned a working group of endoscopic surgeons with both educational and clinical experience to develop consensus guidelines for the validation of virtual reality surgical simulators. [Carter, FJ et al., 2005]. This document identifies a number of variants of the virtual laparoscopic simulator validation process (which can be applied to other medical specialties) and distinguishes

the following validity categories: face, content, construct, competitive, discriminatory, and predictive validities (for more please refer to the Section 6.2.). To date, however, this document remains informational and advisory in nature, and there are still no uniform standards or authorities for certification of medical simulators similar to EMA¹, FDA², or NMPA³. As a result, when a virtual model or patient simulator vendor claims that their device has a “credible mathematical model of physiology as good as the state-of-the-art analogs” from leading manufacturers, you either have to take their word for it or rely on the opinion of colleagues who have already operated identical devices.

Curriculum integration. An important issue is the inclusion of training using a virtual patient or VR simulator in the educational program, allocation of training hours, facilities, equipment and educators in the schedule. These issues are extremely diverse and depend on the level of technical facilities, the target student group, the medical specialty. Such lessons, similar to other simulation sessions, should generally be classified as “clinical practice in a simulated environment”, and when developing the curriculum, it should be considered as a workshop, which differs from its classical format only by describing the educational technology required. But we should not forget that more and more theoretical issues, both in preclinical and clinical disciplines, are brought to learners today in a digital space.

Teacher training, induction course. The implementation of the plan depends on the interaction of simulation training specialists with clinicians and employees of specialized departments. To provide a lesson using virtual patients, a simulation specialist will need not only methodological and medical knowledge, but also certain technical competencies, especially when working in an immersion environment using VR goggles or complex VR simulators with haptic effectors. Even if this department or educational

¹ The European Medicines Agency (EMA) oversees the regulation of medical devices in Europe (ema.europa.eu).

² The Food and Drug Administration (FDA) is responsible for the registration and regulation of medical devices in the USA (fda.gov/medical-devices).

³ The National Medical Products Administration (NMPA) is the authority in China that handles the registration of medical devices (english.nmpa.gov.cn).

unit has technical staff, the teacher may be required to be able to restart the computer, change the WLAN network, log in, pair glasses to each other, update the application, etc. The highlighted in violet text below quotes the opinion of the *ChatGPT* artificial intelligence on the professional skills and competencies required for a teacher to conduct a VR training.

List of competencies that might be necessary for an instructor conducting a VR-based class:

Medical Knowledge Application: The instructor must be able to apply medical knowledge within the VR environment, tailoring scenarios to teach specific medical concepts and procedures.

Technical Proficiency: Understanding of how VR technology works, including setting up the hardware (VR goggles, controllers, etc.) and troubleshooting common issues.

Content Expertise: Ability to develop or select appropriate VR content that aligns with the learning objectives and enhances the educational experience.

Pedagogical Skills: Knowledge of instructional strategies that are effective in a VR learning environment and the ability to integrate VR activities into the broader curriculum.

Student Engagement: Skills to engage students in a VR setting, including managing the class dynamics and facilitating interactions within the virtual environment.

Assessment Capability: Ability to assess and evaluate student performance in a VR context, which may include alternative forms of assessment suitable for virtual environments.

Safety Awareness: Understanding of the safety considerations specific to VR use, such as preventing motion sickness and ensuring physical space for movement.

Ethical and Legal Awareness: Knowledge of the ethical and legal implications of using VR, including privacy concerns and content appropriateness.

Inclusion: Competency in ensuring the VR experience is accessible and inclusive for all students, taking into account diverse needs and potential accommodations.

Facilitation Skills: The ability to facilitate discussions and debrief sessions post-VR experience to reinforce learning outcomes and critical thinking.

These competencies ensure that VR-based classes in medical education are effective, engaging, and aligned with the goals of preparing students for clinical practice.

[ChatGPT-4, generated on November 6, 2023]

Feedback with follow-up adjustment of a lesson plan or virtual training program are an integral part of the modern high-quality and effective educational process. Providing feedback after completion of an educational activity is an important and necessary step in the educational process for several reasons. First, it allows the teaching staff to evaluate how successfully the lesson was conducted, whether the educational goals have been achieved, how well the learning material has been assimilated, the level of student progress. It allows the simulation specialist to identify problems and find ways to overcome them,

provides information about what can be changed, improved, and helps to adjust the educational process in order to increase its efficiency and effectiveness. Finally, providing feedback demonstrates the teachers' attention to students and their learning, helps to establish trusting relationships and positive climate in the classroom.



Credit: Maxim Gorshkov, 2023

Fig. 22. Hybrid simulation training of gynecology examination

2.1. Use of VR devices in medical education

The first and foremost question that arises when assessing the prospects for using virtual reality technologies is whether they can be used in medical training at all and whether they represent a valuable tool for gaining knowledge, skills and abilities in the field of healthcare. Although the answer is apparent, this issue has been extensively researched, and the authors of the relevant studies have repeatedly received a positive answer to this question [Buyego et al., 2021; Herbst et al., 2021; Petrica et al., 2021]. “Virtual reality is a useful tool in medical education which can be effectively applied to practice professional skills in a wide range of disciplines, including emergency medicine, nursing, pediatrics, radiology and cardiology” [Pallavicini F et al., 2022].

In general, virtual systems enable integration at all levels of education, incorporation in curricula in all preclinical and clinical disciplines without exception, using it as teaching aids to deliver learning content (texts, video files, audio recordings, tests), assessing the level of mastery of competencies (including assessment, testing, as well as attendance, duration of activity, academic performance), tracking learning progress, managing educational process at the individual level and also solving general management tasks, serving as a means of communication for participants in the educational process (video lectures, chats, blogs, groups). With the help of virtual education systems, students gain fundamental communication skills, learn procedures and protocols for various activities, medication dosages, hone their practical skills in performing manipulations, diagnostic and therapeutic procedures, surgical interventions, improve cognitive skills, including aggregate competencies, such as clinical thinking or making complex decisions in stressful situations, learn to interact with team members.

When creating a lesson that incorporates virtual simulators or patients, educators should adhere to the fundamental principles of simulation-based training, as this method is simply a technological branch of simulation training. Undoubtedly, the pinnacle of training in clinical disciplines is direct interaction: learning by the patient’s bedside, engaging with actual people, and conducting clinical examinations. There’s no need to contrive scenarios, select tools, or set up a specific environment – the clinical educator merely needs to obtain the patient’s medical history and invite students proceed to the hospital ward.

Nonetheless, this traditional approach encounters several substantial challenges: the curriculum is typically established well in advance, and while it aims to provide a logical educational sequence, students may encounter the difficulty of not finding a patient with the necessary diagnosis as stipulated by their curriculum. This educational model also offers minimal flexibility to address the unique requirements of each student. Moreover, patients even in the university teaching hospitals are increasingly reluctant to participate in educational sessions, particularly those involving painful, embarrassing, or risky procedures. Occasionally, students are expected to differentiate between diseases with similar manifestations within a single lesson, but finding such patients simultaneously is often impractical. Consequently, without the availability of these specific clinical cases, practical training is diminished to merely a theoretical discussion of the subject, which does not adequately equip future practitioners with the hands-on experience they need.

Virtual reality technology extends beyond educational applications in colleges and universities. It serves as a valuable tool for introducing medical careers to schoolchildren, enriches the historical exhibits in medical museums, and is effective for instructing individuals in first aid and CPR. Furthermore, it is instrumental in evaluating professional skills during recruiting processes, assists in the onboarding of new staff, and helps healthcare professionals acquaint themselves with novel equipment or procedures in hospital settings. Additionally, it provides a virtual practice ground for surgeons to “warm up” prior to operations, allows for the simulation of planned medical procedures, and supports clinical studies and fundamental scientific research.

Anatomy, embryology, histology

When studying anatomy virtually, in addition to providing textual and visual information, effective and visual presentation of the learning material, it is necessary to create numerous visual and terminological connections for the student and carefully track the mastery of the program. A group of students crowded around a cadaver, one of whom was reading the corresponding chapter aloud, and the other, under the guidance of a professor, was dissecting the corpse – this picture was typical of anatomy classes in Renaissance universities. Today, anatomy lessons are represented by a combination of several didactic techniques: personal participation in the dissection of a corpse; working with dummies, models, and anatomical specimens;

studying textbooks and anatomy atlases; examining 3D images of anatomical structures, their relative positions, and interactions in virtual environment. Faculty members explain the academic material in lectures and classes, and the rest of the time is devoted to independent work using approved textbooks that have become famous for generations of physicians – Gray, Netter or Sobotta – in both paper and online formats. The more convenient, informative, visual and interactive digital aids become, the more the share of electronic rather than paper-based formats increase. During cadaver labs, students perform dissection of the specimen in an established sequence – limbs, torso and internal organs, studying all sections of the discipline, from osteology to neuroanatomy. However, one cannot embrace all anatomy after just one dissection; not everything can be seen in one cadaver, so classic teaching aids – posters, dummies, and fixed anatomical specimens – come to the aid of future medics. Moreover, even the dissection course can now be taken partially in online form [Fig. 23]. But no matter how respectable the textbooks and realistic the moulages can be, it is impossible to create and consolidate several thousand associative links with their help alone – there is too much information to digest and the level of complexity of the tasks is

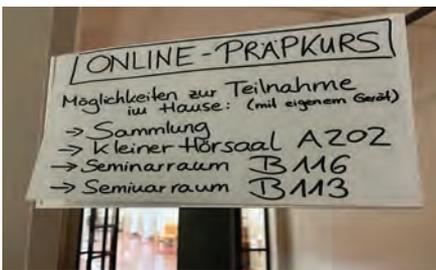


Fig. 23. In the unique historic building of the Royal Anatomical Institute (1907) of the Ludwig Maximilian University of Munich, where the flower petal-shaped semicircular rooms for thirty dissection tables are arranged, a dissection course in online format is offered in addition to the face-to-face course. The announcement says that the “Online Präpkurs” can be taken either at home, on a personal device, or provided in a few listed premises at the institute



Credit: Maxim Gorshkov, 2023

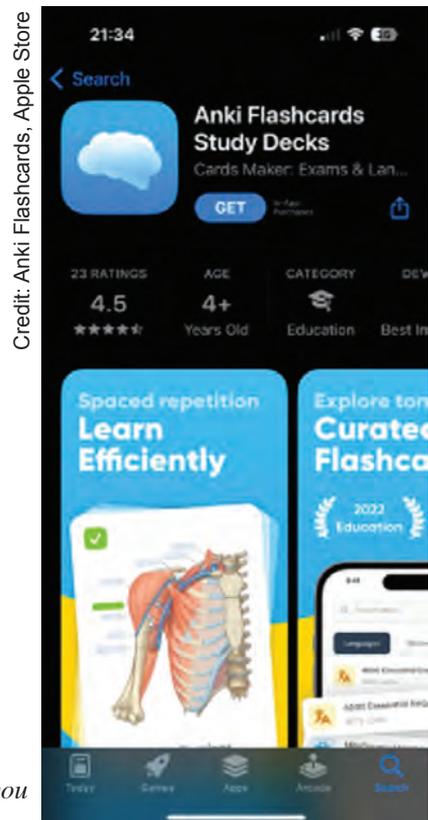
too high. Perception, comprehension, and memorization come as a result of dynamic actions, during which objects, phenomena or concepts evoke the formation of associative connections, that afterwards help to bring up the names and images associated with them. In the context of anatomy, whole chains of visual images need to be composed with associated terminological designations, that can be reproduced in both directions – “find and show the named structure” or “name the shown one.”

This only occurs with multiple interactive repetition – in the traditional version under the guidance of a teacher, and nowadays, with the help of a virtual program that takes into account gaps in the student’s knowledge and repeatedly shows or asks for structures over and over again, eventually selecting them only from a list of unlearned material, thus ensuring that a particular image is associated with the corresponding symbol. A Spaced Repetition System (SRS) applications designed for enhance information retention efficiently are of great help. They employ statistical algorithms to determine the most effective intervals for reviewing material, ensuring that learners encounter information just when they need to for optimal memorization [Fig. 24].

Below, we list some mobile and web apps that can aid in learning anatomy, arranged alphabetically. Since the complete collection has hundreds of programs and is continuously updated, it is impossible to list them all here. We only mention a few of the most popular ones.

- *3D Anatomy by Education Mobile*, Guildford, Surrey, UK

Fig. 24. An example of a Flashcards app that helps you efficiently memorize large anatomy data sets



- *Anatomy 3D Atlas* by *Catfish Animation Studio*, Milan, Italy
- *Anatomyka* – 3D anatomical atlas from *Woodoo Art s.r.o.*, Bratislava, Slovakia
- *Anki Flashcards*, an open-source project created by *Damien Elms* in 2006, is now very widely used by the medical and linguistic students. NB! Beware of copycats using the name “Anki” to take advantage of brand recognition but not belonging to the Anki community
- *BioDigital Human* – 3D human anatomy from *BioDigital*, New York, New York State, USA
- *Complete Anatomy* – by 3D4Medical from *Elsevier*, Amsterdam, Netherlands
- *Daily Anatomy Flashcards* from *Kenhub GmbH*, Berlin, Germany
- *e-Anatomy* by *IMAIOS SAS*, Castelnau-Le-Lez, France
- *Human Anatomy Atlas* by *Visible Body*, Boston, USA
- *Netter’s Anatomy* by *Skyscape Medpresso Inc.*, Marlborough, Massachusetts, USA
- *Teach Me Anatomy* from *TeachMeSeries Ltd.*, Thetford, Norfolk, UK

Some virtual anatomy training systems are represented not only by mobile applications. There are massive stationary platforms based on touch tables and virtual whiteboards that can be used in classrooms and lecture halls:

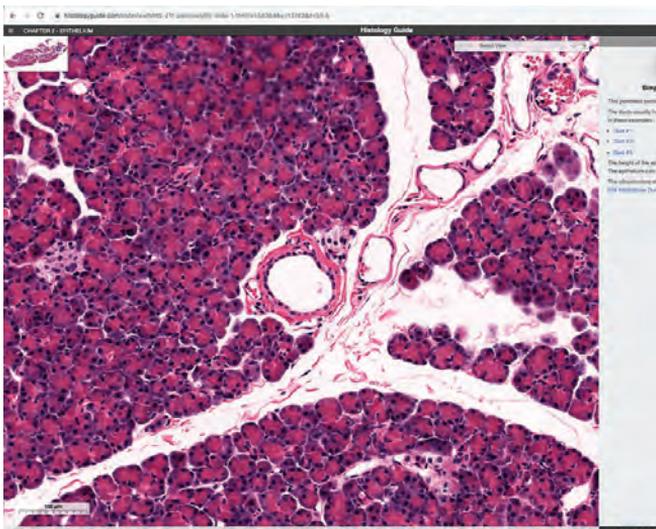
Credit: Maxim Gorshkov, 2022



Fig. 25. Anatomage, virtual anatomy unit, touch-screen table solution

- *Anatmage*¹ is a 3D anatomy visualization and virtual dissection tool for teaching anatomy and physiology, designed to enhance cadaver lab group lessons. Interactive 3D anatomy and cross-section images are presented on a large touch screen table that can be fixed vertically (depicting a standing person) or horizontally, like a section table with cadaver [Fig. 25].
- *SECTRA*² is yet another example of the concept of interactive virtual anatomy in solid stationary design. It provides interaction with virtual representations of real-life bodies and their structures based on clinical imaging of real patients (CT, MRI) stored in the cloud. Together with interactive 3D-anatomy images and sections their original CT-scans and high-resolution microscopic histology images are available.

The development of visual-verbal or visual-terminological associations in histology and pathmorphology is no less difficult task than in anatomy. Matching whole organs, body parts, bones or macroscopic fragments of body organs is one thing; doing the same with microscopic images, often painted violet, which is unusual to the inexperienced eye of a yesterday's secondary school student, is something quite different. Unfortunately, only few digital



Credit: histologyguide.com

Fig. 26. Virtual microscopy

¹ Anatomage is a trademark of Anatomage Inc., Santa Clara, California, USA.

² Trademark of Sectra AB, Linköping, Sweden.

textbooks in this discipline are provided with interactive components for better comprehension of the didactic content. Most web resources only have a series of microphotographs with scant captions or, conversely, extensive text arrays, slightly “diluted” with test questions – and no signs of any interactivity!

An example of a free specialized resource is the English resource in the Internet, *histologyguide.com* allows users to access an interactive atlas of histological images without registration (authors: *Robert L. Sorenson and T. Clark Brelief*, Minneapolis, Minnesota, USA). Over 250 microscopic slides can be studied there online, with search and zoom-in options available for a number of labeled structures.

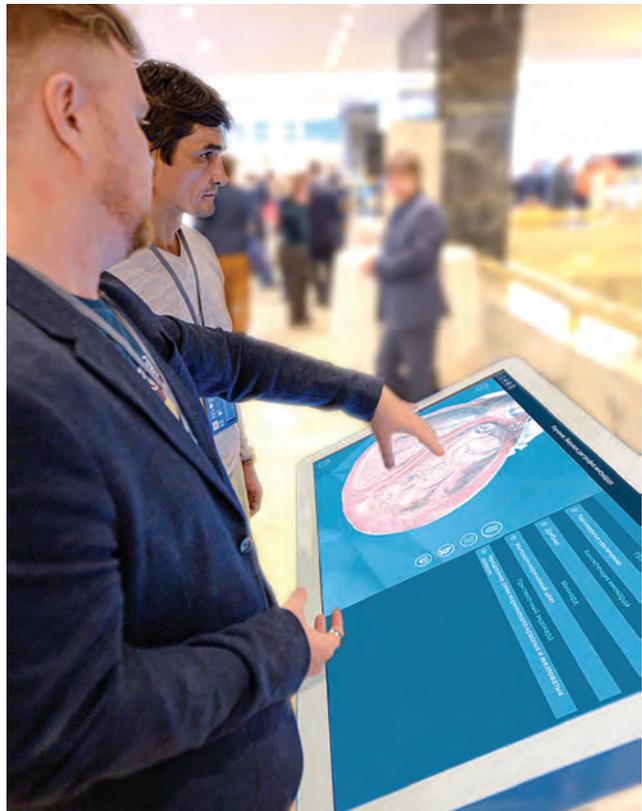
An illustration of a joint development of several universities is the digital educational project on histology and pathomorphology *MyMi.mobile*. The platform was originally created in 2014 at the *University of Ulm* (Baden-Württemberg, Germany), and over the years other German-speaking universities have joined the project – in Freiburg, Bochum, Münster and two universities in Zurich. Students of these institutions study histology not only during classroom lessons, but also at any convenient time using their personal devices. In *MyMi.mobile*, annotations are used to replace verbal comments of the tutor – each drug is provided with a text. Each comment is expandable for detailed description.

Virtual high resolution microscope allows the user to zoom in/out the images and offers options “Search Structure” for fixing images in visual memory, and “Make a diagnosis” for forming an associative link between the cellular structure and function. Due to the modular design of the platform, each university participating in the project can add their own microscopic specimens, which allows them to preserve their identity and teaching culture of each of them, promotes unification among research schools instead of opposition or standardization, and leads to further collaboration. It is clear that joint projects of this kind save money and increase the efficiency of personal effort of each participant.

The Pathology 3D³ program offers even more unusual feature – the ability

³ Pathology3D is a trademark of DreamLight Ltd., Astana, Kazakhstan.

to add pathological changes and use manual settings (slider) to enhance their severity at the macro level with demonstration of various tissues at the microscopic level. With the help of these functionalities, users can deliberately study changes in the tissues and cells of the body caused by various pathological processes, and analyze structural changes that are characteristic of various diseases at the cellular, tissue and organ levels.



Credit: DreamLight Ltd., Kazakhstan

Fig. 27. Interaction with macro- and microscopic pathological specimen in digital 3D

Physiology

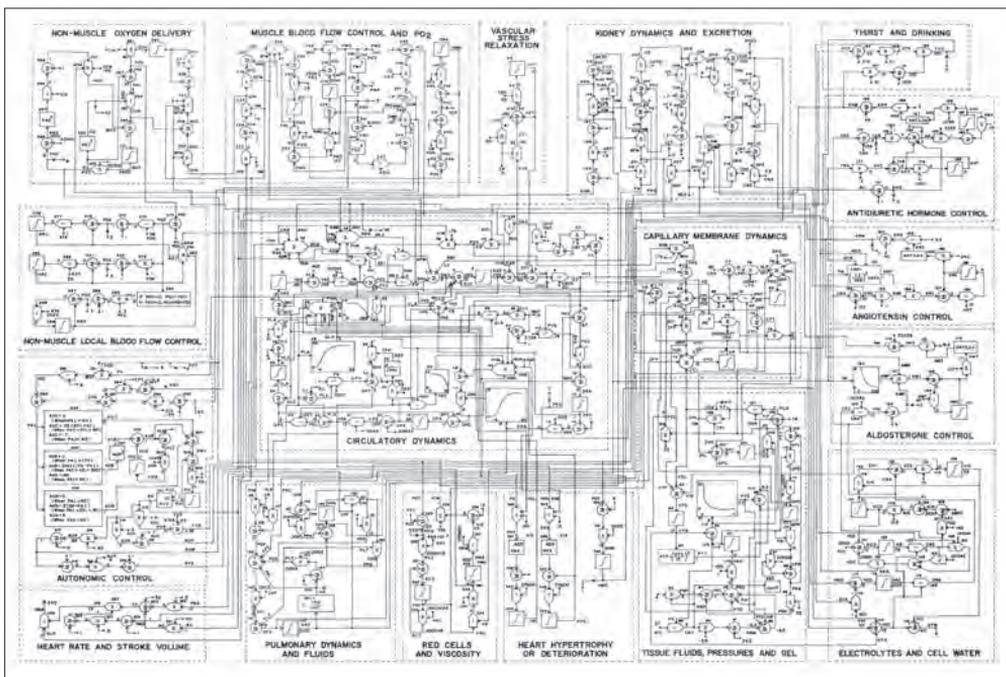
Today, educators have at their disposal more than a dozen virtual reality systems that simulate human physiology. Some of them are integrated into complex firmware units, are part of patient simulators of the highest class of realism, others are built into software versions of virtual patients or are accessible via subscription to an online resource.

Though not yet a virtual model, the first mathematical method of analyzing physiology was the work of English physician *William Harvey* (1578–1657). Observing the work of the heart in living animals, he made a mathematical calculation of cardiac output, according to which the minute volume of blood was so large that such a quantity could not, according to the teachings of Galen, be created in the liver and assimilated by human tissues. By mathematical method he justified his assumption that the blood pushed out by the heart circulates through the body and returns to it. In Chapter 8 of “*De Motu cordis*”, Harvey wrote: “how great the amount of transmitted blood would be [and] in how short a time that transmission would be effected... it might rather have a certain movement, as it were, in a circle.” [Harvey W, 1628].

The first mathematical models of physiology appeared in the late 1960s and early 1970s, both as separate software systems and as part of the computerized mannequins, such as the full-size mannequin *Sim One* for anesthesia designed at the *University of Southern California* (Los Angeles) by engineer *Stephen Abrahamson*, and doctor-internist *Judson Denson*. That simulator had a system for recognition of the medicines from an extensive list and reacted to their administration. The mannequin was designed for practicing airway resuscitation techniques, in particular the trachea could be intubated using a laryngoscopy technique. The simulator was controlled by a hybrid analog-to-digital computer “with a memory capacity of 4096 words” – this computing machine occupied an entire room.

In 1972, *Arthur C. Guyton*, et al. published a large computer model of the cardiovascular system consisting of about 450 mathematical equations covering the interaction of 14 subsystems and processes such as oxygenation, cardiac dynamics, hormones, metabolism, renal excretion, etc., aimed primarily at understanding the long-term regulation of blood pressure and

cardiac output [Fig. 28]. The publication of the circulatory model paved the way for new thinking in analyzing the regulation of cardiovascular dynamics. The model was originally written in the *FORTRAN* language and later ported to a personal computer environment. Today, the reviewed and enlarged by the team of the *Department of Physiology of Mississippi University* the model is available on the *JustPhysiology*¹ website in a modern and expanded form. This is an online learning resource composed of interactive experiments, offers the student to explore human physiology by pairing an intuitive user interface with a “faster-than-real-time mathematical model”, designed for use by undergraduate students in biomedical engineering, biology, nursing, physical therapy and, of course, physiology.



Credit: Department of Physiology UMMC, Jackson, MS, USA

Fig. 28. Guyton–Coleman mathematical Model of physiology, 1972

¹ JustPhysiology.com, Copyright of HC Simulation LLC, USA.

A *Stanford University* research group created an android simulator called *CASE (Comprehensive Anesthesia Simulation Environment)* in 1986. The development was led by *David Gaba*, Professor of Anesthesiology, who went on to become one of the most prominent and important figures in the simulation community, founder and head of the *Stanford University Simulation Center*, and editor-in-chief of the journal *Simulation in Healthcare*. The *CASE* programming logic was based on scripts describing the variations in expected changes in response to different actions of the trainees, while an experienced anesthesiologist-facilitator observed the simulation and could make corrections into physiological status.

Independently from *Gaba's* group and almost simultaneously with it (1988), the developers of the *University of Florida* (Gainesville, USA) under the leadership of *Joachim S. Gravenstein* created the *Gainesville Anesthesia Simulator (GAS)*, which later became the progenitor of a whole series of anaesthesia simulators produced first by *METI (Medical Education Technologies Inc.)* and now by *CAE Healthcare*, a company of the *Madison Industries* group. The mathematical model of adult physiology was further developed by the group of biomedical engineers led by *Willem van Meurs* and was followed by a pediatric prototype, and then the physiology of a woman in labor, consisting of the interacting systems of mother and fetus that are linked through the placenta into one interacting system. More details on the history of their creation can be found in the book *The dolls' engineer* written by *Willem van Meurs*, which describes the breathtaking history of the design and development of mathematical models of the physiology of these patient simulators [van Meurs W, 2023].

Today, these models are not only part of highly realistic patient simulation robots, but also a stand-alone version of a software educational product – *CAE Maestro Evolve*². This is a virtual reality software system that based on mathematical models of physiological systems allowing users to run simulated scenarios in real time with individual reaction on their activities, such as ventilation, defibrillation, and medications. A standard web interface can be used to establish connection with patient simulator, virtual simulations of pharmacological drugs and clinical equipment that interact with the

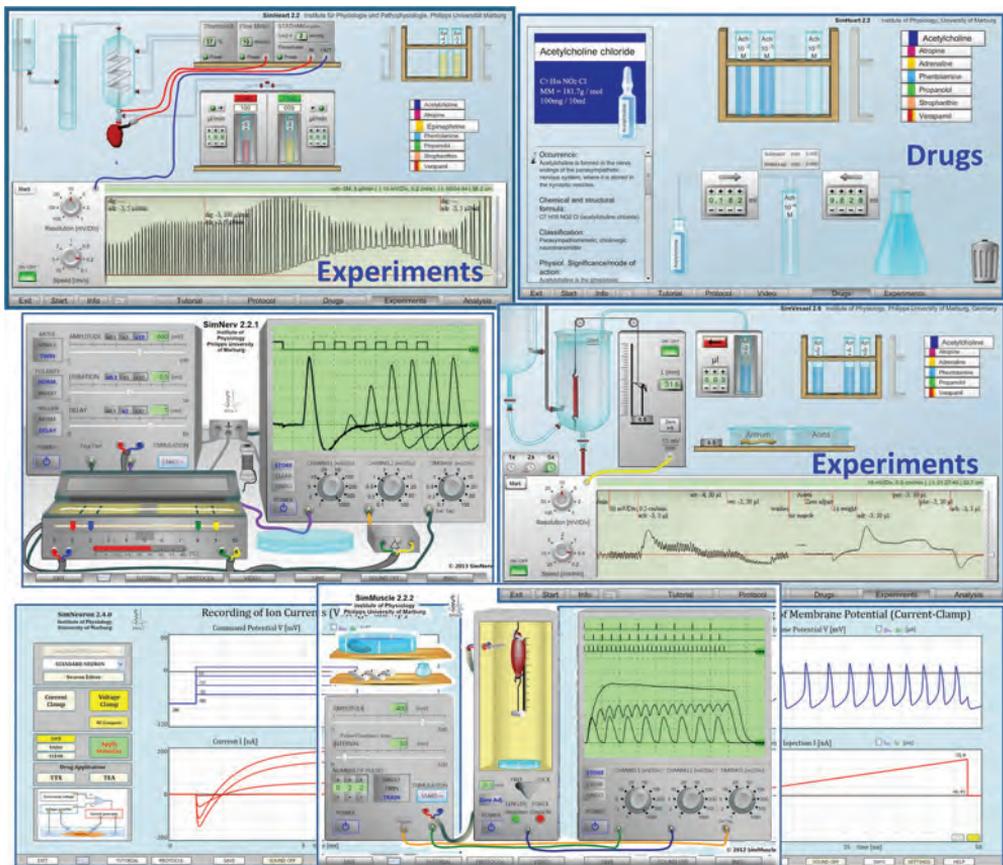
² *Maestro Evolve* is a trademark of *CAE Healthcare Inc.*, subsidiary of *Madison Industries*, Chicago, IL, USA.

simulated organism in real time. The system allows the user to create and edit new patients with various conditions, from healthy to seriously ill, and enables visual demonstration of changes in physiological status during certain pathological processes, for example, show what happens when the volume of circulating blood decreases (simulation of blood loss), a decrease in the partial pressure of oxygen in the air (thin air at high altitudes), heart failure, hyperacidosis, hyperalkalosis, etc. This makes the system an excellent teaching aids in the field of preclinical disciplines – in normal and pathological physiology, biochemistry, and pharmacology, as well as in the teaching of clinical subjects, primarily for gaining diagnosis skills and treatment of emergency conditions, where physiological parameters change quickly and require immediate therapeutic measures.

Well, the last example of a virtual model of physiology in this section, although far from the last of the numerous systems developed and offered in the world today, is simply just called “*Virtual Physiology*”. The roots of the development of this system go back to the 1990s, when it was developed by a group of researchers at the *Philipps University of Marburg*, Germany under the leadership of *Hans A. Braun* and *Aubin Tchaptchet*. Its distinctive feature is a slightly playful design of a laboratory, where experiments are conducted as if in a real one, provided with various instruments, apparatus, and devices for conducting physiological research.

This is not the model as described above in *Maestro*, where “all wires and gears are covered under the hood” – as in a real organism, the magic of physiological processes is hidden from our eyes. Here, the model settings are freely adjustable by the trainees, while mathematical algorithms care of correct reactions of the organism. The system uses the didactic principles of problem-based learning, when instead of boring explanations and tedious rote learning is given to practical exercises and fascinating experiments. Following the instructions of the educator, formulating the goal, students can decide themselves how to achieve it, and due to the introduction of white noise of physiological records and the variety of initial data, the results of each learner will differ from those obtained by their comrades, although they will always stay within appropriate limits.

This method encourages active engagement with the functional relationships of biological mechanisms and their reactions to stimuli through hands-on experimentation, rather than the rote learning of concepts. The results of experiments give impetus to reflection, rethinking of experience, abstract conceptualization, transforming into effective mastering and assimilation of the material.



Credit: virtual-physiology.com

Fig 29. Here are some examples of human physiology simulators' screens by "Virtual Physiology" from Marburg University

Basic medical skills and cardiopulmonary resuscitation

Currently, a wide range of medical skills, competencies and individual steps of surgical procedures can be acquired and honed in virtual environment, with the help of virtual simulators. If haptics is available on a simulator – a system simulating tactile contact with a person and his/her organs – a whole array of various educational tasks can be solved, especially those focusing on practicing cognitive or manual skills and abilities. Screen simulators without tactile feedback, implemented on mobile or stationary devices, are often designed to learn a sequence of actions (Standard operational procedures – SOPs, workflow), not an acquisition of real manual skills. The execution of basic routine medical procedures, encompassing both diagnostic and therapeutic interventions, entails a sophisticated and orderly sequence of steps. Each action and its position within this sequence is crucial and must be carried out meticulously. Mastery of these procedures demands repeated and distributed over time practice, which can be logistically challenging to arrange in both clinical and simulated environments, given the need for consumables, phantoms, premises, and critically, the attentive guidance of an instructor for on-the-spot feedback and correction of errors (“immediate feed-back”). In this context, digital systems offer a distinctive “Learn” mode, where a virtual assistant shepherds users through each phase, providing direction and support. This is complemented by a “Perform” mode, in which students navigate through virtual scenarios autonomously, thereafter, receiving evaluations and suggestions for enhancing their performance. Such features of digital systems are invaluable, offering a remedy for the absence of tactile feedback and interaction with real-world objects, thereby enriching the learning experience in medical education. Despite these limitations, the effectiveness of screen simulators has been repeatedly studied and proven – “virtual reality technology has been found to be an effective educational tool for practicing placement of intravenous catheter and drug administration; therefore, it’s application in nursing education should be actively promoted” [Yildiz H, 2022].

A kind of solution to the problem of difficult modeling of haptics in a virtual environment is the technique of *hybrid simulation*, as referred to in the SSH society dictionary – combined use of various modelling modalities, virtual

and physical, such as virtual patients, phantoms, simulators, standardized patients or robotic patient simulators. Some authors call this technique *Simtegration*, by the term created from two words: “*simulation*” and “*integration*” which emphasizes the key feature – seamless combination of different simulation modalities.

The simplest option is parallel use of different modalities in a single simulation case, for example, onscreen running of the “Hemostasis” scenario could be accompanied by chest compressions and ventilations on a physical CPR-mannequin [Fig. 30]. Another example of hybrid simulation is demonstrated in the research carried out by *Osh State Medical University*, aimed at studying the process of development of endotracheal intubation skills with the participation of 203 students divided into two groups. In the experimental group ($n = 101$), training was carried out in two stages – the procedure was practiced using the virtual case “Endotracheal intubation” on the *DIMEDUS* platform, and using a physical phantom, while the control group ($n = 102$) under the guidance of a teacher underwent practical training only on the phantom. Both groups took an exam based on a 19-item checklist to determine students’ competency in the theoretical aspects of intubation techniques, where students in the main group showed significantly higher results as compared to those from the second group (91.0% versus 67.0%, respectively), which testifies to successful mastering of theoretical material in a virtual environment and the feasibility of this technique as an additional teaching aid [Bugubaeva M. M. et al., 2023].

Another more advanced option is the “dialog” between the physical phantom and the virtual patient, where actions performed on the phantom are tracked in the digital environment and mixed into it. Sensors in the real model track the trainee’s touches and actions and send signals via *WLAN* or *Bluetooth* to the computer controlling the virtual patient. In fact, this merging of objects from the surrounding world with the virtual creatures gradually turns it into a kind of VR Skills Trainer, but equipped with a voice, a physiology model and a pharmacology library, responding not only to the manipulations performed on the phantom, but also to the other properties of the virtual patient — who can be communicated, examined, auscultated, etc. This technique (some authors call it *Simtegration*) has a number of advantages, which are summarized below in this chapter [Table 6].



Credit: Acibadem University, Istanbul, Turkey

Fig. 30. Cardiopulmonary resuscitation training via hybrid simulation is performed both in a virtual environment and on a physical mannequin

Simulators equipped with haptic devices, in addition to practicing a sequence of actions, also provide for the development of motor skills, helping to improve practical skills. The integrated objective assessment system allows to determine whether the manipulation was performed correctly and helps to spot the areas for improvement and repeated practice. In addition to abstract mathematical parameters reflecting movements in numbers (trajectory, angular deviation, linear and angular velocity), the computer can accurately determine a number of clinically important parameters: accuracy of catheter insertion, correct position of the syringe, depth of needle insertion, volume and rate of blood loss, thermal and mechanical damage to the tissues, reliable clip application, tight suturing and many other objective parameters of high clinical significance.

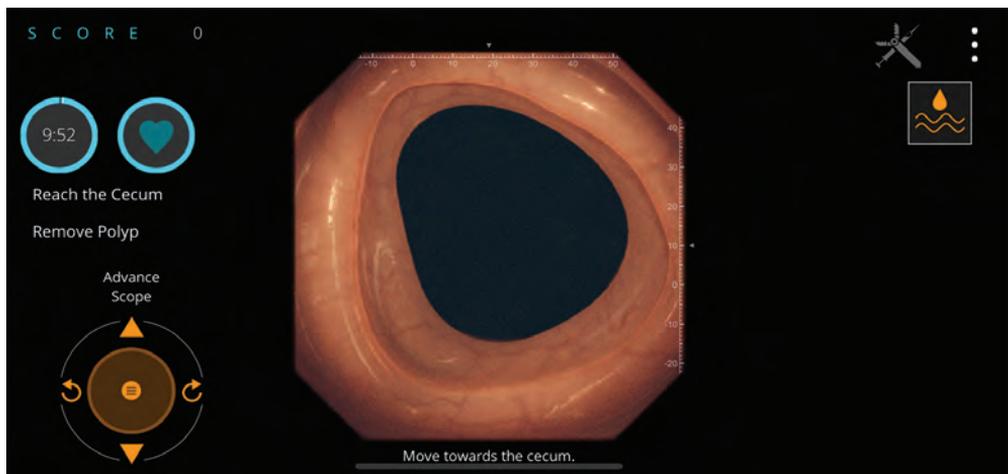
Virtual technologies are widely used to practice cardiopulmonary resuscitation (CPR) in both medical and non-medical specialists, civilians and schoolchildren. For example, a search of the PubMed Database using search query (“Virtual” [Title/Abstract] AND “Training”[Title/Abstract] AND “Reality” [Title/Abstract]) AND “CPR”[Title/Abstract]) yields 32 articles (as by November 2023), among which there are several systematic reviews covering data from an even larger research array. Most of them prove high effectiveness of digital interactive technologies in acquisition of CPR skills. It is significant that due to the widespread use of simulation technologies for practicing CPR on phantoms, which is considered today the “gold standard” for CPR training, a large number of studies are devoted to exploring the effectiveness of training in a virtual environment as an auxiliary or independent educational tool. The newly emerged functionalities in the VR world have prompted a revision of traditional methods and search for an optimal strategy for teaching resuscitation. “According to 6 studies conducted in 2017–2021 (731 participants), virtual technology training significantly improved the rate and depth of chest compressions. VR training has been found to be an effective training method with a positive impact on performance, perception, and competence. Virtual reality in CPR training improves the manual skills and performance in adults and can be a good teaching method in a blended CPR training strategy. VR can improve the quality of chest compressions compared to in-person, instructor-led CPR training [Artero P, 2023].

In addition to on-screen simulators that allow you to master the steps of a medical procedure and learn the correct sequence of actions, there is new data on hybrid modeling, when real-time training on a phantom is combined with training in a virtual environment. This makes it possible to supplement the virtual environment with a very important component of CPR training – performing chest compressions in the right place, with the right depth and speed. This can be realized either by a simple combination (alternate use of one and the other modality) or by the hybrid simulation described above, where signals from the physical simulator are fed to the virtual simulator.

Diagnostic skills

Nowadays, each clinical discipline has examples of implementation of virtual devices for understanding the theory and practicing manual skills. Diagnostic disciplines are no exception. Novice specialists start with learning the theoretical material, protocols and algorithms, and then reinforce their knowledge by developing manipulation skills on a virtual simulator. The existing variety of educational equipment working in virtual and augmented environments allows for effective practical training and objectively assessment of the proficiency level of palpation of abdominal organs, auscultation of heart and lungs, taking and interpreting electrocardiograms, analyzing results of physiological monitoring, conducting and evaluation of data of endoscopic, radiological, angiographic and ultrasound examinations. Thus, “supervised use of a web-based cardiopulmonary auscultation simulation in addition to traditional clinical training improves auscultation performance in senior medical students” [Malmartel A, 2020].

Numerous virtual devices can be divided into two groups according to technological principles: screen simulators, which are interactive electronic atlases of endoscopic, ultrasound or other images [Fig. 31] and more complex virtual simulators equipped with simulated peripheral devices – endoscope handles, linear, convex, esophageal, vaginal or rectal ultrasound probes, with



Credit: Gastro EX

Fig. 31. Example of an interactive mobile application for gastroscopy training

the help of which the actions of a diagnostician can be imitated, thus enabling acquisition of probe handling skills, in particular the connection between the correct probe positioning and informative diagnostic image.

Below is a non-exhaustive list of examples of mobile applications for mastering ultrasound examinations given in alphabetical order. Some of the applications listed below have been developed by major ultrasound equipment manufacturers, while others are represented by small startups scattered around the world.

- *Abdominal Ultrasound Guide* by StudySpring, Lagos, Nigeria
- *Butterfly iQ – Ultrasound* by Butterfly Network, Burlington, MA, USA
- *Clarius Ultrasound App* by Clarius Mobile Health Corp., Vancouver, BC, Canada
- *Deeptime Ultrasound Simulator* by Deeptime, Bangkok, Krung Thep, Thailand
- *Diagnostic Ultrasound Handbook* by easyRadiology AG, Köln, Germany
- *ICCU Ultrasound Education* by CAE Healthcare Inc., Sarasota, FL, USA, a part of Madison Industries, Chicago, IL, USA
- *LELTEK Ultrasound* by LeSono, Leltek Inc., New Taipei City, Taiwan
- *Philips Lumify Ultrasound App* by Philips Healthcare Inc., Andover, MA, USA
- *Scanbooster Ultrasound Simulat* by Scanbooster UG, Ebhausen, Germany
- *SonoAccess: Ultrasound Education* by Fujifilm Sonosite, a company of Fujifilm Holdings Corp., Bothell, WA, USA
- *VistaScan Ultrasound* by Emagine Solutions Technology Inc., Tucson, AZ, USA
- *Vscan Air Wireless Ultrasound* by GE Medical Systems Ultrasound & Primary Care Diagnostics, LLC, by GE Healthcare (USA), a part of General Electric Company, Boston, MA, USA

More technologically advanced and expensive devices are equipped with a torso or pelvis phantom for practicing realistic ultrasound examinations using imitated ultrasound probes.

Simultaneously with diagnostic images, a 3D model of the organ under study can be displayed on screen in real time to create associations between the sonographic picture and the anatomical structure, which contributes to more efficient assimilation of the theory. There is also the option of projecting an image on top or “inside” the phantom using HoloLens mixed reality glasses [Fig. 32]. Due to their high cost, these technologies are not as widely used, although their implementation provides better understanding of complex medical topics as well as confident recognition of anatomical structures leading to more accurate differential diagnosis. A recent study by Danish researchers showed that despite the fact that training course in ultrasound fundamentals conducted by a human teacher is 16 times more expensive than the cost of independent training in an immersive virtual reality (IVR), the learning efficiency of instructor-led training was almost the same as self-learning in IVR (comparison of the learning quality was carried out using the



Credit: Maxim Gorshkov, 2019

Fig. 32. Ultrasound diagnostics training in augmented reality using HoloLens

OSAUS scale). The authors believe that in future core courses, IVR training may become an equivalent alternative to instructor-led training [Andersen NL, 2023].

Below is a list of the six most popular virtual ultrasound training systems equipped with phantoms and ultrasound probe models:

- *BodyWorks, BabyWorks, HeartWorks, ScanTrainer, Medaphor* – product line of *Intelligent Ultrasound LLC*, Cardiff, UK
- *e Sono* – cloud-based SaaS solution by *Innoging Medical*, a company of *3B Scientific GmbH*, Hamburg, Germany
- *inSimo* – product of the *InSimo SAS*, Strasbourg, France
- *Kraken, Schall* – products of *Schallware GmbH*, Berlin, Germany
- *Scanbooster*, ultrasound skills trainer by *Scanbooster UG*, Ebhausen, Germany
- *SonoMan*, a diagnostic ultrasound simulator and *SonoSkin*, ultrasound diagnostic wearable device for FAST and eFAST Training are products of *SimuLab Inc.*, Seattle, WA, USA
- *SonoSim*, a product line by *SonoSim Inc.*, Sant Monica, CA, USA
- *Ultrasound Mentor*, virtual trainer by *Surgical Science*, Gothenburg, Sweden
- *Vimedix* by *CAE HealthCare Inc.*, Sarasota, Florida, USA, a company of *Madison Industries Inc.*, Chicago, IL, USA
- *VirtaMed GynoS* modular virtual simulator for gynecological diagnostics and minimally invasive surgical interventions from *VirtaMed AG*, Zurich, Switzerland

Four of the simulators mentioned above underwent validation and comparison of performance indicators in 2019, whose results allowed the authors to state that “all simulators under study could be used for ultrasonography of abdominal organs, whereas the learning benefits were greater for novice specialists than for experienced sonographers” [Østergaard M.L., 2019].

Virtual Patients and clinical reasoning

Virtual patients (VP) are designed and used to practice communication, diagnosis, treatment and decision-making skills in therapy and surgery. Some products use a mathematical model to simulate changes in the physiological status of a patient and their response to treatment, which is especially important when practicing medical care for patients with life-threatening conditions. Others are programmed to develop students' clinical thinking, allowing them not only to practice the skills of collecting complaints and anamnesis, conducting auscultation, analyzing laboratory data and instrumental examinations, but also to logically deduce diagnostic and therapeutic decisions on their basis.

The use of VP allows to demonstrate a greater variety of clinical conditions in a shorter period compared to the classic bedside teaching option. The student has opportunity to repeat his actions several times and compare different versions of the same disease during one lesson. It is possible to simulate both common conditions that are often encountered in routine practice as well as rare disease that can threaten the patient's life. Repeated execution of standardized tasks helps reinforce acquired skills.

- *BodyInteract* is one of the most well-known VP platforms in the world and one of the oldest. The basic version is represented by a touch screen table depicting a patient lying on a bed; a mobile version is also available. The trainees receive a briefing that includes initial data or handoff report, and if the patient is conscious, they have the chance to conduct an interview. Subsequently, they must utilize the evolving physiological parameters and data from laboratory and instrumental studies, which can be requested as needed, to diagnose and initiate treatment for stabilizing the patient's condition. According to the company, the system can encompass up to several hundred simulated clinical cases across 30 clinical disciplines, depending on the range of scenarios provided.
- *DIMEDUS¹, Digital medical education systems* – virtual educational platform for teaching a wide range of clinical competencies, from basic clinical, communication and manual skills, surgical procedures, to the

¹ DIMEDUS is a trademark of DIMEDUS Inc., Salem, MA, USA.

development of clinical thinking in all principal medical disciplines. There is a set of cases dedicated to the management of seriously ill patients in emergency and critical conditions, supported by built-in mathematical model of physiology and pharmacology. The platform is presented both on mobile devices such as phones, tablets, laptops, and on large touch tables and VR glasses. The simulation experience is supported by interactive theory lessons with 3D animation.

- *EMS, Education Management Solutions*², provides “integrated technology ecosystems for healthcare learning,” including multimodal virtual simulations not only for the healthcare institutions but for other educational fields as well as for governmental services.
- *Maestro Evolve* – a previously mentioned VR system with an advanced physiology model that allows to run simulated scenarios in real time. It provides access to the simulation equipment, healthcare curriculum, and assessment tools on one platform, it is possible to edit the already patients as well as configure new ones, featuring different health conditions, from normal to severely ill. Patients demonstrate individual changes in their physiological status and response to the users’ actions and administered medication dosages, performed defibrillations, etc. due to computer calculations. This feature is especially useful in training of emergencies and allows clinical educators to focus on teaching process, not on the case facilitation. *CAE Maestro Evolve* includes a simulated hospital ward with a patient connected to virtual bedside monitor displaying physiological parameters in real time.
- *OMS*³ can run on both on virtual reality devices and on desktop computers or mobile devices. It is intended for training medical and nursing staff. Individual feedback provides for incremental improvement of the learners’ competency level.
- *SimX*⁴ provides simulation in both wireless and traditional VR-glasses for solo and multiplayer training of nursing, clinical, and emergency cases.

² Trademark of Education Management Solutions Inc., Wain, Pennsylvania, USA.

³ OMS is a trademark of Oxford Medical Simulation, London, Great Britain.

⁴ Trademark of SimX, Mountain View, California, USA.

- *SimSTAT*⁵ is a specialized application for anesthesiologists, a screen-based simulator that integrates *CAE Healthcare*'s modeled patient physiology and pharmacology into each virtual patient, providing physician anesthesiologists with advanced training to manage challenging emergencies. The *SimSTAT* fulfills *CME* (Continuing Medical Education) and *MOCA 2.0* (Maintenance of Certification in Anesthesiology) Part II and IV requirements, developed by the *American Board of Anesthesiology*, enabling training and evaluation remotely.
- *UbiSim*⁶ is focused on training nurses in immersive virtual reality using VR glasses, including Peer-to-Peer facilitation [Fig. 33].



Credit: UbiSim, photo Maxim Gorshkov, 2023

Fig. 33. Team training in VR-glasses

⁵ SimSTAT is a joint development of the American Society of Anesthesiologists (ASA) and CAE Healthcare Inc. Sarasota, Florida, USA, a part of Madison Industries, in collaboration with SimTabs, Los Altos, California, USA.

⁶ Trademark of UbiSim, Montréal, Quebec, Canada.

Table 6. Comparison of simulation features of mannequins, simulated patients (SPs), virtual patients (VP), VR skills trainers/simulators (VRS), hybrid simulation (Simtegration)

	mannequin	SP	VP	VRS	Simtegration
Technical skills	Yes/No (Skills Trainer needed)	No	Yes/No (some skills)	Yes	Yes
Tactile fidelity	Yes/No (only one preset)	Yes/No (norm only)	No	Yes/No (haptic limited)	Yes/No (depends on physical component)
Communication	No	Yes	Yes	No	Yes
Physiological parameters	Yes	Yes/No (norm only)	Yes	Yes	Yes
Physical examination	Yes/No (only one preset)	Yes/No (norm only)	Yes	No	Yes/No
Patient transportation	Yes	Yes	No	No	Yes
Scaling-Up	No	No	Yes	No	Yes/No (depends on physical component)
Iteration	No	Yes	Yes	No	Yes/No (depends on physical component)

Despite the use of innovative technologies – virtual reality glasses, telecommunication systems and artificial intelligence – virtual patients appear to be the continuing tale of the already traditional “case simulation”, and therefore are favorably accepted by medical educators and clinicians. They are designed not only for solo use, but as previously described, can be also integrated with phantoms or physical simulators for the practical skills training. Hence, the combination of a virtual platform providing dynamic changes in physiology (1), a female torso with fetus in birth canal representing anatomy and biomechanics of woman in labor (2), and a simulated patient demonstrating realistic behavior and mental condition (3), allows the user to simulate with maximum realism a wide variety of emergency scenarios in obstetrics, practice group interaction, techniques, communication, pharmacotherapy – in short, cater to the needs of almost any type of obstetrics simulation.

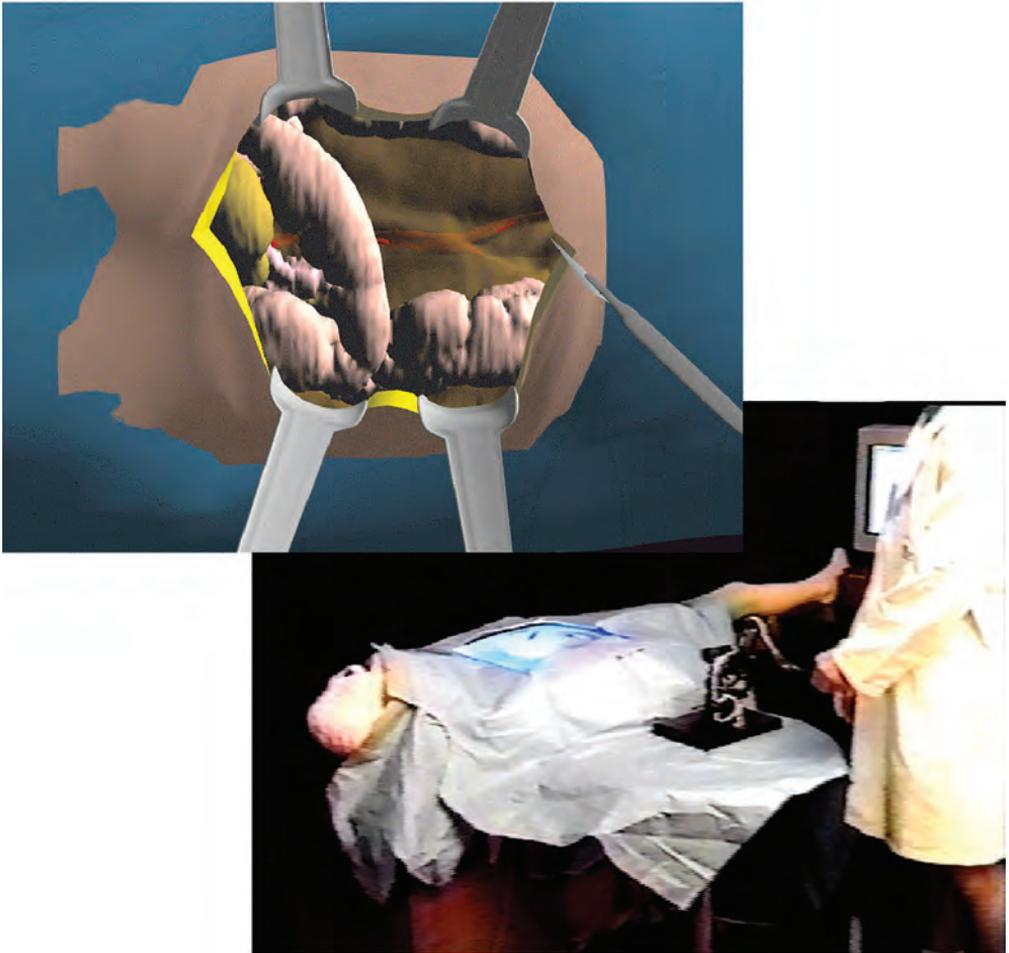
Surgical interventions

First virtual surgical simulation goes back to the end of the 20th century. The development of computer modeling went hand in hand with the triumph of endovideosurgical techniques. One of the pioneers of the field of surgical simulation, *Richard Satava*, argued that “This new surgery should not be regarded as a novelty, but rather as the first blush of a profound change in the viewing of the art and craft of medicine. It is the announcement of the coming of age of the “*Nintendo surgeon*.” [Satava R., 1992]. He was able to create a pilot version of the VR simulator, describe in “*Surgical Endoscopy*” a year after: “This is the first step, a most primitive VR surgical simulator. Using off-the-shelf, state-of-the art VR hardware (*Silicon Graphics* workstation) and software (*Paracomp Swivel 3-D*) from VPL Research, a surgical “world” of the abdomen has been created of a torso which contains the stomach, pancreas, liver, biliary tree, gallbladder, and colon as well as a few surgical instruments (scalpel, clamps). The images of organs and instruments are created using 3-D computeraided design (CAD), resulting in anatomically accurate, cartoonlevel (3,000-7,000 polygons) graphics. The display technology is a commercial *Eyephone* high-resolution HMD (using LCD displays with only 200 lines of resolution) and interaction is with the *DataGlove*, but there is no sensory input of force feedback or tactile sensation.” [Satava R., 1993].

Another example of the pioneering projects mimicking surgical interventions was the system created by the American company *HT Medical Inc.* under financial support of *DARPA*¹ and was called *HATS* [Fig. 34], stands for *HT Abdominal Trauma Surgery Simulator* [Bro-Nielsen M, 1998]. *HATS* simulator was a simulation of a person on operation table, where a screen was horizontally placed in the wound area, displaying the course of surgical intervention – the surgical wound with internal organs. Computer generation of anatomical structure of organs was based on data from the project *Visible Human* (data set of cross-sectional photographs of the human body, that was conducted by the *U.S. National Library of Medicine* from 1986 till 1994) and tactile sensitivity was modeled by a haptic device. It had amazing functions and characteristics for its time: virtual organs with the display of injuries and bleeding could be deformed, dissected, coagulated; among the practiced interventions were gastric resection, spleen removal, revision of the damaged

¹ The Defense Advanced Research Projects Agency, USA.

organ. Its subsequent modifications were then reflected in the simulators that appeared later. A little later, European developments began to appear: *KISMET* (*Institut für Angewandte Informatik*, Karlsruhe, Germany in 1986); *MIST* (*Wolfson Centre for Minimally Invasive Therapy*, Manchester and *Virtual Presence Ltd.*, London, UK in 1996); *XiTact* (*Swiss Federal Institute of Technology Lausanne*, Lausanne, Switzerland in 2000).



Credit: Morten Bro Nielsen et al., 1998

Fig. 34. HT Abdominal Trauma Surgery Simulator, 1998

The first creators of the concepts of virtual surgical training had grandiose ideas and boundless imagination, trying to realize everything at once, advancing in the darkness of uncharted prospects. In their projects shone the idea of three-dimensional study of intraoperative anatomy by “fly-through” organs’ examination, telesurgery with the performance of surgery to a patient on Mars, controlled by surgeons on Earth, digital navigation of the instruments, laparoscopic cybersurgery through single-port flexible manipulators, and so on. Most of them were ahead of the current level of computer graphics, computing performance and haptic interaction in their ideas and many of the project faded away. However, these ideas and solutions worked out in them were not lost and were released decades later, when the technology had grown enough.

The methodology and principles used in practicing surgical interventions in virtual environment are similar to those implemented in the training of basic manipulations, differing only in the need to make various clinical decisions during a surgery which may be outside the standard protocol. Currently, most minimally invasive surgical skills can be trained using dedicated VR trainers, including laparoscopy abdominal surgery, gynecology, urology, arthroscopy, intraluminal endoscopy, microsurgery in ENT and ophthalmology.

Blending traditional and virtual skill training, *augmented reality* serves as a bridge. In this hybrid approach, a semi-transparent virtual layer is superimposed onto the actual devices’ images displayed on a standard screen. This layer enhances the real-world exercises performed in conventionally looking lap-box with additional graphical images, data for objective action assessment, visual prompts, and other pertinent information, creating an enriched, interactive learning environment. Tracking of tools and objects is done using machine vision, and the calculation of trajectory and events is based on coordinate detection and pre-trained artificial intelligence [Fig. 35]. The advantage of this technology is its relative cheapness, as it requires neither special haptic manipulators nor complex programming of variable interactive 3D models of internal organs.

To ensure high level of mastery of endosurgical interventions, training should be started from honing fundamental basic skills – a kind of “alphabet”, playing scales on a surgical “piano”, without which it is impossible to move on to the stage of even routine manipulations – applying clips, suturing, tying knots

Credit: Maxim Gorshkov, 2017

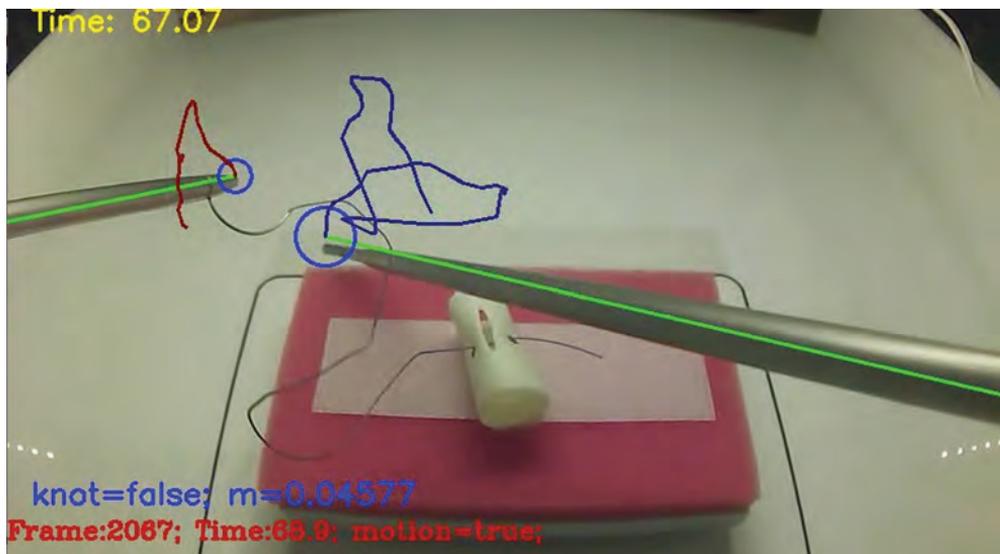


Fig. 35. Analysis of tool trajectory and knot tying quality based on machine vision in the BESTA laparoscopy trainer

[Fig. 36]. The next, procedural stage, where surgical interventions are trained, is secondary and based on the fundamental one. VR-simulator based training has a number of methodological features and nuances that distinguish it from learning on box trainers.

The training course usually begins as in real practice with mastering camera navigation – trainee finds an object in the cavity, point the camera at it and hold it motionless on the screen for several seconds. The task should be completed as soon

Credit: Maxim Gorshkov, 2016



Fig. 36. Laparoscopic skills training in virtual environment

as possible; movements should be quick and at the same time accurate and ergonomic, contact with surrounding tissues should be avoided. Further effort is required to develop proficiency in handling the angled laparoscope.

The difficulty level of the exercises progressively escalates, encompassing the mastery of instrument navigation within the cavity and the development of bimanual coordination during increasingly complex tasks and surgical maneuvers. After finishing, a comprehensive report is presented, showcasing the results in both numerical and graphical form. Gradually, the exercises become more challenging – novices learn how to use electrosurgical hooks, scissors, clip applicators, ultrasonic scissors, apply endloop to structures, place a specimen in an endobag, and finally suture tissues and tie intracorporeal knots. Exercises can be performed one after another or their sequence is set by the teacher who has chosen a particular course. Once students have learned to confidently perform them, they can proceed with virtual surgeries – cholecystectomy, appendectomy, hernioplasty, gastric fundoplication, nephrectomy, bariatric interventions, ventral hernia repair, lung resection – the range of available interventions depends on the simulator model and manufacturer and increases year by year. The list of interventions in endosurgical gynecology is also quite extensive – interventions for ectopic pregnancy, cysts and tubal obstruction, fibroids are practiced in a virtual environment, as well as hysterectomy, polypectomy, myomectomy, and endometrial ablation.

Unlike box trainers, virtual simulators provide digital mentoring that facilitates skills acquisition by giving recommendations as learners perform the exercise and generating feedback after its completion. Learner is provided with a report upon completion of the task covering dozens of parameters, from execution time, speed, and accuracy trajectory of each instrument to indicators of tissue damage in percentage and blood loss in milliliters. Of the shortcomings, high cost and insufficient tactile fidelity of organs and tissues when contacted with an instrument or other organs of tissues, are usually reported.

It shouldn't be left unmentioned that the range of virtual technologies used for surgical training has expanded in recent years. Along with the continuing emergence of new training solutions using immersive virtual environment (helmets and virtual reality glasses), the number of mobile applications is

growing, where not only manual skills are practiced, but also surgery algorithms are learned, options for surgical anatomy and the choice of instruments are studied – and this is, basically, assimilation of theoretical content.

The aforementioned study, which has become classics of VR-based laparoscopic skills learning theory, explores and compares the actions of two groups of novice surgeons, one of which completed a course of exercises on a VR simulator, and the other underwent traditional training using the “see one, do one, teach one” method, gradually mastering skills under the guidance of a mentor at the surgery table. Both groups then independently performed a series of laparoscopic cholecystectomies, which were video recorded and anonymized for subsequent reviewing by two experts, who noted errors and inaccuracies in their actions. According to the results of the study, the group who underwent the VR practical training demonstrated “a 3-fold reduction in error rates during the first 10 laparoscopic cholecystectomies performed by surgical residents, and reduction in surgery time by 58%” [Ahlberg G, 2007]. Thus, it has been proven that surgeons who received practical training in a virtual environment are more accurate and faster than their colleagues trained in a traditional way.

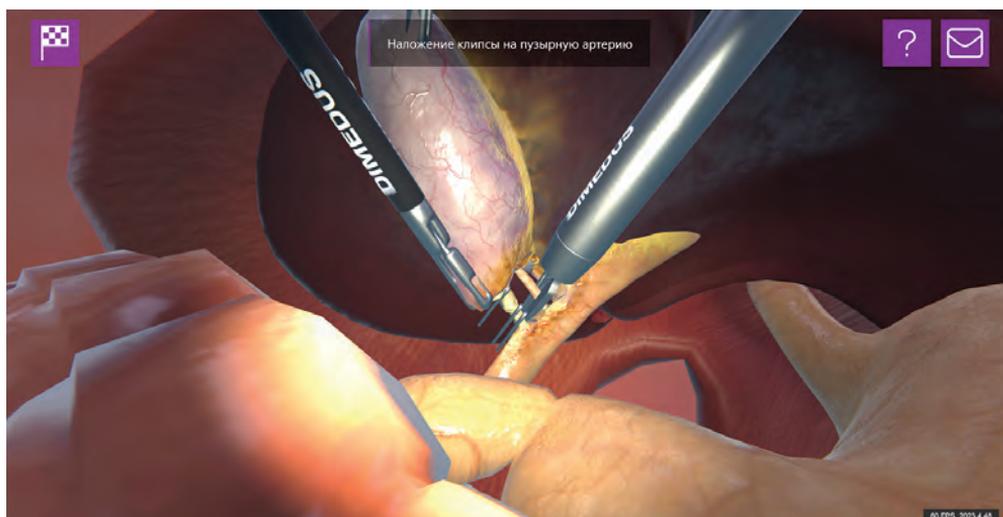


Fig. 37. Studying the sequence of actions when performing laparoscopic cholecystectomy on a mobile device is the first stage of mastering the intervention

The authors of the Swiss study conducted a survey of surgical residents ($n = 557$) of university hospitals in Switzerland, France, Germany and Luxembourg, as a result of which all 100% felt that simulation training was essential for the development of their practical skills, and 84% said that simulation training should become a mandatory part of their curriculum, with the average time of virtual training component amounting to 42 ± 51 hours per year [Seil R, 2022], according to the opinion of the residents. Their American colleagues have come to similar conclusions.

Eighteen orthopedic surgical residents practiced examination of knee and shoulder joints using the *ArthroS* virtual arthroscopy simulator [Fig. 38]. Participants completed a series of training modules and then repeated the diagnostic tasks. The IGARS global scale was used for the assessment of the learners' performance. The mean improvement in the total knee arthroscopy score was 11.2 ± 10.0 points ($P = .0003$) and in the shoulder exercises 14.9 ± 10.9 points ($P = .0352$). The authors believe that training residents on a VR simulator significantly improved the mastery level in performing knee and shoulder arthroscopy interventions [Yari S et al., 2018].



Fig. 38. Arthroscopy simulation in VR

Communication skills

Talking to a patient – well, what’s so difficult? It would seem, saying hello, asking how you are feeling, clarifying when complaints started, talking about relatives, sharing future plans – looks like almost a small talk. In fact, it is already a structured survey according to the *Calgary-Cambridge model*¹. If there are any components missing, this fact should be noted, assessed, and discussed. It is only at first glance that communicating with patients is a simple matter. There are algorithms, models, nothing saying about body languages and face emotions. Failure to engage, to show empathy, to complain, to advise – all these things are considered, the score is lowered. The Calgary-Cambridge model of patient communication is 6 sections in 73 points, try to demonstrate them all! And it’s not the only one – there are *Kalamazoo*, *Four Habits*, *BATHE*, a number of other schemes, international and national. It is when the student sbecome experienced practitioners, it will be up to them to decide what to say, how and when. But while they just learn the basics of the art of healing, it is not for them to decide what is superfluous and what is obligatory! All of this must be learned, assimilated, and most importantly, reproduced. It is not enough to simply mention “*Listen, Explain, Acknowledge, Recommend, and Negotiate*” and even discuss each one – all these actions must be skillfully demonstrated according to this *LEARN* scheme.

Not to mention “difficult patients” or bad news. Terrible information about the fatal disease or about the possible unfavorable course of the pathology is not only a disaster for the patients and their friends and relatives, but also a heavy burden on the soul of the messenger – any normal person. How can one not sympathize? It is twice as bad when this conversation does not work, when the response to the news is reproach, aggression and threats. It would be one thing if the attending physician was to blame – that would be annoying, simply insulting, but partly deserved. It’s another thing if, in fact, not everything went smoothly on the part of the doctors, if there are reasons for this coming wave – here, especially, every word must be verified, every phrase must be appropriate, every fact must be verified. That’s why one teaches the structure of delivering bad news and a clear assessment of the conversation,

¹ The Calgary-Cambridge model is a framework for teaching and assessing medical communication skills, emphasizes a clear structure for medical interviews, covering aspects from initiating the session to closing it.

for example, using *SPIKE*² strategy for delivering breaking bad news.

One of the questions educators ask when using virtual models instead of actors, simulated patients is «would such training be as emotionally charged in a virtual environment?» In this regard, it will be interesting to consider the findings of the North Carolina researchers. As a virtual simulation they took virtual Standardized Patients (vSP) used a hybrid intelligence model that allowed a person to “inhabit” the vSP. “Salivary cortisol and a self-report measure of mood-the Profile of Mood States, Second Edition (POMS 2) were gathered before and after delivering the bad news. Participants in both conditions (real SP vs. vSP) reported increased negative emotionality on the POMS 2 following the SP interaction. There were no significant between-group differences on the POMS 2 or salivary cortisol concentration following the SP interaction. Participants performed similarly on most interpersonal dimensions, except tone of voice. These results suggest that medical students may have similar emotional and behavioral responses when delivering bad news to a vSP when compared to a rSP. These findings provide support for the continued use of vSPs in training learners to deliver bad news and other communication-based skills and to assess their performance on these tasks” [O’Rourke SR et al., 2020].

All the same tasks as in other areas of medical training are solved here, in the field of communication development – the algorithm must be understood, remembered, reproduced many times, and distributed over time, objectively assessed, errors corrected, correct execution reinforced and implemented in practice. And, as in other areas, there are neither enough patients nor, most importantly, teachers, for these essentially standard and routine actions. Yes, they are ready to show once, check twice, evaluate three times. But given the constant flow? From day to day? Dozens, or even hundreds of students with the same typical mistakes, the same errors and deviations in the lot protocol? No human strength is enough for this, no salary can compensate for this monotonous mass flow.

For many decades, computer screen has been used for practicing the skills of collecting patient’s complaints and medical history. Traditionally, such

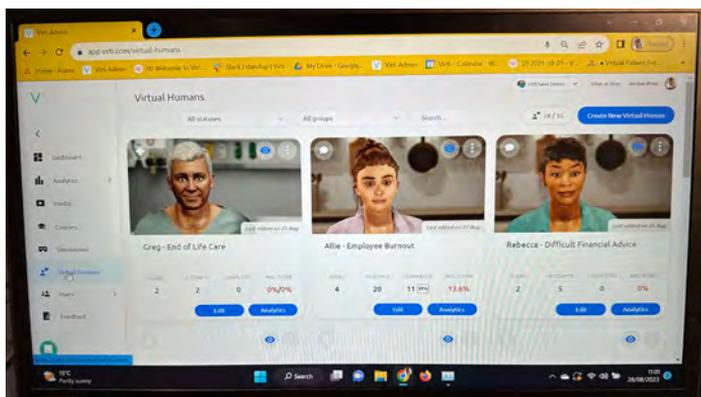
² Acronym SPIKES stands for «Setting up, Perception, Invitation, Knowledge, Emotions with Empathy, and Strategy or Summary.»

interviews are conducted using a “multiple choice” format; a question is asked by clicking the mouse or tapping on the touchscreen on one of the options from the list of proposed questions. Once the patient has answered the question, the student is offered a new series of questions; the dialogue is voiced and/or entered into the medical record in text format.

“The average performance score of students in the VR group increased twice as much (according to the *CliniSpace ISBAR* Rating Sheet, the change is statistically significant, $p < 0.001$). Research showed that students listened to how their peers communicated and learned from them. Students said they had less anxiety, knew what to expect, and had “better communication flow.” They learned to assess the patient’s condition and give recommendations” [Foronda, 2014].

Of course, this technique has a systemic drawback – students are given a hint that at least one question from the list must be correct when conducting a dialog! At present, AI systems similar to voice assistants from Google and other companies designed for home use have paved the way for the development of new methods of mastering professional patient communication skills. Now, students no longer receive hints from the virtual system – they have to conduct dialogues independently. Now a computerized patient evaluates the completeness and correctness of the student’s questions, comments, recommendations and behavior. At the end of the conversation, the system summarizes the results, gives an objective evaluation according to the checklist included in the system; this stage is the most important, because learning progress and competence cannot be achieved without evaluation [Fig 39].

Fig. 39. Virtual Humans for the training and automatic assessment of communication skills



Credit: Virthealth Ltd., M. Gorshkov, 2023

Non-Technical Skills

Non-Technical Skills (NTS) are “the cognitive, social and personal resource skills that complement technical skills, and contribute to safe and efficient task performance” [Fin R., 2008]. Issues of mastering non-technical, or “soft” skills, for example, developing leadership or team interaction skills remain one of the most difficult issues in medical education. Even more difficult appears the development of methods for their objective, standardized and accurate assessment, which requires an integrated and multifaceted approach that takes into account, on the one hand, the complexity of these skills and, on the other, their increasing importance in modern medical practice. The so-called 360-Degree Evaluation is based on feedback from several sources, including peers, teachers, nurses, patients, and self-assessment. Although it provides a more comprehensive understanding of the non-technical skills of trainees from different points of view, it is the most difficult to implement organizationally and requires significant labor costs, and human labor in this case cannot be replaced by a computer.

For more thorough evaluation of NTS, generalized or specialized global rating scales are applied:

- *ANGLES Global Rating Scale, Assessment of Non-Technical Generalizable Learning Effectiveness in Simulation (Assessment of activity of non-technical generalization learning in simulation)*. This global rating scale is used to evaluate the effectiveness of training in non-technical skills such as communication, teamwork and decision making in a simulated environment;
- *ANTS, The Anesthetists’ Non-Technical Skills*. The system is designed to assess the non-technical skills of anesthesiologists and nurses in the clinical environment of the operating room and recovery room and assesses their task management, teamwork, situational awareness and decision making skills;
- *CRM Scale, Crew Resource Management* is a rating tool used to evaluate the non-technical skills of health care teams, usually in the emergency room. It allows to assess teamwork, communication, leadership and decision-making skills in simulated or real clinical scenarios;

- *HFACS, Human Factors Analysis and Classification System* is used in situations involving accidents and incidents in healthcare and other high-risk industries;
- *NOTSS, Non-Technical Skills for Surgeons*. As its name suggests, the system is designed to assess surgeons' non-technical skills in four key domains: leadership and management, teamwork and collaboration, situational awareness and decision making;
- *Ottawa Global Rating Scale* is used to assess general clinical competencies, including non-technical skills, in medical students and residents during clinical rotation;
- *TeamSTEPPS, Team Strategies and Tools to Enhance Performance and Patient Safety* – a universal tool for assessing teamwork, communication and cooperation skills in various groups of healthcare professionals – from doctors to nurses, physical therapists, pharmacists and technicians.

Anyone who has experience conducting NTS training activities and subsequently assessing them using global rating scales knows how challenging this type of educational activity is and how great the contribution of expert professionals conducting such training and its assessment is. Attempts to integrate virtual technologies into soft skills training have been made for quite a long time, but currently the results are not on a large enough scale and the examples are few.

As a rule, team trainings are conducted in a virtual environment or in simulated conditions using virtual simulators, and the assessment of the actions of team members is carried out in the traditional way by tutors or clinicians using a selected global rating scale.

There are examples and studies of conducting team training for medical teams and nursing staff in a virtual environment. “Interaction with VR as part of the curriculum can help junior nursing students develop knowledge, skills and practice different types of non-technical skills, including communication, situational awareness, teamwork, decision-making and responsibility skills, advocacy and empathy” [Peddle M, 2019].

The imperative for a deeper comprehension of the various elements encompassed by the broad notion of Non-Technical Skills (NTS) competencies is evident. As we dissect the individual components of NTS, it becomes possible to standardize the benchmarks for evaluation, leading to a more structured approach to both teaching and measuring these skills. This in turn paves the way for enhanced digitalization within the domain of soft skills education and assessment. Digital platforms and tools can then be leveraged to facilitate consistent and repeatable training experiences, while also providing more objective and quantifiable means of assessing soft skills. As we advance in this direction, the integration of technology in soft skills development is expected to not only increase in prevalence but also in sophistication, potentially incorporating advanced analytics, artificial intelligence, and machine learning to further refine the processes of training and evaluation. This evolution promises a future where soft skills training is as nuanced and rigorous as that of technical skills, benefiting from the clarity and precision that digital tools can offer.



Credit: Acadicus

Fig. 40. Multi-user VR clinical case

2.2. Assessment tools. Testing, examination, accreditation

Hundreds of books, thousands of studies and publications have been written to discuss proficiency assessment issues – both in medical education in general and in simulated training in particular. The efficiency of written tests, practical demonstrations, multiple choice questions, and OSCEs has been reviewed. Manuals are published for assessing communication skills, clinical thinking, practical manipulations, and diagnostic competencies. It is impossible to embrace all the relevant topics and information into the framework of this section, and it was not our plan.

More than thirty years ago, *George Miller* published a short five-page essay in the *Academic Medicine* journal, where he proposed a framework for evaluation of the results of clinical training, consisting of four levels reflecting the stages of formation of a doctor's professional competence, widely known as "*Miller's pyramid*" [Miller GE, 1990]. With the exception of the fourth level, the highest level (*acts* in the workplace, in a clinical setting), virtual systems make it possible to assess the acquired competencies of the first three levels (*knows*, has knowledge, grasps of theory; *knows how* to apply existing knowledge; *shows how* can perform manipulation, demonstrates skills – both cognitive and practical). A system for objective assessment of knowledge and skills based on clear, pre-verified parameters is an integral feature of any educational virtual simulator. Creating an interactive digital educational product without an evaluation function or feedback, devalues this technology and deprives its use of didactic meaning. Instant feedback is the key to effective adult learning; it provides the opportunity for conscious learning, management and control of the educational process. If a virtual training system does not have this option, it ceases to be a teaching tool and simply becomes a virtual environment whose purpose is not learning but "adventure," as in the computer game *Roblox*¹ (no matter how popular and successful it may be).

Virtual simulators with a built-in assessment system use various tools for its implementation: control checklists; assessment of completed key activities –

¹ Roblox Inc., San Mateo, CA, USA.

binary or based on global scales; assessment of duration of manipulations or tests; objective measurement of performance or errors using quantitative indicators. Like any other evaluation tool, a computer-assisted evaluation should have high levels of accuracy, reliability, and validity. The accuracy of the assessment indicates the ability to objectively and reliably measure the level of knowledge and skills of students, reliability ensures the stability of the results when the test is repeated, and validity confirms that the completed assessment corresponds to the stated educational goals and correctly measures the level of the competence that we planned to assess. Below is a more detailed description of these features, generated by the AI.

Accuracy: In the context of assessments, accuracy refers to the extent to which an assessment measures what it is supposed to measure, without being affected by other variables. An accurate assessment provides results that closely match the true values or abilities of the individuals being assessed.

Validity is about the soundness, appropriateness, and meaningfulness of the specific inferences made from assessment scores. It's a measure of how well an assessment actually measures what it claims to measure. There are several types of validity: **Content Validity** that ensures that the assessment content covers all relevant aspects of the subject it's supposed to measure; **Construct Validity** involves determining whether the test truly measures the concept or construct it's intended to measure, and **Criterion-related Validity** assesses how well one measure predicts an outcome based on another measure.

Reliability refers to the consistency and stability of assessment results over time. A reliable assessment yields the same results under consistent conditions. It's an indication of the measure's repeatability and precision. Types of reliability include **Internal Consistency** which assesses whether different parts of the assessment provide consistent results; **Inter-rater Reliability** measures the extent to which different raters/observers give consistent estimates of the same phenomenon and **Test-retest Reliability** that shows the same test to the same group of people at different times to compare if the scores are consistent.

A carefully considered and accurately implemented algorithm for assessing a virtual clinical case or manipulative exercise is the ultimate dream of the examiner, as it can meet almost all of his needs. An assessment carried out using virtual (computer-based, data-based, digital) systems has a number of advantages and can be characterized as follows:

- **Objective.** Computer observations are free from subjectivity and other human factors; they are not influenced by personal bias, prejudices, fatigue or poor health.
- **Instant.** The microprocessor takes milliseconds to evaluate the learner's actions and generate detailed feedback almost immediately. It has no doubts, hesitations, or second thoughts.
- **Automatic.** The system compares each action, parameter values, instrument trajectories, drug prescriptions and answer options with reference ranges, so that after completing an exercise, simulation case or test, it automatically assigns a grade – without participation of a human in the evaluation process.
- **Accurate.** The accuracy of the assessment initially depends on its design. If the organizers of the examination session have selected correct reference values and adequate criteria for assessing competency levels, the computer will provide highly accurate assessment of reliable evaluation of mastery level.
- **Reliable.** No matter how long the assessment activities take, no matter how many examinees take part in them, regardless of the time of day, season or other factors, the digital assessor will still give the same score for a similar level of competencies. The evaluation criteria in the computer program remain unchanged and are measured stably, accurately and objectively, which ensures the reliability of the result.
- **Standardized.** To ensure sustainability of assessment results across different virtual devices, among heterogeneous groups of students, in different educational institutions or over different periods of time, the assessment format should be standardized. All control procedures use uniform criteria and standards that apply to all examinees. Results are presented in a consistent format, making it easier to compare the scores. The criteria for correct implementation are based on approved reference standards. Standardization is especially important in large-

scale examinations, such as university admissions tests, standardized skills assessments, licensing, certification and national accreditation.

- **Analytical.** Virtual systems can generate detailed analytical reports on student performance, including their strengths and weaknesses, progress over a specified time period, build graphs reflecting competency growth dynamics, allowing to identify patterns, trends, make forecasts, improve the learning process or adjust the individual trajectory of a student.
- **Scalable.** An assessment methodology, a set of assessment tools, checklists and methods of their application, in a word, the entire assessment procedure that has already been developed, can be scaled to an almost unlimited number of examinees and carried out in an unlimited number of examination centers.
- **Teacher-saving.** Digital assessment saves time of both students and teachers. Automated scoring and instant feedback allows the tutor to reduce time spent on feedback and focus on the improvement of teaching methods, crucial processes, and targeted support to students.
- **Resource-saving.** Digital exam format reduces the need for paper, print cartridges, filing cabinets and storage space, resulting in a more environmentally friendly and resource-efficient assessment process.
- **Anti-corruption.** Assessment in virtual environment reduces or eliminates the risk of corrupt practices; it is carried out automatically, without the participation of humans as examiners or with a small number of them in administrative support roles. The decision-making process is based on standard criteria and is transparent. Digital systems may contain built-in mechanisms to protect against unauthorized access or adjustments, use randomized question banks, or perform artificial intelligence-based proctoring. Although computer-based assessment can be considered anti-corruption a priori, it is also necessary to take into account the correct configuration and implementation of non-corruption safety systems to avoid new risks or vulnerabilities that could be exploited for corrupt purposes.
- **Accessible** (geographically). Geographically accessible virtual environment is characterized by the ability to take exams for students with disabilities, temporarily ill or geographically remoted (this advantage applies to the remote format only).

- **Available** (time-wise). Application of virtual technologies for remote assessment of learner's performance can be carried out within the allotted period of time, but without a strictly regulated schedule, which allows the student to take an exam at a convenient time.
- **Economical.** Even taking into account the additional costs associated with the implementation of information systems in the assessment procedure, their use turns out to be financially justified, allowing savings on a number of obvious and hidden costs – salaries of members of examination/accreditation commissions, expenses for support staff, office supplies. When examination is carried out remotely, it excludes the expenses on premises, security guards, cleaning of the territory and other administrative and economic costs.
- **Safe.** In conditions of any potential threat to personal participation, for example, in case of epidemiological danger, a virtual test eliminates physical contact between the subject and the examiner.

The use of virtual technologies during exams has a long history. Almost a quarter of a century ago, in November 1999, virtual medical histories were introduced into the USMLE exam Step 3, where these types of OSCEs were called “*Computer-based Case Simulations*” (CCSs). Two years of research into the possibility of computer-based testing for the third stage of the USMLE passed without serious incidents. During this time, approximately 50,000 exams were conducted, but other than some delays in launch, there were no major problems or failures in testing or scoring examinees, according to the authors' report [Dillon et al, 2002].

The creation of an *interactive simulation of patient cases* (ISP) for teaching and examination was first reported in Europe more than twenty years ago by researchers from the *Karolinska Institutet* (Gothenburg, Sweden). The system had a medical history recording function based on video recording of a conversation with the patient, using free text entry, an interactive physical examination, extensive laboratory tests and detailed user feedback. Students from different semesters (n = 70) participated in a computer simulation of patient examination, with a particular focus on learning to solve clinical problems. The authors conducted three research trials during 1999–2001 [Bergin and Fors, 2003]. These studies describe the format that, in our opinion, should be called “*virtual OSCE*”, in contrast to remote conversation

of the examinee with an actor, a standardized patient via Zoom.

An interesting example of training and high-stakes examination system for practicing physicians is the SimSTAT system offered to the American Society of Anesthesiologists [asahq.org/shop-asa/e019n00w01] by its own members. SimSTAT is an online simulation training platform using interactive virtual clinical cases for improvement of clinical decision-making and critical thinking skills. The program uses realistic anesthetic scenarios for trauma, resuscitation, surgical interventions, and childbirth clinical cases. The scenarios are designed to depict, as realistically as possible, the development of critical situations that anesthesiologists may encounter in their practice. Upon completion of the scenarios, participants receive immediate feedback on their decisions and manipulations, allowing them to rethink their actions and learn from their own experiences in the simulated virtual environment. Executing SimSTAT scripts not only promotes the continuing professional development of physicians, but also provides participants with up to 25 CME credits required for reaccreditation under the MOCA certification program, parts 2 and 4.

Professional communities of surgical specialists around the world are also introducing virtual systems into the accreditation of young doctors. Thus, on November 23, 2013, the *Swiss Society of Orthopedics and Traumatology (SGOT-SSOS)* for the first time certified 77 candidates for the qualification of an orthopedic surgeon using objective skills criteria of an arthroscopic VR simulator. The certification exam consisted of two parts: the first one was conducted in verbal format with a discussion of several clinical cases, and the second part included practical performance of arthroscopy interventions using biological specimen and the *ArthroS* virtual simulator [VirtaMed, 2013].

Professor *Lars Konge*, head of the research department at the *Copenhagen Academy of Medical Education and Simulation, CAME* believes that “if you don’t use testing in your training, it’s like not using antibiotics to fight bacterial infections. It’s old-fashioned, ineffective, and contradicts to all the evidence we have. In medical education, the approach “one size fits all” is unwelcomed. People learn at different paces and have vastly different levels of innate ability and confidence. You can’t just say, “Every trainee must go through ten hours of training,” and expect them all to be ready for surgery” [Konge L., 2023].

2.3. Gamification and competition

If built into learning curriculum, learning games, quests, escape rooms, contests, competitions or quizzes significantly increase the emotional perception of what is happening, influencing the final result of training – effective absorption of learning content and positive perception of the learning process in general. For example, children, playing “*House*”, “*Memory*” or “*Cops and Robbers*”, unconsciously, through their roles and game algorithm, familiarize themselves with complicated concepts and competencies – active memorizing of hundreds of pictures, a model of motherhood, hospitality, and practical baby care skills – feeding, bathing, changing, physical training and teamwork.

Every *Microsoft* user is familiar with the game *Solitaire*¹, which was actually designed with an educational intent. Introduced with *Windows 3.0* in 1990, *Solitaire* helped users get used to the graphical environment and the unfamiliar two-button coordinate device – a mouse, which was new to many at the time. They learned drag-and-drop techniques and fast and precise coordinate navigation through a simple and entertaining game instead of tedious training.

The knowledge and skills acquired during a game are consolidated firmly and for a long time. If these competencies were mastered using traditional pedagogical methods, the result would not be as good, and require more effort and time from both student and mentor.

VR game algorithms and individual components of playing games have been successfully integrated into medical training for a long time (this process is called “gamification”), as well as use of computer-based educational games (“game-based learning”) as an independent educational tool.

Already our distant ancestors perfectly understood the importance of including a game and competition component as an addition to training – the process of mastering complex practical skills and abilities. In Ancient Greece there was a whole series of four *Panhellenic Games*, one of which was the *Olympic Games* (Greek: Ὀλυμπιακοὶ ἀγῶνες) at which outstanding athletes representing city-states competed against each other. Today, speaking

¹ Solitaire and Windows are the trademarks of Microsoft Corp., Redmond, WA, USA.



Fig. 41. Students' team solves the sim case, *SimOlympics* at *SESAM-2019*, Lisbon, Portugal

about the Olympic movement within the medical and, first of all, simulation education, it is worth mentioning the *Debriefing Olympics* held by *Peter Dieckmann* with approximately 80 participants during the Annual Meeting of the *Society in Europe for Simulation Applied to Medicine, SESAM* in 2011 in Spanish Granada, and the *SimOlympics* in emergency medicine, which started in 2014 within *SESAM*. Today these competitions are organized for international teams of undergraduate healthcare students in the form of a formative educational experience called *SimUniversity*; the audience of the *SESAM* Annual Meeting is observing the students' actions and considering the scenario design, medical treatment and debriefing styles [Fig. 41]. Today, when the distance format of competitions is no longer in doubt, there are many examples of national and international simulation Olympics with the help of virtual patients. The contests held in different countries using *BodyInteract* and *DIMEDUS* systems allowed to attract more than a thousand competitors from dozens of countries each time with practically no significant costs on the part of the organizers and participants.

Another gamification approach is the internationally popular “escape room” – a fun, challenging, and safe experience for a group of participants, usually locked in a room, who must solve jigsaws and find clues to “escape” from a themed room within a set amount of time, usually 60 minutes [Fig. 42]. Participants usually play in teams while teamwork and communication are critical to solving the puzzles and challenges in the room. Players are advised not to use physical force on objects, puzzles, or any other unfair tricks – after all, this is not a real prison, just a game. It is often possible to get some limited hints or help, often through the game-master overseeing the game. To maintain the mystery and protect the secrets of the game, participants are often not allowed to use phones, cameras or recording devices in the room, and there is no internet access. Last but not least, the principle of “Safety First” must be observed – there should be known emergency exits so that players can leave the game at any time for any personal reason.



Credit: Maxim Gorshkov, 2023

Fig 42. A set of game elements used in the Escape Room series of tasks at the InSim-2023 conference in Reutlingen, Germany

Medical knowledge-based tasks can be composed with the help of a variety of available items and objects. These can be puzzles and jigsaw puzzles – homemade or purchased, a locked chest with a hidden key or a digital cipher to be solved. It is possible to bind or handcuff participants to limit their mobility and enhance the psychological effect, to turn off the lights in the room, providing them only with flashlights and, of course, to lock the room in which they are and from which they need to escape by solving medical problems [Fig. 40]. One of the recent reviews on the topic of use “Escape-rooms” gamification included fifty-two studies. “Escape rooms were employed as learning and assessment strategies for the delivery of diverse topics within dentistry, medical, nursing, pharmacy and physiotherapy pre-registration healthcare education. Most were conducted on nursing students with learning topics focusing on the development of knowledge related to patient care management. Escape rooms were evaluated to be enjoyable and have an impact on students’ cognitive, psychomotor, non-technical and affective skills learning outcomes. However, the learning outcomes compared with conventional learning strategies were inconclusive due to lack of randomized controlled trials. [Quek LH et al., 2023]

The use of virtual systems for gamification of educational process is becoming increasingly widespread and keeps gaining positive feedback from both students and teachers. Not “gamers” skills, but professional abilities and competencies can be acquired through game-based learning – first aid, triage or surgical manipulations. As an example, we can mention the video game “*Underground*”, which uses the *Wii U* console from the Japanese gaming giant *Nintendo* as controllers and joysticks [Fig.43]. The developers designed it in such a way that basic endosurgical skills could be mastered with its help. During laparoscopic interventions, the surgeon has to perform unusual and rather inconvenient movements and manipulations with long (32–42 cm) instruments fixed within trocar ports in the abdominal wall, while the working jaws of the instruments move in the opposite, mirror direction (the so-called “*Lever Effect*”). These peculiarities make it difficult for the untrained surgeon to properly coordinate their hand movement. It is impossible to perform these sophisticated movements while interacting with objects and tissues without prior practical skills acquisitions. For this purpose, a number of dedicated intensive training programs have been developed like *FLS, Fundamentals of*

Credit: Maxim Gorshkov, 2015



Fig. 43. Fundamental laparoscopic skills training using "Undeground" game

Laparoscopic Surgery (five tasks) or *BESTA, Basic Endosurgical Simulation Training and Assessment* (ten tasks), which contain a set of specialized exercises performed on endovideo-trainers. Dutch researchers have proposed an alternative original method for developing bimanual coordination and improving the accuracy of hitting a target with an instrument using a computer game. Slightly modified *Wii U* controllers now include laparoscopic handles. Their movements are displayed on the monitor screen in the form of game assets – laser beams, copies, etc. Ugly creatures move quickly along the paths, bridges and passages of the underground cave, which can be fought using the weapons at hand. The total score depends on the accuracy and precision with which the user hits the monsters, and on the number of defeated enemies. If installed in the resident's room, such a game console allows the student to not only hone their skills, but also to relieve stress at the end of the working day, to relax and to "refresh" their brain. The validity of this game and its effectiveness in basic training of laparoscopic skills have been proven by researchers [Jalink M.B. et al., 2015], which suggests that it should be regarded as an effective and at the same time unobtrusive auxiliary learning tool for enhanced surgical training.

To conclude this short story about the use of game technologies, I would like to give an example of the implementation of very frivolous techniques to solve quite serious problems. German project *Meditricks*² (the name “*Meditricks*” is a portmanteau of “*medical*” and “*tricks*,” suggesting methods or techniques to make learning medical topics easier) offers learners video narratives on various topics such as physiology, pharmacology, internal and infectious diseases enhanced with funny cartoon illustrations, visual and verbal mnemonics, analogies and metaphors, supplemented with flashcards and quizzes [Fig. 44].

Such learning techniques can increase learning results by 331% [Yang A. et al., 2014] due to memorized images, symbolic representations of basic medical concepts, medicine, and, in addition, they are fun to explore. Especially effective are such methodology for memorizing abstract, illogical sets of factual data; building *Eselbrücke* (*Donkey Bridges* – German term for mnemonic phrases) that makes it easier to remember complex vocabulary or concepts.



Credit: Meditricks GmbH

Fig 44. This is how *Meditricks* illustrates the topic “ECG Basics”

² Meditricks GmbH, Freiburg im Breisgau, Germany.

Meditrix is not the only “fun about serious” platform, there are other projects designed to aid in medical education through innovative, amusing, and engaging learning methods. These tools often use mnemonics, visual aids, interactive content, and other creative approaches to make the vast and complex field of medical knowledge more accessible and memorable. To give you an example, here are just a few of them:

- *SketchyMedical* is a popular online learning platform that uses story-based visual mnemonics called “sketches” to help medical students remember high-yield information, especially for microbiology, pharmacology, and pathology.
- *Picmonic* is another U.S.-based learning platform, uses visual mnemonics to help medical students memorize a wide range of topics. It turns information into memorable stories and characters, “paves your path to success from day one of school through your licensing exams and beyond”.
- *Osmosis* is a comprehensive medical study platform that offers a range of resources, including videos, flashcards, and practice questions. Osmosis is known for its clear, concise, and visually appealing content.
- Focused on pathology, *Pathoma* is a resource that combines a textbook and video lectures to provide clear, concise explanations of pathological concepts, often used by medical students studying for the *USMLE* Step 1.
- *Geeky Medics* is a global medical education platform providing comprehensive OSCE preparation resources such as written guides, checklists, flashcards, video demonstrations and mock OSCE stations. Its distinctive feature is the use of *Minecraft*³ style pictures as illustration to the learning material.

These resources are widely used by medical students and professionals to supplement traditional learning methods. They are particularly valued for their ability to break down complex information into more digestible and memorable formats, which is crucial in a field as vast and challenging as medicine. It is important to note, however, that such forms of training are designed as supplementary teaching aids and are not a substitute for basic textbooks and lectures.

³ Minecraft is a trademark of Microsoft Corp., Redmond, WA, USA.

3. Artificial Intelligence (AI) in medical education

Artificial Intelligence (AI), as a term, was first coined by emeritus professor of computer science at Stanford University *John McCarthy* in 1955 and defined by him as “the science and engineering of creating intelligent machines”, and he added later: “Intelligence is the computational part of the ability to achieve goals in the world.” [McCarthy J., 1955, 1997] The ability of computers, artificial intelligent systems, to perform creative functions that are traditionally considered the prerogative of human beings, typically deemed “intellectual”, to simulate human activities, particularly creative ones, to learn at the way like human beings do – this is how we understand it now.

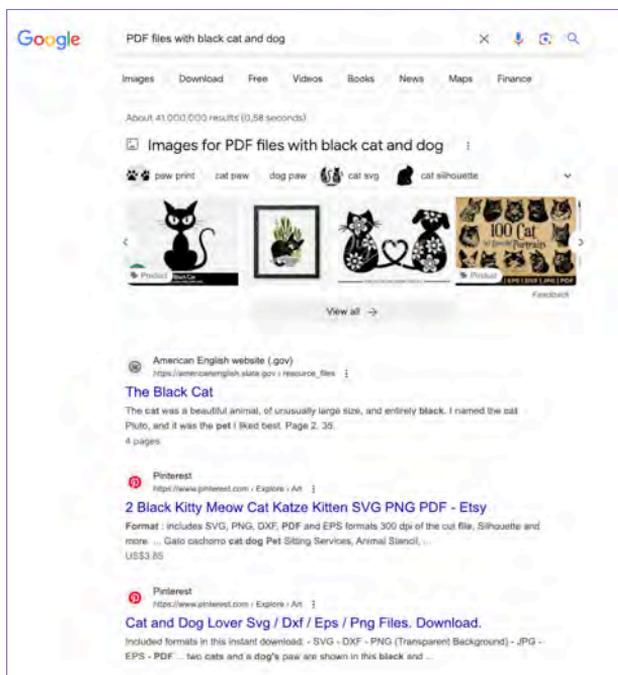
There have been ups and downs, a burst of public attention and almost total oblivion over the long journey of this computing discipline. More recently, at the end of last year and the beginning of this year 2023, there has been another surge of interest in the use of digital technologies in medical education – this time not related to the transition to distance learning due to the coronavirus. The triumphant marketing success of *OpenAI* in the presentation of its brainchild – an open-source artificial intelligence platform, *Generative Pre-trained Transformer ChatGPT-3* in November 2022 fueled the debate and revitalized interest in the application of digital technologies in medical education and medicine in general¹. While the arrival of computers in society since the second half of the 20th century has been visible, with changes taking place before our eyes, the use of artificial intelligence has been less visible to most of us, even though it started more than a quarter of a century ago. Today, everyday life is largely driven by AI systems that underpin a multitude of processes, programs, and devices. GPS navigation, Internet translations, updating online maps, autonomous driving, image search on websites, and facial recognition at the border-control or in the

¹ Since Spring 2023 the new version, GPT-4 is available. It can process and respond to both text and image inputs, enabling a wider range of applications and interactions and it can generate texts, images as well as code snippets, simulate dialogue or role-play scenarios. Such type of AI system is called Multimodal AI.

subways checkpoints are all based on machine learning, computer vision, and other types of smart computer technologies [Table 7].

Nowadays, computers speak to us in human language – there is no need to type “Filetype:PDF find:(([cat]OR[dog]))AND([black]NOT[white]))”. It is enough to formulate a search inquiry like “find PDF files with black cat or dog” – and the documents you are looking for will be found [Fig. 45].

As you know, if you zoom in on a map in Google Maps², you can see three-dimensional models of buildings, and you can view them from four different angles by rotating the map to the sides of the world. This capability is provided by the processing of maps and street panorama images by artificial intelligence. But a much more important function of AI in the process of providing virtual map services is their automatic updating. Every time a



Credit: Google LLC

Fig. 45. Natural language search result (not bad, isn't it? The first results absolutely match the query "find PDF files with black cat or dog")

² Google Maps is a trademark of Google LLC, a division of Alphabet Inc. Mountain View, California, USA.

Google car drives through the streets and transmits fresh images of city panoramas to the system, the AI recognizes signs with street names and house numbers, compares the obtained data with the existing data in the maps, and automatically updates the system if a discrepancy is detected. Every time you switch on the captions in YouTube, the speech recognition and simultaneous transcriptions are done by AI algorithms in the cloud.

Artificial intelligence is used in many areas of human activity, including medicine, with functions such as computer vision (e.g., recognition of faces, car license plates, X-ray images), natural language processing (machine translation of foreign languages, speech recognition and text-to-speech functions, automatic classification of conversation topics), preference and behavior analysis (commercial screening, recommendations for shopping, lifestyle, diet, treatment, learning trajectories), autonomous vehicles (traffic light, sign, and obstacle recognition, car steering, navigation, and other functions), and the development of new capabilities in many areas of human activity.

However, the development of AI also involves ethical and social issues such as privacy, security and the impact on the workplace and society at large (will be discussed in the Part 6 of the book). Let's look at these issues in more detail.

3.1. Artificial Intelligence Systems

The term “Artificial Intelligence” refers to hardware and software systems capable of performing tasks that normally require human intelligence, solving them at or above the human level. AI systems can analyze information, extract facts, definitions, theories from large data sets, learn, draw conclusions, and make decisions similar to those that would normally involve human involvement.

There are several types of technologies used in the creation of systems denoted by the term “artificial intelligence” and variants, approaches to their development – symbolic AI, deep learning with use of multilayer neural networks [see Table 7]. Their work is based on so called algorithms – sets of instructions in solving a problem or accomplishing a specific task. Algorithm¹ is a fundamental concept in mathematics and computer science, a step-by-step methodology, a sequence of instructions that a computer can interpret and execute to perform a specific function or solve a problem.

Table 7. Technologies and techniques understood as Artificial Intelligence (AI)

Type of AI	Description, examples
Machine Learning (ML)	Computer systems learn from data: Supervised Learning (trained on labeled data to predict outcomes); Unsupervised Learning (identify patterns non-labeled data); Reinforcement Learning (interacting with an environment and receiving feedback); Deep Learning (neural networks with many layers, used in image and speech recognition).
Computer Vision	Machine interprets visual data and make decisions based on it: Image Recognition (identifying objects, or actions); Facial Recognition (identification or verification of individuals)

¹ The term “*algorithm*” is rooted to the Latinization of the name of a medieval Persian mathematician *Muhammad al-Khwarizmi*, and his influential work on systematic and logical approach to linear and quadratic equations written in the 9th Century. Later it was translated in Latin and was titled as “*Algoritmi de numero Indorum*” (“*Al-Khwarizmi on the numbers of the Indians*”). Over time, the word gradually evolved into “algorithm” in English, shifting in meaning to denote a specific set of rules for calculations, or procedures used in problem-solving tasks.

Type of AI	Description, examples
Speech Recognition	<p>Converting spoken language into text, used in virtual assistants and voice-controlled applications. Examples and types: Isolated Word Recognition recognizes individual words separately, like by voice input in older car navigation systems; Connected Word Recognition detects short phrases or word combinations spoken naturally. These phrases are typically pre-defined, like by voice input in modern car navi-systems; Continuous Speech Recognition: recognizes natural, continuous speech without requiring pauses between words, used in transcription services and voice assistants; Speaker-Dependent or Speaker-Independent Recognition allows to react different to the different person's command.</p> <p>Keyword Spotting detects specific keywords or phrases in a spoken sentence or conversation and that activates (awakens) a voice enabled device like "Hey Google" or "Alexa"</p>
Natural Language Processing (NLP)	Allows machines to understand, interpret, and generate human language (text2speech)
Robotic Process Automation (RPA)	This is not (only) about steering a robot – it is more about automating routine, monotone ("robotic") operations in everyday life. Software bots can mimic human actions and automate repetitive tasks like invoicing, scheduling, or warehouse management
Neural Networks	Algorithms designed to recognize patterns, inspired by the structure and function of the brain
Swarm Intelligence	Algorithms inspired by the collective behavior of decentralized systems, such as colonies of ants or flocks of birds
Evolutionary Computation	Algorithms that apply biologically inspired concepts like evolution, inheritance, and mutation
Cognitive Computing	Systems that mimic human cognition to interact and reason like people that can help in customer service, healthcare, fraud detection, education, retail
Planning and Scheduling	Algorithms to design sequences of actions that allow an AI agent to achieve a certain goal. Focuses on the development of algorithms and methods for automatic action planning and decision-making in complex situations, such as traffic flow management or energy distribution

[ChatGPT-4's answers to a series of author's queries, October, 2023]

One common approach is **Symbolic AI**, which uses a symbol-based approach and rules for manipulating symbols. Symbols are not just letters, numbers, and punctuation marks – in this context, symbols have a broader meaning. They can represent abstract concepts, such as “man”, “machine”, “cat” or “action”, as well as relations between these concepts, such as “is”, “belongs” or “more than”. Symbols and their relationships form a semantic network that allows a symbolic AI system to analyze and manipulate knowledge about the world and the relationships between its elements. The basic idea of symbolic AI is that the human thought process is broken down into component parts – symbols – and their connections are processed with the help of logical rules, concepts, and logical conclusions. It allows knowledge to be represented explicitly, making it easier to understand and interpret the results. Symbolic AI has found applications in areas such as expert systems, natural language processing, planning and robotics.

Another approach is to create **Multilayer Neural Networks**, AI models whose architecture mimics the central nervous system and learns from large amounts of data. In humans, a single neuron, on average, has approximately 7,000 neural connections with other brain cells. However, this number can vary widely depending on the type of neuron and its location in the brain. For instance, certain neurons – *Purkinje* cells in the cerebellum cortex – can have up to 100,000 or more synaptic connections. Since we have about 80 billion neurons after birth, the total number of connections is often estimated to be in range of 100 trillion to 1 quadrillion (that’s a number with 15 zeros!) – a very extensive network. Higher nervous activity consists of the constant transmission of electrical impulses through the neural network that activate certain groups of elements. In AI systems, networks of interconnected artificial neurons work together to process information and perform tasks. Each element in the input layer of a neural network receives initial signals, weights them, and transmits the result through an activation function. The activation function determines whether the neuron should be activated or not and introduces nonlinearity into the network’s computation. After activation, the result is passed to the next layer of neurons and the process repeats until the output layer is reached. The learning process of neural networks occurs by adjusting the weights between neurons – the neural network involves passing input data through the network, calculating the error between the predicted and expected

results, and then adjusting the weights to minimize the error. This learning process can be repeated many times to achieve more accurate results.

Neural networks have a wide range of applications, including computer vision, natural language processing, speech recognition, recommendation systems, forecasting, robot control, and much more. A distinctive feature of neural networks is their ability to extract complex patterns from data and learn based on experience.

Deep Learning is a subset of neural networks that allows a model to extract complex hierarchical representations from data. Thus *ChatGPT-4* primarily utilizes the following AI technologies from the list mentioned earlier:

Machine Learning (ML): ChatGPT is based on machine learning models, specifically deep learning models, to understand and generate human-like text based on the input it receives.

Deep Learning: The architecture underlying ChatGPT is called the Transformer, which is a type of deep neural network. More specifically, GPT (Generative Pre-trained Transformer) is a model that utilizes layers of transformers to process and generate text.

Natural Language Processing (NLP): ChatGPT is fundamentally an NLP model. It's designed to understand, process, and generate human language in a way that's coherent and contextually relevant.

While other AI technologies like Computer Vision, Robotics, or Automated Planning and Decision Making have their own applications, they are not directly involved in the functioning of ChatGPT-4.

[ChatGPT-4, November 2023]

The training of a computer or machine is accomplished using machine learning techniques. In general terms, machine learning involves the following steps:

- **Goal setting** – as in medical simulation education the first step is always a clear definition of the end goal or task to be accomplished. For example, it could be diagnosis or predicting the course of a disease based on MRI images or detecting abnormalities and analyzing them like recognizing pathology from laboratory data.

- **Collection of data** that will be used to train the model – a series of X-rays, electrocardiograms, protocols with test results. They can be hand-picked, obtained from open sources, or generated as part of an experiment. The more data collected, the better a model is likely to perform.
- Raw data is less suitable for Deep Learning and need to be prepared. So, the next step is **data preprocessing** where it is put into a suitable format for training the model. This step includes cleaning (corrupted, irrelevant or low quality data is removed); scaling numeric data to a standard range; augmentation like by rotation, flipping or zooming image; pre-formatting, and splitting the data into training and validation cohorts.
- **Model Design** to choose an appropriate architecture or machine learning algorithm for the task solving. This might be a convolutional network (CNN) for image tasks, recurrent network (RNN) for sequence tasks, linear regression, random forest, or transformers.
- **Model training** on a sample that contains input data and corresponding output values (target labels), e.g., X-rays or changes in physiological curves are labeled with appropriate labels. Often these labels are

manually assigned by human experts or digital day laborers, *crowdworkers*, who deliver their services through special aggregated online platforms (see below). During training, the model slowly modifies its parameters to minimize the discrepancy between predictions and targets. To increase the amount of training data, various methods can be employed besides gathering as much of it as possible. These methods include *Data Augmentation* (such as changing the size, ratio, position of the image, or mirroring it) or *Diffusion*, which involves adding random noise to existing data or images.

Generation: Crayon, prompt: Maxim Gorshkov, 2023



Fig. 46. Image of an elderly virtual patient generated by AI (Crayon) using the prompt “virtual patient old male”

- **Model evaluation** is done after training, on a large sample to assess its performance and its ability to generalize to new data. For example, the model is given a thousand ECG recordings, pre-coded and analyzed. The model is asked to make its own interpretation and these results are compared to a control group. Depending on the task, different evaluation metrics and methodologies can be used in this step: forward propagation to get predictions; loss Computation to calculate the difference between the predictions and the true values using a loss function; back propagation to compute the gradient of the loss with respect to each weight in the network; optimization with adjusting the weights of the network in the direction that reduces the loss, using optimization algorithms.
- **Model tuning** is done if the model does not achieve the required performance, changes can be made to the model architecture, training parameters or data preprocessing to improve its results. One effective approach to evaluate and tune a model is to use *Generative Adversarial Networks*, or GANs, which consist of two neural networks with different functions. Similar to a lawyer and a prosecutor, the first network, the *generator*, produces new content and advocates for the newly created data. The second network, the *discriminator*, evaluates the validity of the output, prosecutes, and eliminates unauthentic material.
- **Model application or deployment** to real-world problems, to a production environment. The model can take new input data and generate predictions or solutions based on them in real-time or batch mode.
- **Monitoring, maintenance, iterative improvement** of the model are necessary as new data becomes available, the environment changes, or the application field advances.

Paradoxically, machine learning is driven by the labor of a large team of humans. Customers post their projects, known as *Human Intelligence Tasks* (HIT), such as identifying and tagging certain content in photos or videos, creating product descriptions, or answering questions on a special questionnaire. The workers, commonly referred to as *crowdworkers*, *clickworkers* or *turks* – this peculiar digital proletariat – are briefed and often sit at home in front of their computers, marking up massive amounts of data, images, tables, and getting paid per piece by often unknown remote employers. It is interesting that the nickname “*turks*”, as well as the name of the most widespread in the world

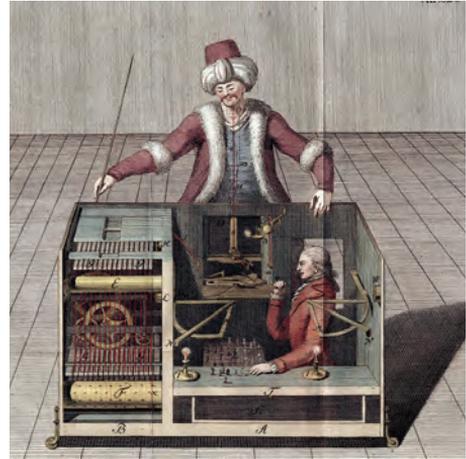


Fig. 47. The sensational intellectual machine “Chess Turk” turned out to be one of the most grandiose frauds of the Napoleonic Wars era. Top – engraving of the XIX century, left – an exhibit of the Chess Museum, Rhein, Switzerland

platform dedicated to such tasks, *Amazon Mechanical Turk*², received from the “Chess Turk” (in original German – *Schachtürke* or simply *Türke*). This was a sensational for its time mechanical automaton created in the late XVIII century by *Wolfgang von Kempelen* [Fig. 47]. The inventor and his machine toured Europe, playing chess for money, entertaining noble spectators and players, among whom were even kings, emperors and presidents – *Maria Theresa*, *Napoleon Bonaparte* and *Benjamin Franklin*. The deception was later uncovered when it was revealed that inside the “machine”, a short grandmaster was hiding in a bollard beneath a chessboard with pieces, controlling the movements of a humanoid mannequin. Similarly, *Mechanical Turk*’s online service uses remote human labor hidden behind a computer interface so that the employer’s contractors can perform tasks that cannot be accomplished with electronics alone.

The process of machine learning can be not only one-time, but also iterative, repetitive, and consist of many cycles to achieve optimal results. In recent years, we have begun to talk about self-learning, where AI generates training models for itself. It is also important to ensure data quality, proper model selection, and fine-tuning of parameters to achieve optimal performance.

² The Amazon Mechanical Turk platform is owned by Amazon.com Inc., Seattle, WA, USA.

3.2. Artificial Intelligence in medicine

Artificial Intelligence is playing an increasingly important role in medicine every year and is being applied in various fields of healthcare. An indirect sign of increasing interest in this topic is the exponential growth of research and other specialized publications. For example, a search for “artificial intelligence” with a “title” or “abstract” restriction conducted in July 2023 in the PubMed database yielded 36,427 articles – query (Artificial[Title/Abstract]) AND (intelligence[Title/Abstract]). The same query in October 2023 already showed 41,818 results, nearly 15% more three months earlier. Within the scope of this book, it is not possible to provide a comprehensive overview of the application of AI in medicine. Therefore, the following are just a few examples of its use in healthcare today and in the near perspective in medical images analysis, making or excluding diagnosis, support of the diagnostic or treatment decisions, personalization of treatment or workflow optimization in a hospital or doctor’s office.

Analyzing medical data and images. AI can be used to automatically analyze and interpret medical data and images such as ECGs, CT scans, MRIs, X-rays, and ultrasound images. This helps doctors to detect abnormalities, determine disease stages, and assist in treatment planning. The use of AI in MRI-based screening has been mentioned above. AI’s work with digital images is one of its most common and studied applications. PubMed query using the keywords “Artificial intelligence image recognition” (((Artificial[Title/Abstract]) AND (Intelligence[Title/Abstract])) AND (Images[Title/Abstract])) AND (Recognition[Title/Abstract]) in the last 10 years alone yields 549 results, including 15 systematic literature reviews.

A systematic review of the use of AI in endoscopic imaging for detection of malignant strictures of biliary tract and cholangiocarcinoma, which summarized the data of five studies involving 1465 patients [Njei B, 2023]. The highest efficiency indices were noted for convolutional neural network cholangioscopy (accuracy 94.9%, sensitivity 94.7%, specificity 92.1%), providing recognition of structures and segmentation of bile ducts for diagnostics of malignant biliary strictures and cholangiocarcinomas.

Chinese authors conducted a systematic literature review and meta-analysis of 28 papers on the effectiveness of using artificial intelligence in image-

based ovarian cancer diagnosis. The analysis of different algorithms showed a sensitivity of 89% (85–92%) and specificity of 88% (82–92%) for machine learning; and a sensitivity of 88% (84–91%) and specificity of 84% (80–87%) for deep learning. Acceptable diagnostic performance was demonstrated in subgroup analyses stratified by imaging modality (ultrasound, MRI or CT), sample size (≤ 300 or >300) and several other criteria. Thus, AI algorithms have demonstrated good performance for ovarian cancer diagnosis using medical imaging [Xu HL, 2022].

Nine studies on the application of Deep Learning algorithms in the identification and classification of dental implant systems using dental imaging (panoramic and periapical radiographic images) were summarized in a systematic review by an international consortium of researchers from India and Korea [Chaurasia A, 2023]. The accuracy of implant classification based on the AI systems ranged from 70.7 to 98.2%. It should be noted that the risk of systematic error and applicability problems were rated as high for most studies, mainly regarding data selection and reference standards. Thus, DL models have promising prospects for use as decision aids and decision-making tools; however, there are limitations to their application in real-world clinical practice.

Impressive results are demonstrated in AI-powered in electrocardiography (ECG) interpretation based on machine learning algorithms and deep neural networks. With expert accuracy technology offers unbeatable speed. First, the system measures all possible intervals almost instantaneously. It detects main fiducial points, determine if the computed variance in the R-R interval pass a certain threshold, finds presence of regular atrial activity, high-frequency fibrillatory waves, etc. – all the things that are now standardly built into modern models of electrocardiographs. Secondly, ECG is nothing more than a set of values of electrical potentials at a certain moment of time, although it is easier for the human mind to comprehend them not in the form of a set of numbers or tables, but in the form of a curve, like a video made up of a series of frames. Typical for one or other condition, cardiograms represent a unique statistical pattern, similar to fingerprints. These peculiar computer images of millions of cardiograms form the basis for training multilayer neural networks.

AI algorithms of ECG analysis can help clinicians in interpretation and detection of arrhythmias, ST-segment changes, QT prolongation, and other ECG abnormalities; predict risk integrated with or without clinical variables

(arrhythmias, sudden cardiac death, stroke); in monitoring ECG signals from cardiac implantable electronic devices and wearable devices in real time and alerting clinicians or patients when significant changes occur according to timing, duration, and situation; signal processing, improving ECG quality and accuracy by removing noise/artifacts/interference, and extracting features not visible to the human eye (heart rate variability, beat-to-beat intervals, wavelet transforms, sample-level resolution, etc.); therapy guidance, assisting in patient selection, optimizing treatments, improving symptom-to-treatment times, and cost effectiveness (earlier activation of code infarction in patients with ST-segment elevation, predicting the response to antiarrhythmic drugs or cardiac implantable devices therapies, reducing the risk of cardiac toxicity); facilitating the integration of ECG data with other modalities like imaging, genomics, proteomics, biomarkers, etc.. In the future, AI is expected to play an increasingly important role in ECG diagnosis and management, as more data become available and more sophisticated algorithms are developed [Martínez-Sellés M et al., 2023].

Making (or excluding) a cardiological diagnosis with the help of AI is not the domain of specialized medical institutions alone – these solutions are also found in everyday life. For example, the Apple Watch¹ Series 4 and later has a built-in portable electrocardiograph that can record an I-lead electrocardiogram directly from the wristwatch. Then, after analyzing the heart rhythm, the watch gives a conclusion from the following options: sinus rhythm, atrial fibrillation, tachycardia, bradycardia or unrecognized rhythm. However, it is important to note that the company has a disclaimer in its user agreement, as the device is not registered as a medical device with the *FDA* (American certification authority, *Food and Drug Administration*). During a 30-second ECG reading, the user is shown a separate warning on the screen that the watch cannot diagnose a myocardial infarction. Nevertheless, the company's website contains a Fact Sheet on detecting cardiac arrhythmias with the Apple Watch (a 17-page document, by the way!), which, in addition to explaining technical aspects, provides data from two clinical studies and references to scientific publications in respectable specialized publications ["Using Apple Watch...", Apple Inc., 2020].

¹ AppleWatch is a trademark of Apple Inc. in Cupertino, California, USA.

Making diagnosis, supporting decisions. Even an attempt to reduce the volume of material by only systematic reviews, not articles, and moreover, published only in 2023, as well as to narrow the topic, for example, to “diagnosis” only, in fact, does not give the desired result – there are more than a hundred review papers, and presenting information from them is not possible. Summarizing the results of recent studies, it can be stated that the use of AI together with high-precision modern diagnostic devices has opened a new era in establishing the diagnosis and predicting the course of the disease. AI can be used to offer diagnostics hypotheses based on symptoms, MRI or X-Rays image patterns and other medical records, to predict cancer, diabetes, cardiovascular diseases, recognize and differentiate coronavirus infection from other respiratory pathologies. And even more, just smartphones with their HD cameras and computing capabilities can become a useful diagnostic instrument. With AI enhancing, the pathology is established faster, less highly skilled human labor required, and sometimes AI-results are even more accurately.

Spanish researchers conducted a systematic literature review summarizing the results of diagnostic accuracy and prediction of rare genetic diseases [Roman-Naranjo P, 2023]. In the 22 studies selected for the review, exome sequencing was used most frequently (59%), with rare neoplastic pathologies being the most common disease scenario (59%). AI was used for differential diagnosis, patient stratification and detection of somatic mutations. In other rare diseases, the most common purposes of AI were prioritization of rare variants or genes and identification of bi-allelic or di-genic sequence.

AI can support doctors and medical staff in their decisions by providing information on best practices, treatment recommendations and prognosis based on the analysis of large amounts of medical data and research. Risk calculators for the development and progression of diseases such as glaucoma, keratoconus, breast cancer.

For example, *IBM Watson Health*² offers a variety of AI-based products and solutions to help physicians and researchers analyze medical data, diagnose and make decisions. Watson for Oncology is used to analyze medical literature and patient data, providing recommendations for cancer treatment.

² IBM Watson Health is owned by IBM Corp., Armonk, NY, USA.

*DeepMind Health*³ develops AI systems for analyzing medical images, such as retinal screening or interpreting MRI scans. They are also working on patient monitoring and prognosis systems to help doctors make more informed decisions.

*Aidoc*⁴ offers AI-based solutions to automatically detect and classify pathological changes in medical images, including CT, MRI and X-rays. This helps doctors diagnose various diseases more efficiently and accurately.

Founded in 2015, *Tempus*⁵ specializes in medical genomics, developing and applying AI and machine learning technologies to analyze genetic, clinical, and molecular patient data. The company provides personalized treatment and disease management recommendations based on this data and uses AI data analytics to personalize cancer treatment. They collect and analyze patients' genetic, clinical, and molecular data to determine optimal treatment strategies and provide individualized recommendations to physicians.

*Zebra Medical Vision*⁶ has developed a few AI algorithms to analyze medical images to automatically detect and classify various pathologies. This includes detection of tumors, strokes, osteoporosis, and other conditions.

Personalized treatment. AI can develop individualized treatment plans and recommendations, taking into account the patient's large-scale genomic data to identify genes associated with specific diseases, predict disease risks, or understand the genetic basis of diseases. This analysis combined with the patient's medical history, and the variability of test and instrumental findings is used by the neural networks that can create a "*Digital Twin*" of each individual. This digital twin can undergo hundreds of simulated treatment options and based on optimal model personalized treatment plans will be elaborated. Such a patient-specific treatment program helps optimize medications and recommendations and improve clinical outcomes.

³ Google DeepMind Health is based in London, UK. A division of Alphabet Inc., Mountain View, California, USA.

⁴ Aidoc Medical Ltd, Tel Aviv, Israel.

⁵ Tempus Inc. in Chicago, Illinois, USA.

⁶ Zebra Medical Vision Ltd. Sheffer, Israel.

Drug development and search for new active molecules. AI can be used to predict the pharmacological properties and characteristics of new molecules, identify potential drug compounds and their interactions with proteins or receptors. Instead of conducting complex, time-consuming, costly experiments, picking one chemical compound after another, AI performs virtual screening to help narrow down potential candidates and speed up the process of selecting drugs for further close scrutiny. AI can be used to design new compounds – to create innovative molecular structures, optimize and modify existing drugs. With the help of deep learning and generative models, AI can suggest new variants of compounds, taking into account pharmacological properties and limitations.

For instance, in 2020, *Benevolent AI*, using its machine learning platform, identified a new drug called *Baricitinib* for the treatment of COVID-19 symptoms. During the study, AI was used to analyze disease data and chemical-compound interactions, which helped identify the potential efficacy of *Baricitinib* in the treatment of coronavirus [Richardson P., 2020]. Another bright example can be *Insilico Medicine*, an Abu Dhabi-based biotechnology company, announced the initiation of a Phase II trial of a targeted drug for the treatment of idiopathic pulmonary fibrosis developed using generative AI technology in late June 2023. *Insilico Medicine's* lead cystic fibrosis drug *INS018_055*, a first-in-class drug candidate with a target discovered and developed using AI technology, has already completed Phase 0 and Phase I (human safety study) in the US and China [Alarabya News, 2023].

An equally important application of AI in pharmaceutical research is its use in analyzing clinical trial data – often huge amounts of data collected over many years, from thousands of patients. AI can help identify patterns, relationships between parameters, and identify subgroups of patients who may have the best effect from a drug intervention.

Optimizing workflows. AI can help automate and optimize some administrative and operational tasks in healthcare facilities, such as resource allocation, patient scheduling and medical records management. Thus, one of the functional variants of AI that can listen to doctor-patient dialog and help fill out medical records is called *Speech Recognition and Processing System, SRPS*. This system uses speech processing and machine learning algorithms to automatically recognize and transcribe speech spoken during

medical consultations. It can convert speech information into a text format and automatically enters individual fragments into the appropriate sections of the medical record. An example of such a system is *Dragon Medical Practice Edition*⁷, that automatically transform conversation into the medical record, supports multiple specialties and medical terms, ensuring an accurate and efficient documentation process. The company claims that physicians spend 45% less time completing paperworks.

Hence, the application of AI already has extensive applications in practical medicine today and shows further dizzying promise [summarized in Table 8].

Table 8. Use of different AI types in medicine

Type of AI	Examples of use in medicine
Machine Learning (ML)	<p>Disease Prediction and Diagnosis: Neural networks can be trained on clinical and laboratory data to predict the likelihood of a patient developing a certain disease or to assist in diagnosing existing conditions.</p> <p>Drug Discovery and Design: Neural networks analyze the chemical and biological interactions of molecules to predict the therapeutic potential of new drugs or optimize existing ones.</p> <p>Genomic Data Interpretation: Analyzing large-scale genomic data to identify genes associated with specific diseases, predict disease risks, or understand the genetic basis of diseases.</p> <p>Treatment Personalization: Based on a patient's genetic makeup, medical history, and other factors, neural networks can recommend personalized treatment plans.</p> <p>EHR Data Mining: Extracting insights from vast amounts of Electronic Health Record (EHR) data, helping to identify trends, improve patient care, and optimize hospital operations.</p> <p>Predicting Patient Admissions: Using historical data to predict patient admissions, which can aid in resource allocation and staff scheduling.</p> <p>Automatic Report Generation: After analyzing medical images, neural networks can generate preliminary reports, aiding radiologists and other specialists.</p> <p>Heartbeat Analysis: Neural networks can be used to detect arrhythmias and other irregularities in ECG data.</p> <p>Pathology Slide Analysis: Examining pathology slides to detect and classify cells or regions of interest, such as cancerous tissues.</p> <p>Protein Folding Prediction: Predicting the 3D structure of proteins based on their amino acid sequence, which is crucial for understanding many diseases and developing drugs.</p>

⁷ Made by Nuance Communications, Inc. a subsidiary of Microsoft, Redmond, WA, USA.

Type of AI	Examples of use in medicine
	<p>The application of neural networks in medicine holds the promise of enhancing diagnostic accuracy, improving patient outcomes, and optimizing various medical processes. However, it's essential to consider the ethical implications, data privacy concerns, and the importance of human expertise in the decision-making process.</p>
Computer Vision	<p>Medical Imaging Analysis: Neural networks, especially deep learning models like Convolutional Neural Networks (CNNs), are used to analyze medical images such as X-rays, MRIs, and CT scans. They can detect tumors, bone fractures, pneumonia or COVID-signs, and other abnormalities with high accuracy.</p> <p>Dermatology: Computer vision algorithms can analyze images of skin lesions and moles to assist in the early detection of skin cancer.</p> <p>Pathology Slide Analysis: CV is used to analyze pathology slides for the presence of disease markers, helping pathologists in their diagnostics.</p> <p>Retinal Imaging: CV can detect diabetic retinopathy, macular degeneration, and other eye diseases by analyzing retinal images.</p> <p>Video Analysis for Physical Rehabilitation: CV can track patients' movements to ensure they are doing exercises correctly and monitor their progress over time.</p> <p>Gesture Recognition for Hands-Free Control: Surgeons can use gesture recognition to control medical devices or access patient information without physically touching any equipment, maintaining a sterile environment.</p> <p>Automatic Patient Monitoring: In hospitals, CV systems can monitor patients to detect falls or any irregular activities, especially in critical care units.</p> <p>Facial Recognition for Patient Identification: Ensures the right patient receives the correct treatment and helps in maintaining their medical records.</p> <p>Dental Imaging: CV can help in detecting cavities, predicting teeth alignment, and planning orthodontic treatments using dental X-rays and images.</p> <p>3D Reconstruction: Constructing 3D models of organs or tumors from 2D images, which can be beneficial for surgical planning or disease monitoring.</p> <p>Automated Counting: Counting specific structures in medical images, such as cells in a blood smear or sperm in a sample.</p>
Speech Recognition	<p>Medical Transcription: Doctors and medical professionals often dictate their notes, findings, or patient updates. Speech recognition systems can transcribe these dictations in real-time, saving time and improving efficiency.</p> <p>Accessibility: Patients with physical disabilities or motor impairments can use speech recognition tools to communicate their symptoms, needs, or to operate medical devices without the need for physical interaction.</p> <p>Virtual Health Assistants: Speech recognition is used in virtual assistants that help in patient triage, answering common medical queries, and scheduling appointments.</p> <p>Radiology: Radiologists can use speech recognition to dictate their findings while viewing images, making the process more streamlined.</p>

Type of AI	Examples of use in medicine
	<p>Voice-activated Medical Devices: There are devices, especially in surgical settings, that can be controlled using voice commands, which can be crucial when the medical professional's hands are occupied.</p> <p>Medication Management: Voice-enabled applications can remind patients to take their medications, inform them about possible side effects, or even order refills.</p> <p>Mental Health Monitoring: Certain systems are being developed that analyze a patient's speech patterns to detect signs of mental health issues, such as depression or anxiety. While still in the research phase, the potential for early detection and intervention is significant.</p> <p>Language Translation: In diverse populations, doctors may encounter patients who speak a different language. Real-time speech recognition and translation can aid in communication between healthcare providers and patients.</p> <p>Training & Education: Medical students can use speech recognition systems to practice clinical exams, surgery procedures, and patient interaction scenarios.</p> <p>Home Health Monitoring: For patients with chronic illnesses, voice-activated systems can be used to check symptoms, provide medication reminders, and even alert healthcare providers if certain parameters are out of range.</p>
<p>Natural Language Processing (NLP)</p>	<p>Sentiment Analysis: Determining the mood or subjective opinions within large amounts of text.</p> <p>Machine Translation: Automatically translating text from one language to another.</p> <p>Chatbots and Conversational Agents: Programs that can conduct a conversation in natural language.</p>
<p>Robotic Process Automation (RPA)</p>	<p>Patient Scheduling and automatic reminders, reducing no-shows and last-minute cancellations.</p> <p>Patient Data Management with automating the entry of patient data into EHRs (Electronic Health Records)</p> <p>Prescription, Supply Chain, and Medicines and Disposables Refilling Management</p> <p>Revenue Cycle Management: Automating tasks related to patient financial interactions, from insurance verification to payment collection.</p> <p>Lab Result Notifications: Automatically notifying doctors and patients when laboratory results are available, warning when test values are outside the normal range.</p> <p>Health Monitoring for patients with chronic diseases, gathering and analyzing data from wearable devices, notifying healthcare providers if any concerning patterns emerge.</p>

[Table compiled from answers given by ChatGPT-4 to a series of clarification prompts from the author, October 2023]

3.3. Artificial Intelligence in medical education

Artificial Intelligence can be a useful tool for teachers, methodologists, and managers of medical education. Interestingly, AI systems themselves have an established opinion on the topic already. Here is *ChatGPT's* response to the question of how AI can be applied to medical education:

Artificial Intelligence (AI) has the potential to significantly enhance medical education in various ways. By integrating AI technologies, medical training can become more efficient, personalized, and up-to-date with the latest advancements in healthcare. Here are some key areas where AI can be utilized in medical education:

Personalized Learning: AI can analyze individual learning patterns and performance, allowing for the creation of customized study plans that address each student's strengths and weaknesses. This can lead to more efficient learning and better retention of information.

Simulation and Virtual Reality: AI-driven simulations and virtual reality (VR) environments can provide students with realistic and interactive scenarios. This is particularly useful for clinical training, where students can practice procedures or make diagnostic decisions in a safe, controlled environment.

Automated Assessment and Feedback: AI can be used to assess student performance and provide instant feedback. For example, in clinical simulations, AI can evaluate a student's decision-making process, technique, and adherence to guidelines, offering targeted feedback to improve their skills.

Data-Driven Insights: AI can analyze vast amounts of educational data to identify trends, predict learning outcomes, and provide insights into the effectiveness of teaching methods and curricula.

Augmented Reality (AR) in Anatomy and Surgery: AR can overlay digital information onto the real world, enhancing the learning experience in anatomy and surgical training. Students can interact with 3D models of

body parts and organs, gaining a deeper understanding of human anatomy.

Accessible and Scalable Education: AI-driven platforms can make medical education more accessible, allowing students from different geographical locations to access high-quality resources and lectures.

Continual Learning and Professional Development: AI can assist in keeping medical professionals updated with the latest research, clinical guidelines, and medical advancements by providing personalized content and learning opportunities.

Language Processing for Research and Study: AI-powered language processing tools can help students and researchers quickly analyze medical literature, extract relevant information, and stay up-to-date with the latest studies and findings.

Chatbots for Learning and Support: AI chatbots can be used as virtual tutors, providing students with instant answers to queries, additional explanations, and study support.

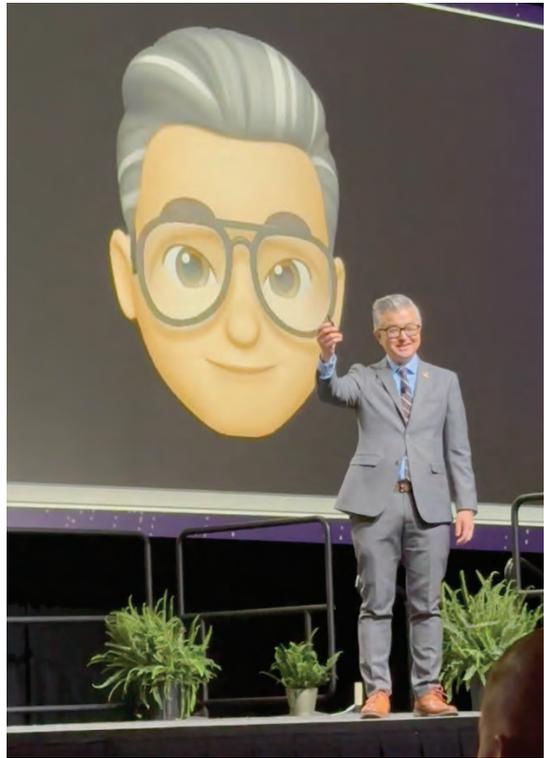
Enhancing Clinical Decision-Making Skills: Through the analysis of case studies and patient data, AI can help students learn the nuances of clinical decision-making, diagnosis, and patient care management.

By integrating AI into medical education, institutions can provide a more interactive, engaging, and effective learning experience. However, it's important to balance technology with the human aspects of medical training, ensuring that students also develop the interpersonal skills and empathy crucial for patient care.

[Generated by ChatGPT-4 on November 17th, 2023]

As you can see, the AI was able to generate a very logical, structured, and quite complete list. Everything is clear, except that it lacks a bit of specificity – what to include, where to attach, how to manage. However, if we continue to ask clarifying questions, the answers will be more detailed, precise, practice-

Fig. 48. SSH President Haru Okuda gave his avatar the opportunity to deliver the opening address at IMSH-2023, with the text generated by artificial intelligence. According to the President and the audience opinion, the AI did a good job of this task



Credit: Maxim Gorshkov, 2023

oriented and, in fact, can serve as a guide to action. Still, let us try to compete with AI, and the reader will have to decide who has done a better job.

There is now so much discussion about the role, place, and prospects of AI in general, and in medical education in particular, that it is not surprising to get lost in this stream of sometimes conflicting information. Let's at least try to structure and sort these facts and opinions. Below, using examples from our own experience and recent literature, we present a systematic discussion of the possibilities for using AI in medical education.

3.3.1. Source of the structured information

Finding and processing vast amounts of theoretical information, including research data, under the stress of time constraints, domestic concerns, and sometimes financial and clinical responsibilities, is a complex and overwhelming task for medical students. Obtaining structured information for autodidactic self-study and instructor-created learning materials is the most obvious, surface-level example of the application of AI in medical education. The function of providing easy, convenient access to information, selecting the main idea, the main endpoint, making it much easier for students and teachers to access the necessary fact without searching for the necessary fragment in a large volume of medical literature. AI systems can analyze and process scientific articles, clinical studies and medical databases to provide up-to-date information on diagnoses, treatment and prognosis of diseases, systematize the answer, provide it in a convenient form.

As you know, even today conventional search engines can handle queries in so-called natural language (although it is not quite correct to call a search engine – this miracle of human thought – “conventional”). The ability of search engines like *Google*¹, *Bing*², *Baidu*³ or *Yandex*⁴ and others to understand and respond to queries asked in natural language is commonly referred to as *Natural Language Processing* (NLP). This ability to talk with live speech is becoming more and more developed in search engines, is based on machine learning AI to understand user questions and then provide accurate and useful answers, such as “What are the distinguishing features of psoriasis?”, “How do you distinguish a hemorrhagic stroke from an ischemic stroke?” or “Name leading symptoms of a stomach ulcer.”

Popular search engines have question-and-answer functionality to improve the user experience and provide more accurate and relevant answers to searches, but their degree of development, their “intelligence” is still

¹ Google is a trademark of Google LLC, a division of Alphabet Inc., Mountain View, CA, USA.

² Bing is a trademark of Microsoft Corp. Redmond, WA, USA.

³ Baidu, 百度 are trademarks of Baidu Inc., Beijing, China.

⁴ Yandex, Яндекс are trademarks of Yandex LLC, Moscow, Russia.

very different, like horses in a race, constantly outpacing each other, with variable leadership. We have conducted a small internet search experiment (17.11.2023), of course not pretending to objectivity and accuracy, and asked the same question “how can one distinguish hepatocytes from other cell types?” to the four search engines mentioned above.

Google and *Yandex*, in our opinion, did a good job on this query, giving only a list of web pages where descriptions of hepatocytes are found. *Bing*, the undoubted leader in this experiment, immediately gives a definition and a detailed description of what a hepatocyte looks like, provides links to histological microphotographs, adds variants of similar queries (about size, shape, processes and differences), and most importantly, in a separate window begins generating an exact answer to the question of how exactly to distinguish a hepatocyte from other cells, and even more, and indicating the source sites of its information.

Baidu's answers, in our opinion, turned out to be the least accurate, which, however, could be explained by the fact that this engine was “lost in translation” – after all, the main language of this search platform is Chinese and even automatic conversion of the request into this language and given in hieroglyphics does not improve the situation.

However, when you ask the AI system this question, the advantages become obvious. *ChatGPT* provides a thorough answer to this query, listing the differences between hepatocytes and other cell types on several points – morphology, staining technique, cellular arrangement, ultrastructural functions, function, location and marker proteins.

These differences are even more pronounced if we ask a more specific “expert” query. Thus, the question “Which cells can be confusingly similar to hepatocytes?” is beyond the power of any of the search sites. At the same time, AI copes with this task brilliantly, offering several variants of cells morphologically similar to hepatocytes, citing not only and – Kupffer cells (liver macrophages), hepatic Ito cells and hepatic stellate cells, supplementing this list with a generalized description of similar structures and their distinctive features. To be fair, the responses of *GPT-3.5* and *GPT-4* are different. So, the previous model produces a list of the following cells resembling hepatocytes: *Hepatoblasts; Bile Duct Epithelial Cells; Liver Sinusoidal*

Endothelial Cells (LSECs); Kupffer Cells, and Hepatic Stellate Cells (Ito cells). The list generated by *GPT-4* comprises: *Adrenal Cortical Cells; Renal Tubular Cells; Enterocytes; Hepatoid Carcinoma Cells; Pancreatic Acinar Cells; Sebaceous Gland Cells.* Judge for yourself which of the two answers seems more reliable to you.

In preparation for a teaching session or during it, an educator can use the AI system's assistance, e.g., by asking for diagnosis options corresponding to the patient's symptoms or laboratory data. Based on a database of clinical cases and machine learning algorithms, the AI suggests possible diagnoses for a symptom, complaint, or combination of symptoms. AI helps to systematize data, facts, indicators, instantly answering a question formulated in natural language.

It should be noted that the more precise the question, the more specific the answer will be. For example, for the query "How to treat diarrhea?" The AI [*ChatGPT3*, query June 30, 2023] gives a 201-word answer with five different groups of recommendations (hydration, diet, probiotics, hygiene, rest), but no specific medication is mentioned. Whereas for the more specific task "What drug can stop diarrhea?", a 112-word generation is given, mentioning the drug *Loperamide (Imodium⁵)*. When it is refined to "What is the daily dosage of loperamide for adults?" The AI gives the clearest, most specific information of 45 words about the initial dosage, maintenance, and maximum daily dosage, supplemented by the traditional "disclaimer" – mentioning the need to consult a doctor and follow the manufacturer's exact instructions (74 words). The newer version, *ChatGPT-4*, also gives a precise answer to the question, also providing small instructions containing use, dosage, and precautions.

One of the new functions available through *ChatGPT-4*, commencing in Autumn 2023, is the capability to obtain any piece of information by downloading specific articles or book chapters in PDF format – a potent means of improving document interaction abilities. The tool can conduct semantic searches and respond to natural language questions regarding the contents of these written works, while its architecture is designed with a conversational style of interaction in mind. Students can communicate with the language model as if they were interacting with a human teacher or assistant, thus making the

⁵ A trademark of Johnson & Johnson Inc., New Brunswick, NJ, USA.

tool easily accessible even to those who are not well-versed in this specific medical domain. In case of complex queries, the AI can simplify them into several simple, step-by-step questions, meticulously searching through the document for comprehensive and reliable results. This summary or highlight of information is particularly advantageous, as it allows for a rapid grasp of lengthy documents or the identification of key points, without having to read the entire text. If required, the AI PDF feature can locate and extract pertinent citations related to certain subjects. Last but not least, the final outcome is a distinctive text that cannot be discovered through any search, thus providing an effortless means of creating “personal homework” without the risk of facing plagiarism consequences. In general, this feature is a noteworthy progress in enhancing document management and data retrieval efficiency for individuals who manage extensive or intricate documents.

At the end of this section, it is worth noting that even today it is difficult to separate “pure” AI systems from “pure” search engines. During the writing of this book, the author observed significant advancements within a mere six-month span. For instance, Google has introduced Bard, an AI chatbot similar to ChatGPT but with real-time web access, in contrast to ChatGPT’s information cutoff in September 2021. Similarly, Microsoft Bing has integrated ChatGPT’s underlying technology to enhance its search capabilities with AI, also with internet connectivity. The rapid pace of innovation in this area implies that such information may become quickly outdated, even before this book is published.

3.3.2. Multilingual education

The ability of virtual systems, including those based on AI, to generate multilingual educational content is another very special feature, kind of a positive side-effect for the foreign student. In the first courses, the use of e-learning aids and virtual patients allows foreign students to quickly and comfortably master English (or local) language during the learning process. The same process goes in the opposite direction – it is enough to switch the application to English, and students e.g., with native Spanish find themselves in the situation of gathering complaints and anamnesis from a foreign patient. International students studying in an English-speaking environment are immersed in a professional environment, actively mastering vocabulary that is unfamiliar to them. The ability to work through a virtual clinical case in their native language first, or conversely, to work through the scenario in English first and then repeat it in their native language, provides the most natural, authentic way of language acquisition.

This potential has long been recognized by higher education teachers, especially in universities with strong foreign language departments and large international students' community. Virtual reality enables the delivery of educational content in a more engaging and easily comprehensible form. It transforms the tedious process of learning a foreign language through textbooks into an exciting immersion in an authentic environment. This approach enhances students' performance and understanding of the material. Using VR, foreign language competence is more effectively developed, student motivation is heightened, and engagement in the educational process is increased. There's also a growing interest in deeper foreign language study, improved communication among students, and enhanced imaginative thinking and spatial visualization abilities. Running through the virtual clinical cases for the OSCE in English is an excellent training in preparation for USMLE Step 2.

3.3.3. Virtual Assistant, Consultant

How else can students and instructors utilize unique functionalities of AI in medical education? Virtual tutor, consultant, teaching assistant for counseling, summarizing lectures and texts, correction of errors – this is another possible application field of AI in medical education.

AI systems do not just possess a huge information base, more important is they structure it perfectly, can easily filter by specificity, specialty, level of presentation, reliability, and novelty, helping to choose the most appropriate source for the request, summarizing the main points. They understand natural language and answer questions clearly, which allows them to be used as a virtual assistant, replacing the teacher in his absence.

Let's imagine a situation where a student had to choose the correct answer to the question "By how many diopters does the optical power of the crystalline lens change during short distance accommodation?" The physiology textbook has an abundance of numerical data, including information on the refractive power of the cornea and vitreous body, in addition to that of the lens. It can be challenging to comprehend this information and locate the required answer.

The subsequent option to acquire a response is to consult Google or another online search engine. Often, a helpful pre-prepared solution can be found. However, in this instance, the query was misconstrued by Google and the cited website and information is inaccurate.

«...During this time the crystalline lens loses approximately 20 diopters (D) of power, from 43 to 47 D in infancy to 25 D by the age of» and «The crystalline lens contributes approximately +15 to +20 diopters (D) to the refractive power of the human eye in its non-accommodative state. A further 43 diopters are provided by the cornea...». The options provided by Bing.com appear more intriguing, though two responses placed next to each other present somewhat conflicting information.

«During the process of accommodation or adjustment to contractions of the muscle, the lens changes the curvature of the anterior and the posterior segment, and thus it becomes stronger by over 10 diopters, when young.» and «The amplitude of accommodation (AA) is the maximum amount of

optical power change that the eye can achieve. In young adults, the AA is around 12–14 diopters.» Unfortunately, online research has increased the intricacy of this subject. If the student turned to *ChatGPT*, the answer would be correct and received immediately:

«The refractive power of the human lens can significantly increase during close accommodation. In young adults, the lens can typically increase its refractive power by about 10 to 15 diopters during accommodation.» [ChatGPT-4, November 2023].

These findings are in line with the information retrieved from Amboss, a reputable online medical education platform (“is around 14 dpt”). However, accessing this information entails formulating a search query, selecting the relevant article, and reviewing the entire chapter on lens accommodation – this figure is located at the very bottom of the page.

Consider another example: a student has been tasked with preparing a report on the treatment of a patient who developed deep vein thrombosis in the lower extremity two weeks ago. For instance, the report must explain why the use of thrombolytics, drugs that dissolve blood clots, is not recommended when treating a cloth, thrombus. To locate specific information in a book, one must first procure a copy, such as “Surgical Diseases,” which may not always be readily accessible. After obtaining the textbook, one should search the table of contents and text manually to locate the required information. The section on “Acute thrombosis of deep veins of the lower extremities” can be found in the chapter titled “Veins of the lower extremities,” which details treatment options along with other pertinent information. Upon thorough examination of several pages, it is apparent that the term “thrombolytics” is not mentioned. Moreover, there is no mention of any treatment for the two-week-old thrombosis. Hence, a conclusive answer cannot be provided at present.

The second way (if not even the first way for a modern student) is an online search. By the first line of the query “Why 2-weeks old thrombosis is not treated with thrombolytic drugs?” Google gives a link to a review article, where it quotes a part of it “Thrombolytic treatment, also known as fibrinolytic therapy, dissolves dangerous intravascular clots to prevent ischemic damage” and another one with phrase “Thrombolytic therapy for DVT is not used a lot for

a couple of reasons: It takes a long time to administer IV drugs.” – of course, such quotes, taken out of context, can only confuse the reader. The second line offers essentially correct text, but its source is a website for a general, non-medical audience, so it cannot be regarded as a serious source in this situation. The third link may be a reliable source, but it leads to a 13-page article that must be skimmed to find the relevant text. The results of the Bing.com query direct the student to popular websites, Wikipedia, and numerous scholarly articles. Thus, trying to clarify a given topic for oneself can take quite a long time.

At the same time, look at how gracefully, clearly, and accurately artificial intelligence responds to a query:

Treating a 2-weeks old thrombosis with thrombolytic drugs is often not recommended for several reasons:

- **Stability of the Clot:** Over time, a thrombus (blood clot) undergoes organization and is incorporated into the wall of the vessel. This process typically starts within a few days of the clot forming. By two weeks, the clot is often too stable and resistant to the action of thrombolytic drugs, which are most effective on fresh clots.
- **Natural Fibrinolysis:** The body has its own mechanisms for gradually breaking down clots, a process known as fibrinolysis. Over a period of weeks, the body may have already started this process, reducing the necessity for thrombolytics.
- **Increased Risk of Bleeding:** Thrombolytic therapy carries a significant risk of causing bleeding, including life-threatening hemorrhages. The older the clot, the less likely the benefit of thrombolytics will outweigh the risk of bleeding.
- **Presence of Collateral Circulation:** With time, the body may develop collateral blood vessels to bypass the clot. In such cases, the urgency to dissolve the clot diminishes as the body compensates for the reduced blood flow.
- **Risk-Benefit Assessment:** For older clots, the benefits of thrombolytic therapy diminish while the risks remain high. The clinician must assess

whether the potential benefits justify the risks, and often, alternative treatments like anticoagulants are considered safer and more appropriate.

- **Guideline Recommendations:** Clinical guidelines generally recommend thrombolytic therapy within a certain time window after clot formation, typically within hours to a few days for conditions like myocardial infarction or pulmonary embolism. Beyond this window, the guidelines suggest other treatments.

In the case of a 2-weeks old thrombosis, the standard treatment approach would likely involve anticoagulant therapy to prevent further clotting and to minimize the risk of the clot dislodging and causing an embolism. The specific treatment plan would depend on the type of thrombosis, the location, the patient's overall health, and the presence of any risk factors for bleeding.

[ChatGPT-4, November 2023]

This explanation will assist the student in understanding why their seemingly logical answer was marked as incorrect. This is akin to how a teacher would explain the subject if they were asked a question by a student. The AI system performed excellently in its role as a knowledgeable consultant and it took no longer to provide an explanation than a typical Internet search query.

Several extensively used applications have demonstrated an unanticipated ability to operate with AI support, such as possessing "secretarial" capabilities. Thus, in October 2023, Zoom released extra features for its "AI Companion," which could pique the interest of medical students, educators, and healthcare organizations. One exciting feature of the online conference is the AI summary, which generates highlights at the end of the conference. This can be useful for educational, autodidactic, and examination purposes. The summary reproduces the main points of the conversation and provides a protocol of the meeting. Additionally, the review can be used to remember key facts and set out the history of the conversation in the event of an appeal after conversation or examination.

So, we have modeled dialog at the clinical case using the DIMEDUS medical education app during a Zoom conference with only myself as the participant.

The virtual assistant *Zoom AI Companion* was activated during the doctor-patient interaction in virtual case “Lung Abscess”. The case was run on Zoom through the screen share function. The virtual doctor introduced himself to the patient, collected information about the patient’s complaints, answered questions about the patient’s health, and provided explanations for clarifying questions. Then, in order not to delay the testing process, the case was temporarily suspended in DIMEDUS and I, as the virtual doctor, continued to give verbal instructions via the microphone regarding the necessary diagnostic and treatment actions. The AI companion was then stopped, the zoom session ended, and the report was automatically sent to my mailbox :

“Doctor’s Symptoms Discussion With Patient.

Thomas Charles Wilson, a doctor, discussed with Jack Williams Johnson, his patient. Jack complained of symptoms such as fever, sweating, headache, shortness of breath, appetite problems, and dyspnea. The symptoms were mostly observed in the morning, with a fever of 37 to 38 degrees in the afternoon, and sweating at night. Examination and X-ray were to be conducted next, with the aim of diagnosing the condition and prescribing new medications accordingly.”

[generated by Zoom AI Companion, 11 October 2023]

As you can see, AI system correctly and clearly highlighted the key facts including the names of the doctor and physician, main symptoms and indicated that further diagnostic and therapeutic measures are planned.

Therefore, today’s AI systems have the capability to sift through vast amounts of medical literature, research articles and monographs, conversations and lectures and extract key semantic fragments in a manner that some educators may fall short of. This capacity for providing consultations, advice, and explanations presents AI technology with excellent prospects in medical education.

3.3.4. Clinical reasoning, problem-oriented tasks

Another option of using AI in medical education can be a form of teamwork, interaction in the development of clinical thinking, conducting a problem-oriented class, a kind of computerized *Dr. House* where AI acts as a senior team-member. The ability to make an accurate list of potential differential diagnoses based on a given clinical picture is one of the main competencies expected of a medical university graduate. This skill requires practice – the more the better! To spare teaching resources, AI can be used – students compare their diagnostic hypotheses in real time with the options offered by AI, using this additional tool for in-depth study of various clinical pathologies and development of diagnostic skills. This allows for invaluable practice and “hands on” experience in simulated conditions, studying and analyzing different patient histories, comparing symptomatology, prescribing laboratory, and instrumental tests, and making differential diagnoses.

Let's consider an example. The teacher has sent a group of students to the emergency department of a clinic where a young man has recently been admitted with complaints of hand tremors, nausea, diarrhea, and loss of appetite. The future doctors' task is to observe the patient, agree on their suspicions and, once the diagnosis has been made, formulate proposals for his treatment. They are allowed to use the Internet and consult with the AI.

After talking to the patient, the students were divided. A few concluded that the symptoms were associated with psychosomatic disorders, stress, anxiety, or possibly *Tourette's syndrome* or *Parkinson's disease*, whereas other students posited that it was a case of poisoning, substantiated by dyspeptic disorders.

Following a brief discussion, several hypotheses were discarded. Subsequently, during a physical examination, a student brought to the attention of their colleagues the noticeable pallor of the hands and feet, specifically the fingertips and toes. It was conjectured that the individual in question may be suffering from *Raynaud's disease*. To confirm or reject the diagnosis and distinguish it from food poisoning, the students sought the assistance of an AI which instructed them to re-interview the patient, comprehensively gather symptoms, and perform an assessment.

Following a second interview and examination, the patient's clinical presentation includes: nausea, diarrhoea, abdominal distress, dizziness, abnormal tingling and burning sensations in the fingers and toes, painful cramps, pharyngeal muscle spasms, repetitive rhythmic hand movements, pale and cyanotic skin of the extremities (especially the feet and hands), general weakness, lethargy and apathy. The complaints have recently developed and persisted for several consecutive days. There has been no recent hypothermia or stress.

Following consultations with AI and an Internet search for possible causes of the acute development of this clinical presentation, students have formulated the main diagnostic hypothesis – poisoning. However, the etiology of the poisoning needs clarification and appropriate treatment. Potential causes include gastro-intestinal infection, lead poisoning or organophosphate fertilizers. A thorough investigation is required to ascertain the course and progression of the condition. During the conversation, the patient reported spending the prior week assisting his brother in agricultural work at the grain dryer, with responsibilities including cleaning and sorting the harvested rye. Furthermore, he had a meal with his brother at his brother's residence and noted the particularly delicious, fresh rye bread baked on-site. No other unusual food items were consumed, no strong alcohol, no drugs.

The additional information about the consumption of unbaked rye bread significantly narrows down the potential diagnosis and according to the advice of AI one condition aligns closely with the symptoms described and the consumption of unbaked rye bread is Ergot Poisoning (also known as Saint Anthony's Fire). Thus, the group of students collaborating with the AI provided an initial diagnosis of ergot poisoning and suggested intravenous administration of sodium nitroprusside or nitroglycerin beyond detoxification and symptomatic management of seizures, nausea, and diarrhoea.

As a closing remark it is noteworthy that students tend to interact with AI systems as if they were conversing with a human being, sometimes even addressing them by name or nickname. If the response is satisfactory to them, they express gratitude to the person. However, if they find it unsatisfactory, they resort to insulting the person and using offensive language, such as calling them a "stupid idiot" or accusing them of being in a bad mood. This phenomenon, which attributes human-like qualities to non-human entities, is known as *Anthropomorphism* or *anthropomorphizing AI interactions*.

3.3.5. Development of educational materials

AI systems have demonstrated their effectiveness in various fields, including the development of instrumental examination results (such as electrocardiograms, spirometry, and EEG), data and images, three-dimensional anatomical models, clinical scenarios, and virtual patients. Their contribution is invaluable in assisting teachers in the preparation of educational materials. Virtual patient profiles and simulation cases offer a highly promising area for the creation of training materials. This innovative approach simplifies the preparation of these materials, especially when based on clinical cases. Their interactive nature makes them a common choice for training. Medical teachers know that conventional training, presented in just one lecture or in a practical session on a specific theme, fails to inspire students to explore new areas, review literature, and most significantly, leaves them without the ability to make informed clinical decisions. The *case method*, also known as *case-study*, or *case-based education*, utilizes structured data to present and analyze a given situation. This active educational technology promotes objectivity by refraining from subjective evaluations. It ensures clear, precise, and logical communication, while avoiding ornamental or figurative language. Furthermore, it adheres to formal language conventions, including consistent citations, standard technical terminology, passive tone, and impersonal construction. By employing causal connections between statements, the resulting structure provides a factual, objective account of the analyzed situation.

Two crucial components are required when working with clinical cases: students need to interact with each other, the teacher, colleagues including those who work remotely and are responsible for creating and interpreting the scenario. The second crucial aspect entails cultivating a problem-based approach among students, which involves applying concepts to real-life scenarios, drawing connections between interdisciplinary ideas and concepts, examining situations from various perspectives, considering how individuals approach or resolve clinical dilemmas, making decisions, developing projects, and contemplating the ethical implications of situations. However, the benefits of instructive approaches that rely on clinical case solutions are offset by a major drawback, specifically the intricacy of their development. The preparation of a case necessitates detailed descriptions of the complaints,

symptoms, medical background, illnesses, as well as compiling a laboratory analysis and selecting medical images with detailed reports, among other tasks. Although the use of genuine medical records streamlines this process, it comes with caveats related to safeguarding sensitive personal information and the potential absence of eligible patients in the current medical institution. Over time, any case script becomes outdated, and smart students constantly exchange information with each other, so even a good scenario needs to be redone from time to time.

Believing that no one knows its own capabilities better than the AI system itself, we asked the system: «How can you help to create virtual patients for medical educational purposes?»

Creating virtual patients for medical education is a multifaceted task that involves designing realistic and interactive case scenarios. Here's how I can assist in this process:

- **Symptom and History Compilation:** I can help generate detailed patient histories and symptom presentations, mimicking real-life cases. This includes chronicling patients' medical, social, and family histories, along with their current symptoms and complaints.
- **Differential Diagnosis:** For each case, I can list potential differential diagnoses, encouraging students to think critically and consider various possibilities based on the presented symptoms.
- **Flowchart Creation:** Using tools like Whimsical, I can create flowcharts that map out different decision-making pathways. These can include steps like choosing diagnostic tests, interpreting results, and deciding on treatment plans.
- **Branching Scenarios:** I can design branching scenarios where choices at each step lead to different outcomes, simulating the consequences of clinical decisions.
- **Learning Goals:** Each virtual patient case can be tailored to specific learning objectives, ensuring that students gain the necessary skills and knowledge from each scenario.

- Quiz and Assessment Questions: I can formulate quiz questions and assessments to test students' understanding and decision-making skills based on the case scenarios.
- Automated Feedback: For each decision point in the case, I can provide detailed feedback and explanations, helping students understand the implications of their choices.
- Evidence-Based Medicine: I can incorporate references to current guidelines and research to support the feedback, ensuring that students learn evidence-based practices.
- Adaptability: Cases can be adapted for different levels of medical education, from pre-medical students to residents, by varying the complexity and depth of the cases.
- Case Updates: I can help update and create new scenarios over time to keep the content relevant and challenging.
- Ethical and Sensitivity Considerations: Ensuring scenarios are culturally sensitive and ethically sound, promoting an inclusive learning environment.

By combining these elements, you can create an effective and engaging virtual patient simulation environment for medical students, enhancing their learning experience and preparing them for real-world clinical situations.

Well, it sounds very tempting and promising. Maybe we can try together and create a virtual patient ready to work with students in the clinic? Let's try to give such a task to *ChatGPT* (requests and generation of responses on November 19, 2023). The *ChatGPT-4* features a *Project Creation Tool*, that aims that this time was to develop a simulated patient. Initially, general information was given to the AI system, including age, place of domicile, and social status. Next, a description of health status is provided, such as "COPD, alongside liver and heart problems caused by long-term tobacco use and excessive alcohol consumption." Whenever new information is incorporated, the AI updates the model, accordingly, making suitable modifications. Finally, the screen is split into two parts. In one section, there is a service dialogue with the "*GPT Builder*," which oversees the model and its attributes, allowing for changes to be made to the model properties at any point. On the right

side of the screen, there is a dialogue with the virtual patient, with dialogues created uniquely in real time.

MG

Can you create a patient profile for educational purposes? The patient is 53 years old, has been smoking since age 30, lives in a rural area, and belongs to a demographic group with low access to health care.

GPT Builder

The update to Virtual Patient Sim is complete. The simulation now portrays a 53-year-old individual who has been smoking since the age of 30, lives in a rural area, and belongs to a demographic with limited access to healthcare. This profile will guide the patient's descriptions of symptoms, feelings, and personal history, enhancing the educational experience for users.

MG

Please make him talking like a low-educated rural citizen, a farmer

GPT Builder

The Virtual Patient Sim has been updated. It now represents a 53-year-old agricultural worker from a rural area, with low education. The simulation will use simpler language and colloquial expressions typical of this background. This change enhances the realism of the patient's portrayal, focusing on their health experiences and lifestyle.

MG

Can you generate an image of this person?

GPT Builder

Here is the generated image of the 53-year-old male agricultural worker from a rural area. This visual representation aligns with the updated profile of the Virtual Patient Sim. Let me know if there's anything else you need!

MG

Thank you. But this man looks too good. We do not see the traces of wind, alcohol and smoke on his face. Can you regenerate it according to the above prompts?

GPT Builder

The image has been regenerated to better reflect the life experiences of a 53-year-old agricultural worker, including signs of exposure to wind,

Generated: DALL-E, prompting: Maxim Gorshkov, 2023



Fig. 49. First attempt. Definition of the AI is “53-year-old male agricultural worker from a rural area, with a weathered, friendly face showing signs of aging and a lifetime of outdoor work” Doesn’t really match our expectations

Generated: DALL-E, prompting: Maxim Gorshkov, 2023



Fig. 50. Second attempt. AI believes this is “53-year-old male agricultural worker from a rural area, showing clear signs of a harsh life including exposure to wind, alcohol, and smoking”. Seems to be AI understood “smoke, dirt” instead of “smoking”

alcohol, and smoking. Let me know if this version meets your requirements or if you need any further adjustments.

MG

This version is better. But the man should not be literally “dirty”. It should have less intellect in his eyes, should have signs of vascular disorders on the skin. Try again please.

GPT Builder

The image has been updated according to your specifications, showing a 53-year-old agricultural worker with a less intellectual expression and signs of vascular disorders on his skin, reflecting a tough life without appearing dirty. Please let me know if this version aligns with your requirements or if any further adjustments are needed.

The remarkable capability of AI to create images from written descriptions is known as *Text-to-image generation*. While the earlier iteration, GPT-3, lacked this feature, the more recent GPT-4 now interfaces with various plug-ins, one of which enables it. The prompting of the *GPT Builder* pictures generator *DALL-E*¹ was continued several rounds more, adding concrete signs like unkempt, greasy, and unwashed hair, mustache with pale color due to constant smoking, and some other features reflecting a life of hard work and limited self-care. This ability to use information from previous tasks and gradually improve future responses is called *Prompt chaining*. So, here are several variants with all alterations including the final version [Fig. 49-52].

GPT Builder

The image has been adjusted to include a chapped face, dry skin, visible capillaries, spider veins, and the dull look of an alcoholic. The subject's hair is unwashed, the mustache stiff and completely gray with a reddish tint around the lips, and he sports a three-day stubble instead of a full beard. This portrayal aims to reflect the hard life and limited self-care of a 53-year-old agricultural worker from a rural area.

Please review this version and let me know if it meets your requirements or if you need any further modifications.

MG

Can you create auscultation sounds typical for CPOD?

¹ DALL-E is text-to-image models developed by OpenAI Inc., San Francisco, CA, USA.

Generated: DALL-E, prompting: Maxim Gorshkov, 2023



Fig. 51. Third attempt. Description was “A 53-year-old male agricultural worker from a rural area, with a less intellectual expression and signs of vascular disorders on his skin”. Really better, but still not exactly what was needed

Generated: DALL-E, prompting: Maxim Gorshkov, 2023



Fig. 52. Last, seventh attempt of imaging a not really healthy person. AI describes it as an image of “A 53-year-old male agricultural worker from a rural area with a chapped face, dry skin, visible capillaries and spider veins, and the dull look

GPT Builder

Creating an actual sound of auscultation typical for Chronic Obstructive Pulmonary Disease (COPD) is beyond my capabilities. However, I can describe what such a sound would typically be like:

In COPD, during auscultation (listening to the sounds of the body, typically using a stethoscope), a doctor might hear:

1. **Wheezing:** A high-pitched whistling sound, most prominent on exhalation. It's caused by the narrowing of airways.
2. **Decreased Breath Sounds:** Due to poor airflow in and out of the lungs, the breath sounds might be quieter than normal.
3. **Prolonged Expiration:** The exhalation phase of breathing is longer than normal, a characteristic feature of obstructive lung diseases like COPD.
4. **Crackles or Rales:** In some cases, especially if there's a concurrent infection or other lung conditions, there might be crackling sounds.

These sounds are key indicators that help healthcare professionals in diagnosing and assessing the severity of COPD. For actual audio examples, medical training resources or auscultation simulators would be the most accurate sources.

Even though AI refused to provide an audiogram, it's worth noting that an online search for "find mp3 audio wheezing crackles and rales typical to COPD" yields several appropriate options. Therefore, an AI-powered function for this purpose will likely be available soon. It's safe to assume that a tool for searching and generating sound effects like this will be developed in the next few months, or perhaps at most a year or two.

MG

Due to his style of life this patient may have *tension angina pectoris*. Can you create an electrocardiogram with typical stenocardia changes?

GPT Builder

Creating an actual electrocardiogram (ECG) image with specific changes indicative of stenocardia (angina pectoris) is not within my capabilities. However, I can describe what such an ECG might typically show: In a case

of stenocardia, particularly during an anginal episode, an ECG might exhibit the following changes:

- 1. ST-Segment Depression:** The most common finding in angina pectoris during an episode is ST-segment depression. This is due to subendocardial ischemia.
- 2. T-wave Inversion:** T-waves may become inverted as a result of ischemia, but this change is less specific and can occur in other conditions as well.
- 3. Transient Changes:** These changes usually occur during the pain episode and return to normal once the episode resolves.
- 4. No Q-Wave Formation:** Unlike a myocardial infarction, stenocardia typically does not lead to the formation of pathological Q waves.

It's important to note that during periods without symptoms, the ECG of a patient with angina pectoris may be completely normal. For training or educational purposes, medical textbooks, online educational platforms, or specialized software would be the best resources to find actual examples of ECGs with these specific changes.

MG

Can you make an ECG-image looking like real ECG? Do you have samples of real ECG?

GPT Builder

I don't have direct access to real ECG samples, as my capabilities don't include storing or retrieving real patient data or medical images. However, real ECG samples can typically be found in medical textbooks, online medical resources, and educational platforms. Here are some suggestions for where you might find them:

- 1. Medical Textbooks:** Books on cardiology or general medicine often have chapters dedicated to ECG interpretation, complete with real samples.
- 2. Online Medical Libraries and Databases:** Websites like PubMed, Medscape, and the American Heart Association often have educational sections with ECG examples.

3. Educational Platforms: Online platforms like Khan Academy, Lecturio, and Geeky Medics offer tutorials on ECG interpretation, often including real ECG tracings.

4. Medical Journals: Journals like the New England Journal of Medicine or the Journal of the American College of Cardiology often publish case studies that include ECG tracings.

5. Hospital and University Websites: Some academic hospitals and universities provide educational resources that include ECG samples.

Remember to use these resources in accordance with their terms of service and any applicable privacy laws, especially if using them in a professional or educational setting.

MG

Ok, give me the real laboratory test findings with actual numbers relevant to his conditions

GPT Builder

For a patient like the one described in the Virtual Patient Sim, with Chronic Obstructive Pulmonary Disease (COPD), slight hypertension, and alcoholic liver disorders, typical laboratory test findings might include the following. Please note, these are generalized examples and actual patient values can vary widely:

1. Complete Blood Count (CBC):

- Hemoglobin: Could be normal or slightly elevated due to chronic hypoxia.
- Hematocrit: May be elevated, reflecting polycythemia, a common response to chronic hypoxia in COPD.
- White Blood Cell Count: Normal or slightly elevated, especially if there's a concurrent infection.

2. Arterial Blood Gas (ABG):

- PaO₂ (partial pressure of oxygen): Lower than normal, indicating hypoxemia.
- PaCO₂ (partial pressure of carbon dioxide): May be elevated in advanced COPD, reflecting respiratory acidosis.

- pH: May be normal or slightly decreased by respiratory acidosis is present.

3. Liver Function Tests:

- AST (Aspartate Aminotransferase) and ALT (Alanine Aminotransferase): Elevated levels, indicating liver damage.
- GGT (Gamma-Glutamyl Transferase): Often elevated in chronic alcoholism.
- Bilirubin: May be elevated, depending on the degree of liver damage.
- Albumin: May be decreased in chronic liver disease.

4. Lipid Profile:

- Slightly elevated cholesterol and triglycerides, common in alcoholism.

5. Renal Function Tests:

- May be normal or show mild dysfunction depending on the hydration status and overall health.

6. Electrolytes:

- Potassium and Sodium: Can vary, especially if the patient is on diuretics for hypertension.

7. Cardiac Biomarkers:

- Normal unless there's concurrent cardiac involvement (not directly related to COPD or liver disease).

Remember, these values are hypothetical and for educational purposes. Actual patient results would depend on many factors including the severity of the conditions, comorbidities, and individual variation. For specific patient cases, it's always best to consult with a healthcare professional.

As you can see, *ChatGPT* generated an acceptable text, but lacks specificity needed for this learning scenario where students require printed data to analyze. Additionally, AI mechanisms are in place to safeguard against potential legal issues, leading to frequent disclaimers in generated texts. However, it is crucial to note that negotiating with the system is viable:

MG

This is not a specific patient case; it is an educational fictive simulated scenario you created by yourself. Please repeat laboratory tests above but with concrete numbers, figures that are out of the normal ranges.

GPT Builder

Certainly! For an educational, fictive case of a 53-year-old male with COPD, slight hypertension, and alcoholic liver disorders, here are some hypothetical laboratory test results with specific numbers that indicate abnormalities:

1. Complete Blood Count (CBC):

- Hemoglobin: 16.5 g/dL (normal range: 13.8–17.2 g/dL)
- Hematocrit: 49% (normal range: 40.7–50.3%)
- White Blood Cell Count: 12,000 / μ L (normal range: 4,500–11,000 / μ L)

2. Arterial Blood Gas (ABG):

- PaO₂: 60 mmHg (normal range: 75–100 mmHg)
- PaCO₂: 50 mmHg (normal range: 35–45 mmHg)
- pH: 7.32 (normal range: 7.35–7.45)

3. Liver Function Tests:

- AST: 80 U/L (normal range: 10–40 U/L)
- ALT: 70 U/L (normal range: 7–56 U/L)
- GGT: 100 U/L (normal range: 9–48 U/L)
- Bilirubin: 1.8 mg/dL (normal range: 0.3–1.2 mg/dL)
- Albumin: 3.2 g/dL (normal range: 3.4–5.4 g/dL)

4. Lipid Profile:

- Total Cholesterol: 220 mg/dL (normal range: <200 mg/dL)
- Triglycerides: 250 mg/dL (normal range: <150 mg/dL)

5. Renal Function Tests:

- Creatinine: 1.2 mg/dL (normal range: 0.6–1.2 mg/dL)
- Blood Urea Nitrogen (BUN): 18 mg/dL (normal range: 7–20 mg/dL)

6. Electrolytes:

- Potassium: 4.5 mmol/L (normal range: 3.5–5.1 mmol/L)
- Sodium: 142 mmol/L (normal range: 135–145 mmol/L)

7. Cardiac Biomarkers:

- Troponin: Within normal limits (as there's no active cardiac event).

These values are purely hypothetical and for educational purposes, demonstrating typical abnormalities you might expect in such a case. Actual patient results can vary based on numerous factors, including the stage and management of their conditions.

MG

What other instrumental examinations and diagnostic tests could be useful in determining the condition of this patient?

GPT Builder

For a patient with Chronic Obstructive Pulmonary Disease (COPD), slight hypertension, and alcoholic liver disorders, several instrumental examinations and diagnostic tests would be useful in determining their condition and managing their care. Here's a list of relevant tests:

1. Pulmonary Function Tests (PFTs):

- To assess the lung function, including spirometry to measure the volume and flow of air during inhalation and exhalation.

2. Chest X-ray:

- Useful for visualizing the lungs, heart, and chest cavity. Can show hyperinflation, flattening of the diaphragm, or other changes associated with COPD.

3. CT Scan of the Chest:

- Provides a more detailed image of the lungs than a standard X-ray and can help in detecting emphysema and other lung conditions.

4. Echocardiogram:

- To evaluate heart function, particularly the right heart, which can be affected in advanced COPD.

5. Electrocardiogram (ECG):

- To monitor heart rhythm and detect any strain on the heart from lung conditions.

6. Blood Pressure Monitoring:

- Regular monitoring to manage hypertension.

7. Liver Ultrasound:

- To visualize the liver and assess for any signs of liver disease, such as fatty liver or cirrhosis.

8. Endoscopy:

- If there are symptoms suggestive of gastrointestinal complications from alcohol use, such as esophageal varices.

9. Alpha-1 Antitrypsin Level:

- Especially if the patient is young or has a family history of COPD, to rule out alpha-1 antitrypsin deficiency.

10. 6-Minute Walk Test:

- To assess the functional exercise capacity and the impact of COPD on daily living activities.

11. BNP (B-type Natriuretic Peptide) or NT-proBNP Testing:

- If there's suspicion of heart failure.

12. Blood and Sputum Cultures:

- If there is suspicion of a respiratory infection.

These tests provide a comprehensive assessment of the patient's respiratory, cardiovascular, and liver health. The choice of tests would be guided by the patient's specific symptoms, the severity of their conditions, and their overall health status. Regular monitoring and follow-up tests are also crucial for managing chronic conditions like COPD and hypertension.

Thus, carrying on the conversation with AI will provide access to the comprehensive text of the final outcomes encompassing twelve proposed research methods, including specific indicators and precise clinical diagnostic formulations. However, the system presents an even more astonishing feature – the ability to communicate with a fictitious patient. Have a closer look. I pose questions on behalf of the attending practitioner, and a simulated patient, generated with AI, gives immediate responses.

MG

Hello, my name is Dr. Gorshkov. Tell me what were the reasons you to visit us today.

Simulated Patient GPT

Hey there, Dr. Gorshkov. Well, I've been havin' some trouble with my breathin' for a while now. It's like, I get short of breath real quick, especially when I'm workin' out in the fields or even just walkin' around. It's been gettin' worse over the past few years, I reckon.

Also, I've been coughin' a lot, and it ain't just a normal cough, you know? It's this heavy, kinda wheezy cough, and sometimes I spit up this stuff that's all thick and sometimes a bit discolored. And, well, I've been smokin' for a good number of years, so I don't know if that's makin' things worse.

Oh, and I've been feelin' kinda tired all the time, even when I ain't done much work. My wife says I should've seen a doctor sooner, but you know how it is, we're always busy and it's not easy to get to a clinic from where we live.

Also, I've had some issues with drinkin' in the past, and I've been told that ain't good for my liver. But I can't say I've felt much pain or anythin' there, just this tiredness and the breathin' trouble mostly.

That's about it, Doc. What do you think could be goin' on?

MG

Ok. I see. How difficult is for you condition with breath shortage? Is it bad only by physical activity?

Simulated Patient GPT

Yeah, the breathin' thing can get pretty rough sometimes. When I'm doin' physical work, like heavy liftin' or movin' stuff around the farm, that's when it gets real bad. I gotta stop and catch my breath more often than I used to. It feels like I just can't get enough air in, you know?

But it ain't just with the hard work. Even walkin' a bit faster or takin' the stairs can set it off. Mornings can be tough too, with all the coughin' and tryin' to clear my chest. It feels like I'm fightin' for air at times.

And it ain't just recent, it's been buildin' up over time, gettin' worse bit by bit. I thought it was just 'cause I'm gettin' older, but it don't seem normal now.

MG

What do you do for life, where do you work?

Simulated Patient GPT

I work on a farm, Doc. Been doin' it pretty much my whole life. It's mostly crop work, you know, tending to fields, planting, harvesting, that sort of thing. It's a lot of physical labor, being outdoors most of the time. I deal with

all sorts of machinery and tools, too.

The work's hard, but it's what I know and it's how I provide for my family. With all the dust and stuff in the air, especially during the harvest, it can get pretty rough on my breathing. I've been doin' this kind of work since I was real young, never really thought much about how it might be affecting my lungs, you know? Plus, with the smoking for so many years, I guess it all adds up.

MG

You have mentioned, you smoke for a while? How many cigarettes a day?

Simulated Patient GPT

Yeah, I've been smokin' for a long time now. I'd say I go through about a pack a day, sometimes a bit more if it's a particularly long or stressful day. I started smokin' when I was pretty young and just never really stopped. I know it ain't good for me, especially with how I've been feelin' lately, but quittin's easier said than done, you know?

MG

You mentioned cough. Do you cough only in the morning or throughout the day? Is the cough dry or wet with sputum?

Simulated Patient GPT

The cough, it's kinda there most of the day, but it's definitely worse in the morning. That's when I have this heavy spell of coughin', tryin' to clear my chest. Throughout the day, it comes and goes, especially if I'm doin' somethin' physical or if there's a lot of dust around.

It's not a dry cough, Doc. There's usually sputum comin' up when I cough. The stuff I cough up, it's thick and sometimes it's got a bit of a color to it, like yellowish or greenish. It feels like there's always somethin' there in my chest that I gotta cough out. It's been like this for a while, but I reckon it's gotten worse over the past year or so.

And so on, so on... the dialogue appears to be natural, and the virtual patient comprehends questions and offers answers that align with the given scenario. However, it may be excessively detailed, hindering the development of diagnostic skills in the student. Let us refine the dialogue to enhance its utility for learners.

MG

Your simulated patient answers all the questions too precisely with many details. Please change his habits, make his answers shorter, give the learner more space to develop communication skills of collecting complaints and anamneses.

ChatGPT Builder

I've updated Virtual Patient Sim to provide shorter and more concise answers. This change will give learners more opportunity to develop their skills in gathering complaints and collecting anamneses. The patient will now avoid long, detailed explanations unless specifically prompted, while maintaining a casual and approachable demeanor. Anything else you'd like to adjust?

MG

Let us try to communicate with him and we will see.

ChatGPT Builder

Absolutely, feel free to start a conversation with Virtual Patient Sim. You can ask about his health, lifestyle, or any other related topics to see how he responds with his updated behavior. Let's see how it goes!

New dialog appears to be different from the first one:

MG

Hello, my name is Dr. Gorshkov. Tell me what brought you here today.

Simulated Patient GPT

Hi, Doc. Been feelin' short of breath lately, especially when I'm workin' on the farm. Cough's been worse too, more in the mornin'. And yeah, this cough's been hangin' around for a while now. Just feels harder to breathe these days.

MG

Ok, I see, so you have coughs and problems with breath. What kind of cough you have? Is it dry or wet, with sputum?

Simulated Patient GPT

It's a wet cough, Doc. There's usually some sputum when I cough, especially in the mornings.

MG

Does sputum have any smell, what kind of color it is?

Simulated Patient GPT

The sputum's kinda yellowish. Don't really notice any special smell to it.

MG

Your cough is in the morning only or during the day as well?

Simulated Patient GPT

It's worst in the morning, but yeah, I do cough during the day too, especially if I'm doin' somethin' a bit more strenuous.

As you can see, the style of dialogue has been thoroughly transformed in accordance with the given learning goals. The responses have shortened, demanding greater exertion from students to extract essential AI data from reticent virtual patients. This example definitely demonstrates AI's aptitude for generating infinite simulated patients. Thus, the use of AI in creating educational clinical cases seems very promising.

Generated: DALL-E, prompting: Maxim Gorshkov, 2023



Fig. 53. According to the opinion of the AI this should be “a realistic, modern bedside monitor in a hospital setting. The monitor displays vital signs relevant to a 53-year-old male patient with Chronic Obstructive Pulmonary Disease.” As you can see, the DALL-E has utterly failed at this task

When working with the virtual patient constructor, different tasks emerge, some of which AI copes brilliantly (imitation of a farmer's rural speech), others not so well, some tasks prove to be challenging for the AI. For instance, it has not yet accomplished creating precise images with accurate data, figures, or curves, and almost no electrocardiograms or radiographs are generated despite their descriptions being in good order. The appearance of the bedside monitor may seem appealing at first, but upon closer inspection of the individual graphs and the corresponding parameter values, it becomes apparent that these iterations are not suitable for educational purposes at present, cannot be used for teaching students [Fig. 53].

The image may be more appropriate for a low-budget medical drama set in an ambulance. However, this irony is reassuring, friendly and encouraging, as AI is in its early stages. Considering the speed of its development, it is likely that generating credible monitoring screens with dynamic physiological changes is imminent. Nevertheless, this functionality is not of paramount importance to achieve the educational objectives of practicing questioning complaints, collecting anamnesis, and making a diagnosis. The recognition and treatment of chronic and acute conditions do not necessitate the utilization of dynamic patient monitoring with a mathematical model of physiology, which is only indispensable for stabilizing patients in life-threatening emergencies. Broadly speaking, the implementation of AI in crafting educational clinical cases appears highly encouraging.

3.3.6. Objective assessment of knowledge and skills

Artificial intelligence systems can provide automated assessment and feedback in medical education through a variety of methods and technologies. Complementing the capabilities of training systems already in use today, AI can be embedded into the educational environment, giving it new functionality. For example, by analyzing students' written and verbal responses to tests, assessments, and exams, AI can automatically grade them. This includes not only multiple-choice tests, but also randomly written essays and even oral exams. Using speech recognition and *Natural Language Processing* (NLP) systems, AI understands the speech of examiners or patients, as well as complex medical texts, medical records and objective studies, algorithms them and gives an objective assessment of students' answers according to predetermined criteria of clinical knowledge, practical application and even grammar.

Obviously, having reference answers available, it is not a difficult task to compare students' answers with them. Many researchers have gone further to see if the AI systems themselves can successfully cope with medical exams and generate correct answers. Thus, there have been several studies investigating *ChatGPT's* ability to pass medical exams, in particular the *USMLE* (*United States Medical Licensing Examination*, a three-step multiple-choice exam).

For example, in one of the first papers to investigate this topic at the end of the last year, 376 publicly available test questions were taken from the publication of all three steps of the June 2022 mock exam on the official *USMLE* website. Questions containing visual items such as clinical images, medical photographs and graphs were excluded, and the remaining 305 *USMLE* questions (Step 1: 93, Step 2: 99, Step 3: 113) were allowed for the virtual exam. After excluding the undefined options, the results of the selected ChatGPT responses showed for *USMLE Steps 1 – 75.0%*, Step 2 – 61.5% and Step 3 – 68.8% respectively. It is noteworthy that according to the literature, the previous iteration of the *GPT LLM* (*GPT3*) achieved an accuracy of 46% with zero prompts, which improved slightly to 50% after machine learning the model and extensive adjustment of prompts, while the previous models only a few months earlier showed a result of 36.7%, thus, there is a rapid increase in model competence [Kung TH, 2023].

The authors of this article were thinking not only about the system's ability to pass the licensing exam, but also about its potential application in preparing students for the exam. The answers generated by the artificial intelligence also offered unique insights, modeling a valuable deductive reasoning process for learners. Approximately 90% of the output data contained at least one such significant insight. Thus, *ChatGPT* has a partial ability to teach medicine by identifying new and non-obvious concepts that may be inaccessible to learners. Such revelation of unintended abilities of the AI is called *Emergent behavior*, which refutes the common misconception of ignoramuses who believe that AI systems are only capable of reproducing what a person has discovered or thought of before them.

The 14 multi-part case studies were selected from clinical reasoning exams administered to pre-clinical medical students between 2019 and 2022. For each case, questions were provided twice to the *ChatGPT* and their responses were recorded and independently scored by two clinician educators according to a standardized rubric. To further assess the degree of variability in AI system performance, one of the most difficult cases was retaken 20 times. 12 of the 28 sample *ChatGPT* exam answers achieved a passing score (Passing score = 43%) with a mean of 69% (95% CI: 65–73%), meaning that these answers were considered passing. However, the AI system did not reach the pass threshold (Passing threshold = 70%) that should have been reached in this section to be considered a successful test taker. When completing the same task 20 times, the results of the *OpenAI* creature varied from 56% to 81% [Strong E, 2023].

By successfully passing the US Medical Licensing Exam, *ChatGPT* has proven that it has mastered the program at levels one and two of the Miller pyramid – the system is knowledgeable, “knows about” all the theories available at the time of its training (September 2021) and even “knows how” to apply them. However, fulfilling these formal requirements does not end the doctor's professionalism. So far, the AI has not demonstrated how it can apply its knowledge (even though, it has not been asked to do so!). Although this software solution lacks an interface for interacting with the environment, natural language dialog capabilities, and a system for cognition and image generation, these functions can be easily combined with existing software solutions to create a “*SuperChatGPT*” in just a few months or even weeks. It is important to note that the pyramid also has the fourth level, known as

“does.” The evaluation of a doctor’s performance extends beyond the range of medical procedures carried out or medication prescribed. It is equally crucial to comprehend the doctor’s patient interactions, response to failure, decision-making in times of ethical dilemmas or limited resources, and professional communication with colleagues and patients. It is necessary to assess the physician’s ability to retrain, to reject outdated doctrines and adopt new advanced concepts, to understand how and why these changes occur. These points should be given more attention in medical education, and an attempt should be made to assess these competencies during the study and after graduation.

The main takeaway from the research demonstrating *ChatGPT’s* ability to pass the physician licensing exam is that it is time to rethink how and what we assess students. In addition to verbal and written responses, AI can also assess the direct actions of students, residents, and physicians, which is especially relevant in practical skills training and surgical specialty training.

Here are several instances of AI systems employed for automated assessment of medical students and practitioners presently operational. Consequently, researchers have been endeavouring to develop an objective method for evaluating practical surgical skills for numerous years. Currently, the gold standard is the systematic evaluation of surgical videos by experienced surgeons using standardized global scales, which is a precise but highly labor-intensive process – numerous hours of manpower are necessary to assess each procedure. Nevertheless, AI has opened up new prospects. Similarly, a recent British study appraised three cloud-based AI-driven video analytics platforms for minimally invasive surgery (*CAV*, stands for *cloud-based artificial intelligence-driven video analytics*): *Theator*¹, *Touch Surgery*² and *C-SATS*³ enable video storage and viewing, alongside the integration of a structured skill assessment and progression results for surgical residents and surgeons’ portfolios [Gendia A, 2022].

The *Theator Surgical Intelligence Platform* is the world’s first and only surgical

¹ Theator, Palo Alto, California, USA.

² Touch Surgery is a trademark of Medtronic, Dublin, Ireland.

³ C-SATS is a trademark of Johnson & Johnson Inc., Seattle, Washington, USA.

AI system for real-time video (as the name and wording are on the website). *Theator* automatically turns on recording and analysis at the start of surgery, providing operational updates to optimize surgical efficiency and notify surgeons of critical events occurring during surgery. Each user has their own on-demand cloud-based video library that organizes each user's experience and provides a convenient list of favorites, shared and saved intervention videos, including on-demand viewing of key surgical moments.

The *TouchSurgery* service, primarily known for its free educational mobile application for studying the stages of various surgeries using artificial intelligence algorithms, automatically segments the surgery video into key stages of intervention, which, as in the previous example, allows you to conveniently find the necessary fragment of any recording.

The C-SATS platform automatically captures video, uploads it to the cloud, AI systems remove metadata from the file, including date and time stamps, and performs step-by-step segmentation for individual interventions. The user or the administration of the educational or treatment institution is then provided with analytics and benchmarks of the interventions performed, a personalized surgeon's dashboard, expert feedback, and objective performance evaluation. It is specifically stated that this service has a number of conditions, is performed for a limited number of operations and is only available to specialists and clinics from the United States.

Automated assessment of actions in simulated conditions is no less important than in the real operating room, because it is during simulation training that the foundations of future mastery are laid, and an incorrectly learned skill will require long retraining, not always successful. At this point, constant feedback, formative assessment of actions, hints, corrections, adjustments of movements, posture, grip, and the like are especially important.

A group of researchers from Texas developed a system to evaluate simple knot suturing of a Penrose drain, a basic skill for any surgeon. The video was provided by sophomore students who learned the technique on their own during the coronavirus pandemic from a training video. The criterion for successful execution was to apply the knots in less than two minutes without critical errors. AI models based on convolutional neural networks performed the automatic evaluation. They were able to classify and recognize a range

3.3.7. Proctoring

Traditionally, in English-language literature on education, the term *‘Proctor’* refers to an official responsible for invigilating exams and monitoring students. The term *‘procurare’* originated from Latin, meaning “to act”, “to obtain”, “to acquire”. Through various periods, its meaning evolved from “acting on behalf of another person” to “farm manager”. Other terms which share the same origins include “Prosecutor”, “Prokura”, and “Procurator” – the last of which pertains to governors appointed by the Emperor to oversee remote provinces in Ancient Rome. Today, online proctoring refers to a complex setup for monitoring and managing assessments conducted distantly. Predictions from some authors suggest that online proctoring technology will soon become ubiquitous, a “new norm” in higher education globally. [Andrejevic M, Selwyn N., 2021].

Today, a number of medical schools use automated proctoring systems on an ongoing basis—technological solutions using artificial intelligence systems supplemented by human observers, designed to effectively monitor students taking online exams in a virtual presented (via computer in the classroom) or in a remote online environment (in absentia, at home), ensuring strict compliance by examinees with regulations and rules, see below the AI’s opinion on this matter:

Proctoring an examination refers to the process of supervising or monitoring students during a test to ensure the integrity of the exam. The role of a proctor, whether it’s a person or an AI system, typically involves several key responsibilities like ensuring a fair and equal testing environment, verifying student identity, enforcing exam rules, documenting irregularities, cheating or rule violations. In the context of AI proctoring, these tasks are performed using technology such as video monitoring, browser lockdowns, and algorithms that detect suspicious behavior. AI proctoring is increasingly used for remote or online examinations, offering a scalable and efficient way to maintain academic integrity. However, it also raises concerns about privacy and the potential for false accusations, requiring careful implementation and oversight.

When conducting an online exam, the following mechanisms are usually used:

- **Real-time Video Monitoring:** Students are required to keep their webcams on so that AI can observe them in real-time throughout the exam to detect any suspicious activities.
- **Screen Sharing:** Software requests screen sharing during the exam to ensure that the student does not access external reference resources.
- **Browser Lockdown:** Online proctoring software may prohibit students from accessing other websites or applications during the exam, limiting the possibilities for seeking external help or looking up information on the internet.
- **Behavior Analysis Based on Artificial Intelligence:** This involves detecting unusual behavior, such as head or eye movements, which may indicate cheating or receiving prompts.
- **Document Verification or Facial Recognition:** Before the exam, identity verification is performed, for example, requesting an ID or conducting biometric verification to ensure that the person in front of the screen is indeed the one listed in the roster.

The use of AI in proctoring medical education exams can be seen from multiple perspectives, both positive and negative:

Advantages

- **Objectivity and Fairness:** AI systems can provide unbiased assessment, ensuring equal treatment of all students.
- **Efficiency and Scalability:** AI can handle large volumes of exams simultaneously, reducing the need for human proctors and saving time.
- **Sophisticated Monitoring:** AI can detect subtle signs of academic dishonesty that might be missed by human proctors.
- **Convenience for Remote Exams:** In the era of online learning, AI proctoring allows for secure testing environments even when students are not physically present in a classroom.

Challenges and Concerns

- **Privacy Issues:** Continuous surveillance by AI can raise concerns

about student privacy and data security.

- False Positives/Negatives: AI systems might mistakenly identify honest behavior as cheating, or vice versa, leading to unjust outcomes.
- Technical Limitations: AI may not always accurately interpret complex human behaviors and contexts.
- Ethical Considerations: There's a debate about the ethical implications of constant surveillance and the pressure it might put on students.

While AI proctoring in medical education offers efficiency and objectivity, it is essential to balance these advantages with considerations of privacy, fairness, and the psychological impact on students. Continuous improvement of AI algorithms and careful policy-making around its use are crucial to address these challenges.

[ChatGPT-4, November 2023]

As a small comment, let me point out that the text above has been generated by ChatGPT-4 based on three prompts. So, generally, it is sufficient to formulate appropriate questions to obtain the precisely tailored information. Would you agree that this is a ready-made outline of a manual for the application of AI systems in proctoring? This function alone, the ability to generalize, systematize and make recommendations is enough to appreciate the generative linguistic model and to express our gratitude to the developers who created it!

As part of the process of ensuring “fair play” in medical education and scientific research, plagiarism detection tools based on artificial intelligence can be utilised. These tools can assist teachers in identifying and dealing with instances of academic dishonesty, including cheating in student assignments, essays, term papers and research papers. These tools can detect not only verbatim copying, but also modifications created with copyright-avoidance programs, and can be used not only during examinations, but in various other areas as well.

Automated proctoring platforms for monitoring online tests appeared over 15 years ago, and today there are dozens of systems available. These

software solutions are equipped with necessary functions for controlling the course of assessment processes, including: *Verification* that is conducted through automated facial biometrics, comparing the results with data from a passport or student record book; *Telecommunication*, *Video surveillance* and *360° overview* are employed to monitor the examinee's actions, and a video recording of the entire room is made to analyze all accompanying activity; *Audio Monitoring* ensures control over silence and prohibits conversations and prompts; *Covert Communication* refers to the undisclosed communication among the members of the examination committee and their ability to switch between various points of suspicious activity; *Locked Browser* feature ensures that users cannot open any other sites for reference information during testing; *Screen Share* feature enables direct observation of the user's monitor, while *Markers* are red flags that are set covertly by the system to draw attention to an account due to suspicious activity; *Scoring* is the automatic counting of penalty points for detected violations.

Such features have obvious appeal to universities, providing them with significant automation of the exam process, reducing the burden on faculty and administrative staff. "Our system is constantly learning, adapting and getting smarter with each exam. It's goal in incorporating AI into proctoring is not to replace humans, but rather to improve proctoring accuracy by helping humans identify details such as shadows, whispers or low pitches, reflections, etc. that might otherwise go unnoticed," states the developer of one such system, *ProctorU*¹. But these technologies have alarmed students and teachers, some of whom see them as a threat to personal data, personal freedoms, and the potential for unfair and discriminatory evaluations. After all, not everyone would like to expose their private room or share personal information, including facial biometrics and passport data, with third-party companies, service providers, and software developers. "The rapid and controversial proliferation of online proctoring applications is an example of how AI is penetrating all spheres of life, creating certain social consequences and ethical challenges," say the authors of the study, which they titled "Good Proctor or Big Brother? The Ethics of Online Examination Control Technologies" [Coglan S. et al., 2021].

¹ ProctorU is a trademark of ProctorU, Inc. Birmingham, AL, USA.

3.3.8. Adaptive, personalized learning

As discussed above, AI is able to create teaching materials and manuals by itself or under the instructor's prompts, and then automatically assess the degree of mastery of the program by the students. The next logical step is to combine these tasks into a qualitatively new functionality – the organization of the learning process itself, including conducting classes and adapting the material to the individual characteristics of each specific student.

We already know very well and widely use Learning Management Systems (LMS) in higher education. But the application of AI to these LMS platforms will open wide perspectives, potentially revolutionizing how we approach teaching and learning. It could also automate administrative tasks, like grading and feedback, allowing educators to focus more on interactive teaching. Furthermore, AI-driven analytics can provide deeper insights into student performance and engagement, identify areas needing attention and support.

This program personalization addresses the following issues: Accurate and detailed assessment of the student's mastery level is crucial to diagnose gaps, errors, and difficult-to-understand topics. Based on the analysis of the student's performance, the pace and complexity of the material will be adapted to their needs. Additional explanations and repetition will be provided for insufficiently mastered topics, and practical exercises will be repeated to refine potentially dangerous manipulations. The program will provide in-depth coverage of intensely important topics, as well as guarantee comprehensive coverage of all necessary topics. Distributed learning will also be utilized to optimize the student's progress. All these measures will be taken to ensure the student's successful acquisition of the material.

Such professionals in the field of medical training who perform such duties are referred to in various ways – supervisor, instructor, coordinator, mentor, tutor, facilitator – but, in fact, they all provide adaptive, personalized learning with regular feedback in the classical form. Virtual platforms equipped with AI realize this functionality in an autonomous mode. This not only increases the efficiency and effectiveness of learning, but also potentially reduces student stress associated with mastering a complex program.

3.3.9. Psychological monitoring and forecasting of results

Artificial intelligence has the potential to monitor the psychological state of learners, which can be useful for optimizing their curriculum and providing support to prevent stress. AI algorithms can detect mood dynamics by analyzing written or verbal responses, forum posts or online interactions to identify signs of stress, anxiety or other emotional states. This data can help teachers and administrators adjust workloads, modify curricula, identify abnormalities, including in grades or teaching styles, and provide preventive conversations in the most challenging situations. Virtual student support systems, chatbots or virtual assistants based on artificial intelligence can not only answer academic questions, but also chat, discuss student news and even give advice on how to approach a strict examiner. Refer students to counseling services if signs of prohibitive levels of stress, anxiety, or worry are detected. Early warning systems, by analyzing academic and behavioral parameters, can identify patterns and alert educators and counselors to intervene and provide appropriate support.

By analyzing academic achievements, the AI can create performance profiles that reflect not only their notes but competency progress, social engagement, and general interest in learning. By grouping these profiles and matching them with behavioral patterns, the AI can accurately predict future events, such as the likelihood that they will fail to advance to the next course, take a leave of absence, or drop out. Depending on the strategic objectives of the university, different scenarios of work with these cohorts are possible – from preventive organization of curatorial assistance, to suggesting their transfer to another faculty, training in another specialty.

AI systems in education offer advanced progress tracking capabilities, enabling teachers to monitor each student's development over time. This technology provides valuable insights into learning patterns, helping educators make data-driven decisions. It facilitates personalized learning paths, ensuring that teaching strategies effectively meet individual student needs.

3.3.10. Administration of the education

From the admission process and the schedule of entrance exams to the final exams and the organization of graduation ceremonies, there are areas for the implementation of AI systems. Built into university management software, they take over many routine processes, freeing up administrative staff to solve more complex and non-standard tasks.

Artificial intelligence can help in the admission process by analyzing primary documentation and other materials, selecting suitable programs and faculties. An AI-based chatbot embedded on the website can support applicants by answering frequently asked questions on admission conditions, list of required documents, dates, addresses of the admission committee, schedule of consultations and entrance exams.

Already today, many universities are actively using automated translation systems in their administrative resources and applications. When recruiting international students, working with this contingent is significantly simplified – no matter whether they speak common English or exotic Bengali, AI systems will also answer their questions in detail and accurately.

Thus, AI can autonomously execute a diverse range of administrative tasks, enhancing the efficiency of university and educational process management procedures. Develop and review curricula for compatibility; generate study group rosters; create a schedule; allocate educational tasks to the teaching faculty; formulate their hourly workload and devise individual plans; organize the usage of facilities, teaching aids, and simulators in accordance with the schedule; submit orders for restocking office supplies, consumables, and disposable materials; and oversee the entire documentation process from student application to final state exams. Recruit international students and conduct marketing activities within a multilingual environment. Utilize the previously mentioned performance analysis features to generate reports and academic certificates. Maintain electronic records for both students and employees and create a database of educational materials. Additionally, control access to this database and generate reports for management and faculty, both for individual students and for groups, courses, and faculties.

Thus, the integration of artificial intelligence into medical education has the potential to positively transform the learning process, improve learning outcomes and ensure effective and high-quality training of medical specialists for their future professional responsibilities. However, it is extremely important to comply with ethical standards, ensure transparency and fairness in the use of AI, and protect students from potential problems and hidden dangers amid the euphoria of their benefits. These principles of AI-ethics designed to protect humans from AI-related harm will be discussed in section 6.3. “Threats and disadvantages of using AI in medical education.”

Generated by DALL-E, prompts by Maxim Gorshkov



Fig. 55. This is how AI imagines its role in managing administrative processes in a modern hospital. It looks a little naive, childish, but whatever you want, by the standards of the age of humanity, AI is still in its infancy

4. Maslow's hierarchy of human needs applied to medical education

One of the fundamental theories in the field of humanistic psychology was developed by an American psychologist Abraham Maslow [Fig. 56]. His theory of hierarchy of needs is of global importance to humanity, especially in the fields of business, education, sociology, and organizational behavior. It has had a profound impact on our understanding of human motivation, well-being, and personal development, it has explained what drives human behavior and aspirations. The underlying principles of the theory are applicable not only to general but also to specific aspects of society and individuals. Below is an attempt to apply Maslow's theory of hierarchy of needs to the medical education, including that part realized in a virtual environment.

4.1. Maslow's theory of the hierarchy of human needs

Abraham Harold Maslow (1908–1970), an outstanding American psychologist, published in 1943 his fundamental theory on hierarchy of human needs, where he distributed these motivating demands onto five levels [Maslow, 1943]. This structure was later typically presented and known as “Maslow's pyramid”.

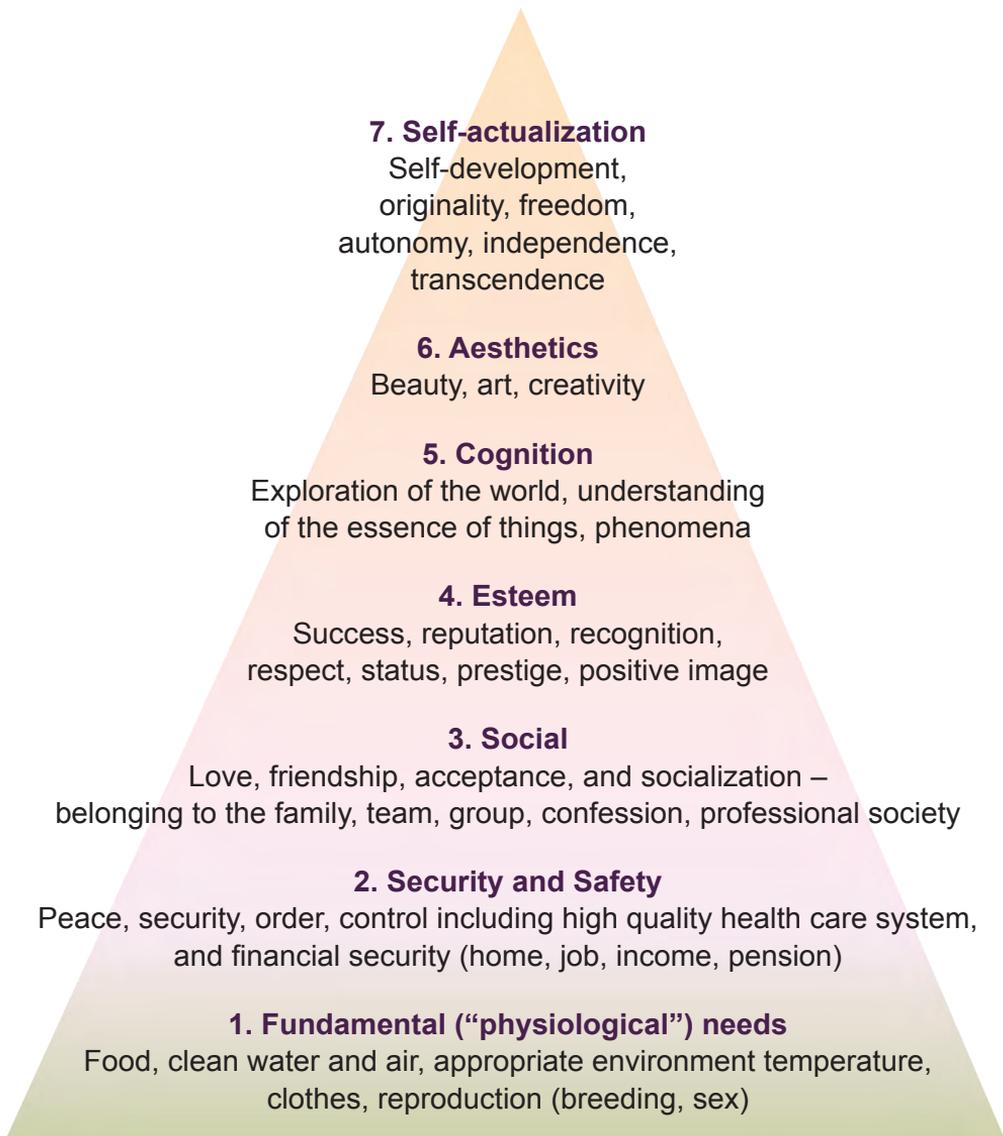
In the second edition of the book “Motivation and Personality”, the author continued to develop his theory and provided more explanations, additions, and comments [Maslow, 1954]. So, important extension was given to the description of the highest self-actualization level: “Cognitive needs” – desire for new knowledge, and “Aesthetic needs” – pleasure from beauty of surrounding objects and natural phenomena, as well as creations in the form of musical and artistic images, works of art. “Self-actualization” – self-development, self-improvement, autonomy, identity, transcendence. Meeting these needs, people's attempt to transcend the physical self in search of meaning, helping others, spiritual practice, and connecting with nature are some of the ways that the full range of these needs can be met.



Fig. 56. Abraham Harold Maslow (1908–1970), the creator of the Hierarchy of Needs theory also known as Maslow's Pyramid

Thus, in his final version of the motivation theory, the author expanded the further division of the highest level of self-actualization in the hierarchy into three steps, hence creating a seven-level hierarchy [Table 9].

Also, it is worth mentioning that all the needs of both higher and lower levels constitute the fundamental nature of an individual as an integrated whole and cannot be considered separately from each other, although their priority ranking is subject to the principle of relative dominance. A person with unsatisfied basic physiological needs will not think about higher matters, just as a person suffocating in a fire seeks only salvation or a traveler dying of thirst in the desert dreams of nothing but a glass of water. It is no coincidence that Abraham Maslow created his theory during the Second World War, when a visible threat of physical destruction hung over all of humanity and over him personally, a man of military age. However, only a glimmer of hope, not supported by the slightest improvement in living conditions, not the slightest hint of compromise, pulled the trigger and prompted a person to seek friendship, love, strive for recognition, creative self-realization and

Table 9. Seven levels of Maslow's hierarchy of needs

[Abraham Maslow, 1954]

self-actualization. According to Maslow, “It is a mistake to think that all needs lower down the pyramid must be 100% satisfied before the next need arises. It would be more correct to say that the degree of satisfaction of needs decreases as the individual moves up the hierarchical pyramid.” And emphasizing the inextricability of the complex of needs, he argued: “None of the needs arises separately, in isolation from others... and truly important processes are necessarily dynamically interconnected with everything that is important for a person in general”.

His scientific publications became widely known, their popularity went far beyond the professional community of psychologists as a fundamental theoretical work, but also received wide recognition and extensive practical application, usually cited under the title “Maslow’s Pyramid of Needs.”

In marketing and retail, Maslow’s pyramid is used for market analysis and audience segmentation. This helps to find out what needs are most pronounced in the selected target groups. The promotion of goods and services is studied to understand the processes of making consumer decisions, how the audience sees the satisfaction of a particular need. In personnel management, the theory is used in constructing ways to motivate employees, in long-term planning to make forecasts about future needs for various goods and services. By understanding the needs of employees, the most effective management mechanisms for certain groups of personnel can be applied.

It is extremely interesting to observe how relevant Maslow’s pyramid is today. Almost complete fulfillment of basic needs in the modern world – not only in traditionally prosperous Western countries, but also in many states of South America, Asia, and Africa, many people, especially young ones not worrying about already satisfied lower levels of the hierarchy, shift their attention to the third and fourth levels – socialization, friendship, love, and esteem. Since the everyday realization of these needs has been largely transferred to the digital environment, success, recognition and respect also begin to be measured not by orders and honorary letters, but by the number of “likes”, “friends”, and followers. Instantaneous overwhelming public success of some individuals, which is based and provided by virtual space, inspires one part of the audience, encourages it to increase their activities in the virtual world, while the other part has an extremely negative reaction to this transformation up to aggressive rejection.

4.2. Maslow's theory applied to medical education

The process of a doctor's professional development, especially the initial stages of education – university, graduation and postgraduate specialization – occupies a significant part of life, thoughts and aspirations at that time. This period is not only crucial, but also relatively long; a physician, upon entering the profession, has already devoted a third of his or her life to university studies and internship! It is precisely during the years of medical education that young people usually begin to satisfy their needs on their own, to live independently, not relying on their parents, because once they start their autonomous life, this responsibility falls squarely on their shoulders. Students

Fig. 57. Palazzo Archiginnasio, University of Bologna, Italy (founded in 1088).



Credit: Maxim Gorshkov



Located here is the arguably most stunning anatomical theater in the world. It is embellished with exquisite wood carvings and marvelous wooden sculptures of renowned physicians, both contemporary to the creator and from the past.

actively satisfy not only their basic needs, but also begin to establish their internal world order, determine individual principles of security and stability, make new friends, seek recognition, search for love, actively explore and consciously study the surrounding world. And no matter how important studies and grades are for future doctors, they do not overshadow desire to meet the demands of all levels, right here and now, under the motto “we only live once!”

The University of Bologna [Fig. 57] is the oldest in the world, founded in 1088. It still uses another name given to it many centuries ago as its proper name: *Alma Mater Studiorum* (literally “Nourishing Mother of Studies” or “Mother who feeds the students”). To this day, graduates of colleges or universities around the world are called “*alumni*” (from Latin meaning “those who were nurtured”). This emphasizes the fact that the university provided its students not only with knowledge and spiritual nourishment but also with material sustenance, satisfying all their essential needs. To this day, the leading traditional face-to-face universities, the alma maters, consider it their duty to perform these “auxiliary” functions, providing students with all the necessary conditions or helping them to solve everyday problems.

Basic needs (housing, food, health): a student lives in a designated room in a dormitory, dines in the student cafeteria, undergoes annual health check-ups at the university clinic, participates in sports lessons and plays in university basketball or soccer teams.

By fulfilling the need for **security** (job, career, order, protection), a student realizes that with their current efforts, they are laying the cornerstone for a future professional career, which will provide them with a high social and material status and a respected and interesting job for their entire life. The student studies in a safe environment, in educational premises that meet all standards, state regulations, and construction norms. And if all the requirements of higher education are met, they will receive a higher education, and their professional future is secured and guaranteed.

Socialization (friendship, love, communication) thrives during the study period – the student is surrounded by peers and mentors, participates in sports games or competitions between faculties and other universities. Friendly or

romantic relationships often begin during the study years and frequently last a lifetime.

The needs for **self-esteem** (success, reputation, recognition, status, image) begin to be realized as soon as one is admitted to the university – the prestigious status of a medical student, the “future doctor” guarantees respect from parents, relatives, former classmates, and new friends. Moreover, within the university itself, a student can take up a formal or informal leadership position – in their group or faculty, as the chairperson of the student council or captain of a sports team. High-achieving students can rightfully take pride in their excellent grades and may even receive rewards in the form of diplomas, encouragements, prizes, grants, or scholarships.

The pursuit of **knowledge** (understanding, studying, comprehension, research) – the university certainly fulfills this need to the fullest! Intense, prolonged learning is associated with gaining unique knowledge about the human body and its pathological processes, mastering patient treatment methods – students acquire a deep and extensive wealth of knowledge unparalleled to what laypeople know about the intricacies of the body.

Self-actualization: self-development, independence, creativity. At some point, the future doctor comes to a conscious expansion of their academic activities, goes beyond the knowledge and skills provided by the curriculum, stays in the clinic for night shifts, becomes a tutor in the simulation center, joins a student science club, or conducts research under the guidance of a research supervisor.

Thereby, obtaining a medical education in the traditional face-to-face format provides the student with all the prerequisites for satisfying any needs according to Maslow's hierarchy [Table 10].

Table 10. Seven levels of Maslow's hierarchy of needs applied to medical education

<i>Needs in Maslow's Hierarchy</i>	<i>Needs realization in the University</i>
7. Self-actualization	
Self-actualization: self-development, originality, autonomy, freedom, independence, transcendence.	Self-development, independency, autonomy, self-paced trace personal growth during medical study
6. Aesthetics	
Aesthetics, beauty, art	Social student life offers many cultural and aesthetic events and phenomena
5. Cognition	
Exploration of the world, understanding of the essence of things and phenomena, creativity	Scientific research, learning new things, reaching beyond the traditional curriculum
4. Recognition	
Esteem needs. Success, reputation, recognition, respect, status, prestige, positive image	Belonging to highly respectable social community. High academic achievements respected by groupmates, friends, parents and relatives
3. Social needs	
Love, friendship, acceptance, and socialization – belonging to the family, team, group, confession, professional society	Student years offer unprecedented possibilities for social life, friendship, belonging to the student corporation (Germ. <i>Zunft</i>), fraternities and sororities, communication with groupmates and teachers
2. Security and Safety needs	
Peace, security, order, control including available high quality health care system, and financial security (home, job, income, pension)	Gain knowledge and skills in secure environment to get a good grade at the test, current examinations, and high stakes certification exams like USMLE
1. Basic needs	
Fundamental (physiological) needs. Food, clean water and air, clothes, reproduction (breeding, sex).	Study medical specialty, become professional, get medical degree – basic need and function of medical education

[Abraham Maslow, 1954; Maxim Gorshkov, 2021]

4.3. Do students dream of electric patients?

Despite obvious and indisputable advantages of digital methods of learning and teaching described above, as well as substantial efforts to integrate it into medical education system, its usage was relatively limited until the year 2020, when the coronavirus pandemic broke out, and the use of digital technologies in medical education began to grow exponentially. In fact, that distance learning outbreak was similar to explosion – swift expansion and relatively rapid collapse, return to the status quo level a year after. Will digitalization in medical education remain at a precedent level as the epidemiological threat abates? Is virtualization of learning a natural process or is it a temporary phenomenon imposed provoked by quarantine regulations only? Will the prevalence of digital technologies in education remain the same or will it drop to the levels observed before the pandemic?

In the previous part of the chapter, we considered the possibility of realizing all seven levels of personal needs in the conditions of receiving higher education at the university, higher medical school. *Alma Mater Studiorum* provides students with all conditions and prerequisites for this – from basic, fundamental needs (medical education, confirmed by a diploma, necessary for the future profession), to self-realization and transcendence, especially in the last years of higher education. So, what happens when the focus shifts from face-to-face learning – attending lectures, anatomical theaters, and clinical classes – to virtual and distance formats? Does the introduction of virtual simulators deprive something important not only professionally and educationally, but also socially and humanly? The purpose of this chapter is to discuss medical education in virtual environments from the perspective of Maslow's hierarchy of needs theory.

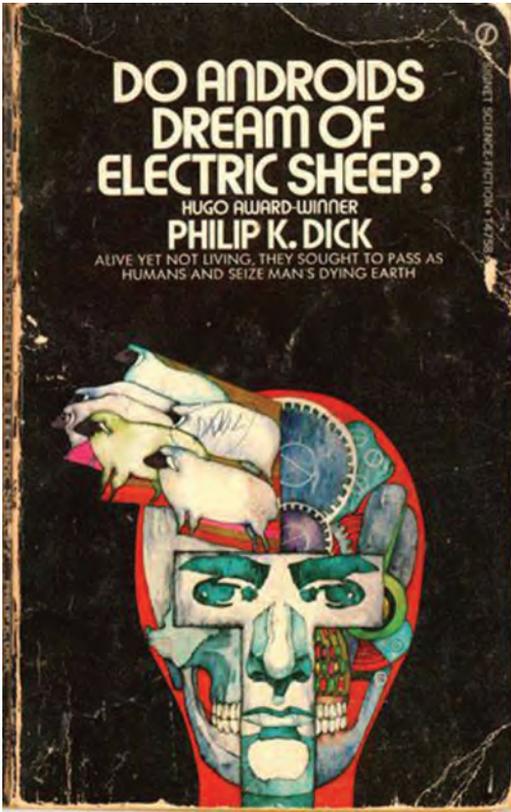
By replacing or extensively supplementing traditional face-to-face forms of learning with distance and virtual ones, we are not just changing the format of the learning process, but also invading other, deeper spheres of students' lives, sometimes in a very significant and painful way. Young people spend much more time in the walls of an educational institution than at home with their relatives, and in the transition to virtual online learning, the stress of the disappearance of their much-valued micro-society can hardly be overestimated. Instead of moving to a "pure-university town", large regional

or even metropolitan university city, out-of-town students see around boring rural or industrial landscapes that they have been bored with since childhood. They take distance learning courses at home, sitting in their own “children’s” room (even if they are lucky enough to have a separate room – or it could be a shared kitchen!). They lose face-to-face contact with most of their classmates and are cut off from the social life of their campus and community. Evaluation of anxiety, stress and the quality of life showed an overall detrimental effect of distance learning on the medical students [Demirekin BZ, 2022].

Consideration of unavoidable negative consequences of VRS and their on-time compensation should be taken into account when creating virtual medical education curricula, especially if their remote use is planned. Virtual learning environment should be regarded as an essential part of the individual’s microcosm, a place of their daily pastime intended to satisfy all the needs of their personality, just like in face-to-face learning.

At the same time, obvious benefits of distant learning could not be ignored. Thus, “moderate to strong correlations” were found between the item “Zoom lectures have reduced stress compared to in-person lectures” and preference for Zoom, quality of education using Zoom compared to the in-person lectures, belief that Zoom lectures should continue as part of the curriculum delivery method, staying motivated with lectures fully online with Zoom, and liking that Zoom lectures save commute time to campus” [Altaf, Rida et al. 2022]. This distance online mode is a unique tool not only for the students but helps universities to grow. Hence, *Indira Gandhi National Open University (IGNOU)* in India has been frequently cited as one of the largest universities in the world in terms of student enrollment. *IGNOU* is an open educational organization, which means that it offers a range of distance learning and online courses, that allows it to have over three million students enrolled in its various courses simultaneously (!), making this institution significantly larger in terms of student numbers than any other university in the world.

That is why it is so important to present the virtual educational sphere not just as an electronic textbook, a methodological manual, but as an essential, significant part of the individual’s universe, the environment of his daily hours of pastime, designed to satisfy not only basic but also higher needs of his personality, just as in face-to-face education, when physically present in the academic world. And if this artificially created microcosm, this new vir-



Credit: flickr.com/photos/cdrummbks/3809652408

Fig. 58. Book cover “Do androids dream of electric sheep?” by Philip K. Dick

tual mini-universe, is not able to meet any of the requirements placed on it, it should be properly modified, changed, and adjusted.

In all likelihood, the balance of technological and methodological advantages and disadvantages between traditional and innovative teaching methods will not be the only factors influencing the use of computerized systems in education; subjective characteristics based on the diverse needs of students and teachers, such as aesthetics, convenience, prestige and other features that increase the motivation of all participants in the educational process, will be decisive. If virtual systems can fully respond to their needs and satisfy all their requirements, from basic to advanced, the

ubiquity of digital technologies will become inevitable.

In 1968, Philip K. Dick wrote a book *Do androids dream of electric sheep?* [Fig. 58], which was later adapted into the popular movies *Blade Runner* (1982) and *Blade Runner 2049* (2017). Antropomorphic robots, androids, which resembled humans outwardly and performed more difficult and dangerous tasks, were at the lowest status of the social ladder. Wanting to satisfy their demands and improve their social level, at least in their own minds, Androids’ dream of a status object, an “electric sheep”, implies satisfaction of basic needs in the future world and thinking about deep things not only among humans, but also among cyborgs [Dick, Ph. K., 1968].

To paraphrase the author, in terms of medical education using simulation in virtual mileage, we can ask: “Do students dream of electric patients?” Would today’s students appreciate the use of 3D human models to study anatomy, a PC atlas to review histology, smartphone headphones to improve auscultation skills, or a virtual patient to practice differential diagnosis? Or would future doctors still prefer the traditional physical learning methods we are all used to?

Many of those who have experience in introducing information technologies into the teaching process note that, to their surprise, students are often reluctant to use scientific materials developed and recommended by the university, turning to “*Dr. Google*” or “*Professor Facebook*”¹ for advice or a lecture. When studying the structure of the human being they can refer not only to textbooks such as *Gray’s Anatomy*² or *Sobotta*³ (even if in electronic form, e.g. *e-Sobotta*), but also to sources such as videos on *TikTok*⁴ or shorts on *YouTube*, which are often of poor methodological and didactic quality, unstructured and sometimes simply misleading with grammatical errors.

Obviously, providing educational product of high educational value, even if it is innovative, high-tech, approved by the university academic council and strongly recommended by the head of the department, is only half of the battle. A paper textbook converted into electronic format becomes an electronic version of a textbook only, like “hardcover, paperback and *Kindle*”⁵ options of the same book, not really an educational virtual product. A classic face-to-face lecture recorded on video becomes a video lecture, but not a digital teaching product. It is not a secret that online courses and computer programs are often introduced at the initiative of the university administration, which means that they use already outdated technologies, old software products, ready-made solutions – all that only based on ease and accessibility for them, not

¹ Facebook, Meta Platforms Inc., Menlo Park, CA, USA.

² *Gray’s Anatomy*, one the most widely used anatomy textbook in English-speaking medical schools, first published by Henry Gray in London, in 1858.

³ *Sobotta*, famous atlas of anatomy in the German-speaking community, first published by Berlin anatomist Johannes Sobotta in 1904.

⁴ TikTok, short video service of ByteDance Ltd., Beijing, China.

⁵ Kindle is a trademark of Amazon Technologies Inc., Seattle, WA, USA

for scholars. The qualifications of the faculty members will prevail over the students' needs when it comes to the course development process.

Such online courses typically lack the components of communication, interactivity, encouragement and learners' recognition. Abraham Maslow emphasized the importance of "focusing on problems, not methods" [Maslow A, 1943]. Mastering any brand-new method often leads to the desire to push the boundaries of its intended use, and at the same time, boils the process of solving any problem down to the use of one customary method. As once Maslow expressed "If the only tool you have is a hammer, [you] treat everything as if it were a nail" [Maslow A, 1966].

This is even more surprising considering that over decades the social networks have replaced in some areas most of the components of communication, interaction, recognition, and self-actualization, especially among young people – that generation that now graduates from high schools and gymnasiums and study in universities. The triumphal march of social networks and specialized online communities is precisely based on the possibility of successful replacement of the real world.

People share their ideas, opinions, photos and videos, comments, and conclusions, join groups, and participate in discussions, read, and comment on news through *Facebook*, *X (Twitter)*⁶, and *Reddit*⁷, initiate petitions and collect signatures on them through *Change.org*⁸. Some social networks are specialized in specific social, age or professional audiences. Many people's job searches and career paths are inextricably linked to *LinkedIn*⁹, *Xing*¹⁰, and *Monster*¹¹ where discuss industry trends, share professional insights, and engage in specialized discussions. Young people connect to each other,

⁶ Twitter Inc., part of X Holdings Corp., San Francisco, CA, USA.

⁷ Reddit, Advance Publications (majority shareholder), San Francisco, CA, USA.

⁸ Registered by Change.org, San Francisco, CA, USA.

⁹ LinkedIn Corp., Sunnyvale, CA, USA.

¹⁰ Xing, Hamburg, Germany.

¹¹ Monster, Weston, MA, USA. Subsidiary of Randstad Holding, Diemen, Netherlands.

share content, and become millionaires on *SnapChat*¹², *Instagram*¹³, *Tumblr*¹⁴, and *TikTok*, primarily used for images and videos but has a story feature for sharing thoughts and narratives. IT-professionals use code hosting services for developers to collaborate on the projects they are building in *GitHub*¹⁵, DJs and musicians “live” in *SoundCloud*¹⁶, illustrators and animators use *Flickr*¹⁷, *Pinterest*¹⁸, and *EyeEm*¹⁹, artists exchange ideas and post photos of their paintings for sale in *DeviantArt*²⁰.

There are social networking sites in the medical field as well, both for patients and healthcare professionals, with some combining both audiences. Thus London-based *HealthUnlocked*²¹ is according to their statement the world’s largest virtual patient community. It is social platform connecting 1.3 million patients, representing over 300 diseases and conditions. The next example of medical networking solution is *Sermo*²² that engages according to company’s data more than 1.3 million Health Care professionals across 150 countries that offers online community of clinicians to communicate about medical issues. *Doximity*²³ is another professional social web-resource with over half a million users. It targets U.S. based physicians in all specialty areas and is also dedicated to the pharmacists, physician assistants and nurse practitioners.

¹² SnapChat, Snap Inc., Santa Monica, CA, USA.

¹³ Instagram, Meta Platforms Inc., Menlo Park, CA, USA.

¹⁴ Tumblr, Automattic Inc., San Francisco, CA, USA.

¹⁵ GitHub Inc., San Francisco, CA, is a company of Microsoft Corp., Redmond, WA, USA.

¹⁶ SoundCloud Global Limited & Co. KG, Berlin, Germany.

¹⁷ Flickr, SmugMug, Mountain View, California, USA.

¹⁸ Pinterest Inc., San Francisco, CA, USA.

¹⁹ EyeEm, Talenthouse AG, Baar, Switzerland.

²⁰ DeviantArt is a subsidiary of Wix.com Ltd., Tel Aviv, Israel.

²¹ HealthUnlocked Holdings Ltd., Altrincham, Cheshire, UK.

²² Sermo Inc., New York, NY, USA.

²³ Doximity, Inc. HQ, San Francisco, CA, USA.

Vast and rapid introduction of IT technologies is impossible without the consistent desire of the trainees to use informational technologies and virtual reality environment in their studies. Lack of interest, curiosity, motivation on the part of the trainees can lead to a passive boycott, silent protest that even the control and constraint mechanisms built into the digital device cannot overcome. And if the creators of medical virtual learning platforms are able to combine features that address more than just the basic needs of learners with components that address higher-level needs, the ubiquity of these systems in medical education is inevitable and will only be a matter of a short period of time.



Source: craiyon.com, Prompt: Gorshkov M.D.

Fig. 59. Generation of virtual patient image by the query “old female patient cyborg”

However, before making such an earnest recommendation, it is necessary to discuss and credibly confirm the hypothesis about the constructive ability of virtual reality medical education systems to satisfy all students' needs. To do this, it is necessary to dissect each level of the hierarchy in relation to them and to analyze thoroughly virtual learning aids in terms of Maslow's theory of hierarchy of needs.

4.4. Extrapolation of Maslow's hierarchy of needs to virtual learning

Let's discuss in order, level by level, whether and how all human needs can be met in virtual medical education systems.

1. The **basic needs** of individual within the framework of “medical student” are to obtain an officially confirmed medical education – the realization of the intention to become a doctor, the acquisition of all the necessary knowledge, skills and receive a diploma of higher education according to the rules of the country (location) of future medical practice. Ideally, all educational materials should not only correspond to the current level of medical knowledge, but also have appropriate certificates or other documents confirming this fact, issued by an authorized body. Thus, the digital learning material in order to implement basic needs must comply with national clinical guidelines, the current level of medical knowledge, approved in this university program and be recognized by its teachers and administration. In other words, the completion of a training course or program must be noted by the issuance of an official diploma, certificate or CME points, just as if the course was taken not in virtual reality, not online, but in a medical school by physical presence.

2. **Security, safety needs.** The educational organization is obliged to create safe environment for studying, getting a profession. In the distance (and often in virtual) learning format, student is essentially responsible for his or her own physical safety. However, the concept of a “Safe, secure learning environment” is not about physical safety only, it is much broader – didactical, psychological, social, mental. Will a textbook be “safe” (reliable) if a student fails to pass an exam after thoroughly studying it? Is it possible to call a practical course as “secure” if after its faithful completion a student fails at the practical test? The university is responsible, among other things, to provide trainees with a full, high-quality learning environment in the broadest sense of the word: recommended (provided) textbooks of the best available level in adequate quantity, provided sufficient access to the anatomical theater, histological specimens library or atlas of medical images.

In the context of virtual education, the system should guarantee full and effective mastery of the required knowledge and skills needed to pass current

and final examinations, so that the student feels calm and confident. If the virtual materials are not sufficient to pass the graduation or licensing exam or their quality and composition do not meet the requirements of the examiners, the learner will justifiably feel anxious and worried, as in the presence of a real physical threat. If a multiple-choice questionnaire is not composed of clear and concise wording, and if the incorrect answers cannot be definitively ruled out, or if it includes negative or double-negative constructions, or if it employs absolute terms like ‘always,’ ‘never,’ ‘all,’ or ‘none’ that could potentially be confusing, and the complexity of the questions exceeds the expected level of knowledge, then students are likely to view such an MCQ as problematic and dangerous. An institution that overlooks such flawed assessment methods could be criticized for lacking professionalism or for adopting a confrontational stance towards student examination.

In addition, the training will not be calm and comfortable if there is a possibility that poor knowledge, low grades, ineffective actions may be publicized, the video of simulation training will be shared – all this will cause additional stress, nervousness, anxiety, which does not fit with the concept of a “danger-free learning environment”. It is not for nothing that the so-called *Las Vegas Rule* (“What happens in Vegas stays in Vegas”) is generally recognized in the medical simulation community¹.

Thus, for an individual to feel calm and confident about the virtual simulator or digital educational system, it should provide training options or education material of high quality, with a clear and logical presentation in it, the system should use modern interactive techniques for effective acquisition of theory and practical skills, while the presentation of the material should correspond to the official position of future examiners.

3. Socialization – the scholar’s need for friendship, community, belonging to a group, team, collective, society. Family psychologists say that “the most unhappy people in the world are eighteen-year-old girls”. Similar can be

¹ A city of luxury hotels surrounded by desert, Las Vegas is known for gambling, mind-blowing shows, and a raucous nightlife. People who come there to «party hard» would not have a blast so radically if they were afraid of publicity. However, in recent years, the city, which suffered from both the pandemic and its negative image, has been trying to improve it. Today in Las Vegas, they say, «What happens here, only happens here». Looks like it fits virtual reality quite well, too.

stated for many junior students – the first semesters are incredibly difficult, full of stress and threats! These insecure freshmen, exhausted by the rush of application papers, school leaving tests and medical college entrance exams, now stumble hesitantly in the university hallway among other strangers, wondering which seat to take, which group of classmates to join, how to make sense of the social hierarchy of upper years students, tutors and professors they will encounter over the next 10–12 semesters. Many of them have just separated from their parents, siblings, classmates, and buddies from their backyard. This sudden loss causes anxiety, social isolation, sadness and even depression. The resulting emptiness creates in their souls a huge craving for new social contacts, friends and mates, instantly creating new acquaintances, relationships and attachments. At this stage, they are all in dire need of companionship, camaraderie and participation, all the things that a community of peers and friends provides.

If in addition to these stressful moments the transition to distance learning is added, it is the socialization of the learner that suffers the most, on a catastrophic scale. As a result of the introduction of telecommunication digital technologies in the educational process, the student is deprived of direct interaction with classmates and teachers, at best receiving instead a mosaic of windows with images of the faces of teleconference participants.

Young people are trying to fill this gap in every possible way, discussing academic and personal issues through social networks, messengers, chat rooms and video meeting applications, which may encourage developers to come up with digital solutions to this new educational problem.

It is important for students to be able to communicate within the members of the educational environment without going outside it, without switching to other applications and devices, trying to contact their antecedent past – school buddies or childhood friends. They should stay here, inside the educational meta-universe, seeking and finding new educational and professional contacts. For this purpose, an obligatory characteristic of the digital educational space is the presence of an identification account – the creation of a profile with basic data. It does not necessarily have to contain personal information; in some cases, only a nickname and avatar will suffice. More advanced features of the profile like placing a photo, indicating the group, course, professional and personal interests, achievements in studies and in this virtual application – allow

to realize the function of self-presentation and recognition by other members of the virtual community, to increase friends. In any case, it is important that profiles can be grouped on the basis of administrative division by university groups or by interests, specialization, hobbies. The personal account allows you to address counter questions to the author of a post or comment, have conversations, dialogs, divide messages into public, group or private.

Another important feature of socialization is group activity, team interaction – from cooperation in achieving joint goals, such as public viewing of video materials, virtual lectures, distance learning, conducting group student projects, sharing interesting educational materials, to such actual educational tasks as conducting team trainings. This group of competencies referred as “*soft-skills*” will become by each of them the object of further special educational programs and trainings, and the lack of basic skills can significantly complicate this task. Already today, numerous virtual platforms provide group training sessions with simultaneous mastering of a topic by several trainees or multiplayer game mode where team of participants runs simulated scenario with elements of group interaction, practicing crew resource management principles.

The opportunity to communicate with peers and like-minded people, along with general socialization, is also an important emotional outlet. By chatting with them one can find laughter, joy, delight, outrage, and fear – these feelings are invaluable – in the procrustean bed of the everyday student, and especially sessional, period, devoid of emotions, filled with stressful classes. The conclusion is self-evident: virtual platforms where students study alone for long periods of time, deprived of a natural educational environment and direct contact with classmates and friends, should be equipped with social networking functionality to compensate for this communication vacuum.

4. **Esteem** – the need for respect, recognition of one’s personal achievements confirmed by other people, acknowledgement of one’s high social status – all this is impossible in a vacuum, without reflection and reaction given by friends, comrades, associates and even mentors and teachers. As in a mirror, students display their own achievements in their consciousness and public opinion. Without fans, a singer will not know if his new song is a “hit or shit”. A writer can’t just create a manuscript and stash it in a drawer – he needs readers, critics and admirers. Without a red carpet with crowds of photographers and fans, a movie star will never feel like a celebrity. But all this

can be completely intangible, totally virtual, reflected in the number of likes under a YouTube video or the number of printed copies of a bestseller sold (while the writer may never see real crowds of readers or staples of books).

Thus, satisfying the need for recognition requires several components: on the one hand, formal assessment of achievements (prize, medal, grade, points, award), on the other hand, publishing information about successes among the target audience, communicating this information to fellow students, friends, teachers, and, most importantly, receiving feedback from them in one form or another (“smiley” emoji, “thumb up”, “like”, “excellent” grade, becoming a mentor, or moving to the next year of study). The third important element is a kind of podium, a public stage. Such a platform provides an individual not only a place for self-expression and recognition, but also allows to influence groups of people, to get others to follow him/her, which can increase self-esteem and give a sense of power or leadership. Sounds good, a tantalizing prospect, doesn't it? This dependence on external validation can be detrimental to mental health, but the complete absence of external recognition can have negative consequences as well.

5. **Cognition** can seemingly be easily realized through the introduction of digital technologies. By their very nature, they were designed to fulfill this central task of delivering knowledge and building skills. However, there is more to this concept than meets the eye. The mechanical process of memorizing a haphazard set of information, formulas, anatomy terms, histology images, and recipes with dosages cannot be considered a process of “cognition”. Only independent study of the interrelationship of phenomena, identification of correlations, prediction of the consequences of actions are the real driving forces of the true process of thinking, allowing one to feel oneself a full-fledged *homo sapiens* – “a person who knows”.

Students and residents, as adults, learn according to the principles of andragogy formulated by Malcolm Knowles in 1967 [Knowles, Malcolm, 1967; in 2005 edition, revised and expanded]. In particular, he argued that the process of acquiring knowledge and skills should be reduced to a clearly defined goal, be based on a baseline, remain under the control of the learner, be concrete, relevant, and practice oriented. In addition, the introduction of problem-based learning in the late 1960s revolutionized medical education, marking a shift from a teacher-centered learning paradigm to a student-

centered learning based on clinical problem solving. The attempt to underpin practice with a scientific basis led to a giant breakthrough, in part because adult learners, clearly recognizing the practical application of their knowledge, became extremely motivated to master those intricate Latin terms, laboratory norms, and cumbersome flowcharts. The natural urge to learn was well supported when the basic science of preclinical programs was immediately transferred to the clinical application.

Importance of the “cognition” need is difficult to underestimate. One of the corner-stone postulates of the Western philosophy is expressed as *cogito, ergo sum* (“I think, therefore I am”), highlighting that thinking and existence are set on an equal plane, originated from *René Descartes* work published in 1641. A virtual textbook can be considered as satisfying all the needs of an adult student in cognition only if the above mentioned principles are observed. Only independent and individual-controlled cognition similar to scientific research, not just memorizing biochemical formulas, terminology or dosages, but analyzing this information, taking oneself to the upper level of understanding, making discoveries for oneself – that brings emotional satisfaction, this is what Abraham Maslow meant by the realization of the need for cognition.

6. Aesthetics and virtual technology go hand in hand. A simple but swanky, easy-to-use and fancy, efficient though cool app is always welcome. Beautiful, aesthetically pleasing, delightful and admirable design brings nice program to the light. *Steve Jobs*, founder of *Apple*², said that “Design is not just what it looks like and feels like. Design is how it works.” [Walker R, 2003]. A beautiful application is not characterized by flashy fonts, intricate logotypes, or sparkling animations. When people talk about the aesthetics of a virtual

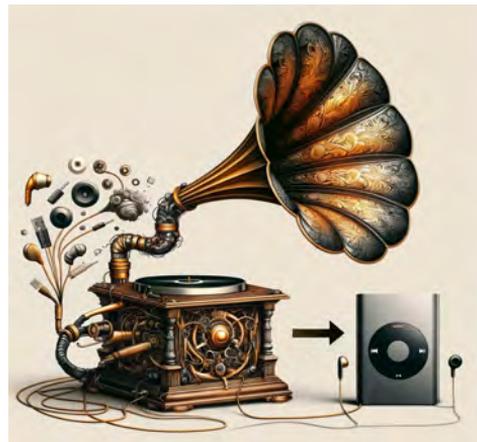


Fig. 60. The transformation of the gramophone into a modern device shows the evolution of design and our understanding of what design is.

Generation: DALL-E, Prompt: Gorshkov M

² Apple Inc., Cupertino, California, USA

program, they mean, first of all, its extensive functionality, thoughtful ease and elegance of work, efficiency of the learning process and user convenience. The simpler the more chic!

The ideal servant fulfills his master's wishes even before they are spoken aloud. The ideal training aid is one in which effective and quality learning takes place unobtrusively, spontaneously, joyfully and without apparent effort. This is especially true for the user interface, the beauty of which lies in functionality and comfort. Another important aspect of satisfying aesthetic needs is pleasure and fascination, which can be achieved by incorporating game technologies into learning. If the application is essentially a game (so-called serious games), where learning takes place in a playful form or environment, such an educational process will be effective and fruitful, and its results will be deep, thorough and long-lasting.

7. **Self-actualization** is situated at the upper level of Maslow's pyramid, reflecting a person's aspiration to fully identify and develop his/her talent, realize potential, become better than possible or wished to be – not in the eyes of others, but in one's own consciousness, to surpass himself or herself. An individual at this stage sets own tasks, solves them, discusses them internally and evaluates independently. Not everyone can reach such a state, but the environment plays not the least role in satisfying this need. If a student can create own projects, develop clinical cases or medicines, independently conduct research or part of it, and improve own competencies, then this functionality of creativity, creation, and self-realization is enough for a person capable and ready for transcendence.

Thus, a properly designed virtual educational product satisfies all the needs mentioned in Maslow's pyramid, not only basic needs, but also higher ones, including communication, cognition, mastering a profession and further professional growth beyond the set requirements – transcendence, self-development and personal self-expression [Table 11].

So, do students dream of electric patients? Yes, they do, but only those that are created with intention, love, meaning, and intelligence for creativity! Students dream of virtual learning solutions that, within an educational context, meet all their needs without exception, from basic to advanced, from the first educational breath till the last professional insight.

Table 11. Extrapolation of Maslow’s hierarchy of needs to VR learning

<i>Needs in Maslow’s Hierarchy</i>	<i>Medical education VR-Systems</i>
7. Self-actualization	
Self-actualization: self-development, originality, autonomy, freedom, independence, transcendence	Self-development, independent problem solving, personal growth, scientific research in virtual reality
6. Aesthetics	
Aesthetics, beauty, art	Aesthetics of VR App – beautiful and awesome. It’s simply cool! Nice and playful functionality brings pleasure even during learning process in VR
5. Cognition	
Exploration of the world, understanding of the essence of things and phenomena, creativity	Learning new things, reaching beyond the traditional curriculum, analyzing facts, and getting to new knowledge level
4. Recognition	
Esteem needs. Success, reputation, recognition, respect, status, prestige, positive image	High academic achievements cause respect among groupmates, friends and relatives, other digital environment users clearly displayed and presented in VR
3. Social needs	
Love, friendship, acceptance, and socialization – belonging to the family, team, group, profession, professional society	Communication within VR with friends, mates, tutors and teachers, exchange of views, create communities, complete collaborative projects
2. Security and Safety needs	
Peace, security, order, control including available high quality health care system, and financial security (home, job, income, pension)	The VR Simulator offers learning materials in the quantity and quality to give students the confidence and composure that they will score high on a test, midterm, or final exam
1. Basic needs	
Fundamental (“physiological”) needs. Food, clean water and air, appropriate temperature, clothes, reproduction (breeding, sex).	Designed to fulfill basic need –providing information and other functionality for getting knowledge and skills necessary to learn a profession, graduate from university and get a job

[Abraham Maslow, 1954; Maxim Gorshkov, 2021]

5. Digital world and 12 roles of medical teacher

Nearly a quarter of a century ago, Ronald Harden and Joy Crosby delineated twelve functional roles for medical teachers [Harden, RM et al., 2000]. These roles were evaluated by 251 medical educators to determine their relative importance and significance [refer to Table 12]. It is noteworthy that nearly two decades later, Professor Harden attempted to reassess these notions – given the rapid and substantial changes in both the world and medical education, he collaborated with Pat Lilly to pen «The Eight Roles of Medical Teachers» [Harden RM, 2018]. However, it is the option of twelve roles divided into six subgroups that has become more widespread – perhaps teachers find it more meaningful to discuss the problems of fulfilling twelve roles rather than «only» eight. In any case, most of the work cited is from 2000, which will be discussed below.

In our opinion, the global introduction of virtual technologies into the educational process will continue to be accompanied by a radical revision of these roles, as the performance of some of them will be taken over by the virtual tutor

to a significant or even complete extent. Since the issues surrounding the VR substitute teacher function are emotionally sensitive and quite controversial, let's look at each of them separately below.

Credit: Maxim Gorshkov, 2019



Fig. 61. Ronald Harden and the author at ROSOMED-2019

Table 12. Twelve roles of medical teacher and their relative importance

<i>Group</i>	<i>Role</i>	<i>Importance</i>
Information Provider	Lecturer in classroom setting	3.6
	Teacher in clinical or practical class setting	4.2
Role model demonstration	On-the-job role model	4.2
	Role model in the teaching settings	3.6
Facilitator	Mentor, personal adviser or tutor	3.5
	Learning Facilitator	3.8
Examiner, Assessor	Planning or participating in formal examinations of students	3.9
	Curriculum evaluator	3.6
Planner	Curriculum planner	3.8
	Course organizer	3.9
Resource Developer	Production of study guides	3.5
	Developing learning resource materials in the form of computer programmes, videotape or print which can be used as adjuncts to the lectures and other sessions	3.6

[Harden RM, Crosby J, 2000]

5.1. Providing information

Providing and explaining new material to students, demonstrating practical techniques, presenting an algorithm for performing manipulations – all these actions, traditionally performed by teachers, can be performed by digital systems, especially using generative AI. To do this, virtual simulators and applications are equipped with interactive content – lessons and courses, educational videos and animated 3D materials (performing the functional roles of “*Lecturer in classroom setting*” and “*Lecturer in clinical or practical class*”) is one of the key tasks of a medical teacher and digital technologies cope with it well. As mentioned above, data from numerous studies prove that “virtual reality is a useful educational tool in the field of medical education and practical training skills in many preclinical disciplines and clinical specialties, including emergency medicine, nursing, pediatrics, radiology and cardiology” [Pallavicini F et al., 2022; Buyego et al., 2021; Herbst et al., 2021; Petrica et al., 2021].

Virtual and augmented reality technologies are widely used in the study of anatomy, where their invaluable advantage is the three-dimensional (3D) visualization of human organs and body parts. These technologies utilize large touch screens to project a life-size volumetric model of an adult males, females and children. These models can show or hide individual layers and anatomical systems as needed, allowing for the study of structures and organs relevant to the lesson. The advantage of these technologies is the availability of an unlimited number of different models, the ability to explore different layers and systems individually or collectively, and the ability to visualize and mentally manipulate 3D structures, accurately identifying them and their related structures and continuously monitor learners’ mastery of concepts, terminology and structures in real time.

In addition, modern information resources with interactive 3D features often offer higher quality information materials compared to lecturers. Recognizing this, many teachers today actively use video materials and interactive virtual aids during lectures and classes – sometimes a human’s function is reduced to pressing the START and FINISH buttons. However, a good teacher still takes the opportunity to comment on and add to the material being demonstrated bringing personal point of view to the topic.

For example, a prospective study conducted in a cohort of the 4th and 5th year medical students at the Medical University of Göttingen (N = 100, in study 58 and in control groups 42) showed a significant improvement in diagnostic accuracy and correct treatment recommendations among students who participated in six 90-minute sessions of a serious game (“*learning phase*”) in which they treated virtual patients with various conditions: non-ST-elevation myocardial infarction; pulmonary embolism; and hypertensive crisis. Students in the virtual learning group were more than twice as likely to make the correct diagnosis and were significantly more likely to adhere to current clinical guidelines, such as measuring troponin and D-dimer in suspected Pulmonary Embolism [Raupach T, 2021].

As far as the teaching of practical skills in the classroom or in the clinical environment is concerned, the scope of activity of a modern teacher is already significantly reduced, and this activity is gradually being transferred to the walls of the simulation center, especially for the practice of basic medical manipulations. Obviously, a verbal story about the algorithm of performing a manipulation is not as effective as its demonstration (“*Seeing is believing*”, it is better to see once than to hear hundred times). Demonstrating the same manipulation hundreds of times, day after day? It’s ineffective and boring. Of course, a live demonstration can be videotaped and viewed at the student’s convenience, as is increasingly being done. However, it is not enough to review the manipulation – to master and consolidate it requires repeated independent execution. To avoid risk and discomfort for the patient, more and more practical manipulations and skills are being mastered with the help of simulation, including virtual technologies.

Well, for faster understanding and memorization, as well as confident mastery of practical skills, a method of interaction with teachers, as proposed by *J.W. Rodney Peyton*, is very effective. The author formulated four obligatory phases of mastering manipulation:

1. *Demonstration*: teacher shows manipulation in a normal, fast pace.
2. *Deconstruction*: breaks down the manipulation into its logical fragments, demonstrates and comments on them in slow motion.
3. *Comprehension*: teacher follows the student’s instructions and performs the manipulation step by step.
4. *Performance*: student performs the manipulation, simultaneously speaking aloud each step.

Once the manipulation has been mastered at the first level, it should be worked out until it becomes automatic, for which it is necessary to go through two more stages:

5. *Evaluation*: the performance of the task must be regularly evaluated and corrected.
6. *Repetition*: the exercise must be repeated to develop automaticity, distributed over time (distributive learning).

[Peyton JW, 1998; Gorshkov MD, 2017].

Virtual systems have already come close to implementing this model in practicing manipulations, performing demonstration, deconstruction, checking the correctness of understanding, and also providing the opportunity to repeat exercises with their evaluation and adjustment [Fig. 58]. For example, according to Swedish researchers, virtual simulation training reduces the error rate when residents perform their first 10 laparoscopic cholecystectomies by 3 times and reduces the duration of the operation by 58% [Ahlberg G, 2007]. Similar conclusions were reached by Danish educators who found that gynecologists trained on the VR simulator performed laparoscopic salpingectomy in half the time (12 minutes instead of 24 minutes), which corresponds to the average level of practical experience acquired in VR – of 20–50 independent laparoscopies [Larsen C, 2009].

Credit: Maxim Gorshkov, 2019



Fig. 62. Virtual surgical training with instant feedback allows the resident to correct his actions immediately

5.2. Demonstration of role models

Of particular difficulty is the possibility of applying two role models in the virtual environment: “*On-the-job role model*” and “*Role model in the classroom*”. Finally, the teacher is required to serve as a role model, a kind of reference person for students who, voluntarily or involuntarily, will begin to copy the “model” – dress, speak, gesture, move, communicate, answer, and ask questions in the same way. As a workplace role model, sometimes even “professional idol”, the experienced clinician becomes a source of inspiration and learning for students by demonstrating exemplary professional clinical behavior, relationships with patients, and colleagues. Students observe, reflect, and imitate the teacher’s passion for the profession, respectful and empathetic attitude toward those who suffer, and compassion and professional concern for them. When choosing a role model, the student himself evaluates the mentor – she or he must have extensive knowledge and skills, be a professional, enjoy authority among patients and colleagues, and have life goals, principles and beliefs that are understandable and approved by them.

Workplace role models has critical importance in shaping learners’ professional identities and behaviors. They provide a clear example of what it means to be a competent, emotionally stable, yet empathetic health care professional. Observing and interacting with role models while actively participating in clinical sessions or other educational activities helps students develop clinical competencies, professionalism, and a deeper understanding of the values and attitudes necessary to work effectively and humanistically in health care.

Role modeling in a teaching environment embodies effective teaching practice and also serves as an inspiration to students who will soon become mentors to junior staff, nurses, and less experienced colleagues. In this context, *Ronald Harden* emphasizes the importance of educators serving as role models for their students, demonstrating the qualities of an excellent teacher, such as enthusiasm, competence, effective communication, and passion for teaching. A talented teacher creates a positive learning environment, motivates, and inspires students to achieve their learning goals, and encourages active learning, critical thinking, and a problem-based approach. By observing and interacting with such role models, students not only gain knowledge of the subject, but also learn how to become effective teachers in the future.

So, is a virtual mentor incapable of being a role model? Of course, a digital assistant cannot fulfill all of these qualities and characteristics – it is hardly destined to become an idol, a role model. While a virtual learning assistant can provide instructional guidance, it cannot fulfill all the aspects of a role model to the same extent as a human teacher.

At the same time, modeling professional behavior, ethical decision-making, and effective communication starts small, with the simplest algorithms and skills – at the beginning of the conversation, say hello to the patient; at the end, say goodbye; before physical contact, treat your hands hygienically; after the examination, repeat the treatment; listen to the patient carefully, without interrupting; start palpation on the healthy side; before the injection, warn “now it can hurt a bit, please be patient,” and so on. All these small but important nuances are not only individual elements of the procedure, but also tiny bricks, individual mosaic elements that make up a holistic picture of a doctor’s professional behavior in the workplace. And these elements are already being practiced effectively in a virtual environment. Clinicians can already see that students who have taken courses on virtual simulators do not forget to ask for informed consent, to check at the end of the interview that the patient understands everything, and to check for their own safety before performing resuscitation – without having completed these actions in a virtual environment, of course.

So far, at the present stage of development of computer technology, only one person can serve as a model for another, only a mentor can show his own example to students of how one should and can fulfill his professional duty, especially in a psychologically difficult situation, when faced with one or another moral choice. The solution lies in the humanistic field. However, if the performance of a “role in the clinic” is understood in a narrow sense as a clear algorithm of actions in a standard situation, then the mastering of such a scenario, the mastering of this algorithm is possible today in a virtual environment.

5.3. Facilitation of the educational process

The role of the medical educator as a learning facilitator according to Prof. Harden involves the creation and management of a structured, interactive, and friendly environment for the effective learning of medical students and includes a number of subtasks and diverse functions. The medical teacher as a “*Mentor, personal adviser or tutor*” and “*Learning Facilitator*” does not only determine the content of the course, the main tasks and educational goals, methods, and forms of assessment. First of all, he/she should encourage and motivate students to study the topic, preferably on a problem-oriented basis for more effective study and in-depth perception. Guided by this professional experience, he chooses various teaching methods that best suit the learning objectives and needs of the students – he may use lectures, group discussions, case methods, problem-based learning, show the practical relevance of the material being studied, and introduce elements of competition or teamwork.

As the student completes a task, performs a manipulation, or solves a clinical problem with the virtual simulator, the actions are corrected, or some other form of feedback or formative assessment is provided. As the student masters the material, the simulator can adjust the individual learning trajectory, changing the speed and difficulty of presenting the material depending on the depth and quality of its assimilation, as well as provide advice and explanations during the lesson – acting as an assessor and as a mentor, curator.

5.4. Assessment, examination

Carrying out assessment activities – conducting formative and summative test, evaluations and exams – is one of the main duties of a teacher, according to *Ronald Harden “Examiner, Assessor”* (two roles: “*Planning or participating in formal examinations of students*” and “*Curriculum evaluator*”). Only by monitoring the degree and correctness of acquisition of the material, as well as by making corrections in the student’s actions, can one be sure that the program has been fully studied, that the basic theoretical concepts have been correctly mastered, and that the appropriate practical competencies have been acquired, i.e., that the future doctor is ready to perform professional activities at the appropriate level. To ensure that such evaluation is as clear, structured, and free of subjectivity as possible, Prof. Harden published an article in the *British Medical Journal* in 1975 that revolutionized assessment in the medical education systems worldwide. In his article on the assessment of clinical competence he offered its new form – an *Objective Structured Clinical Examination, OSCE* [Harden RM et al., 1975]. This fact alone speaks of a systemic problem – the difficulty for an individual to suppress own human essence, such a personally impressed assessment will always suffer from liberties, deviations from the standard, and have subjectivity in relation to various examinees.

Assessments given by humans will always suffer from “assessment bias” – deviations from the standard, subjectivity in relation to a particular examinee. Bias and subjectivity in assessment can affect a student’s future career and self-esteem, especially when it comes to important exams such as final exams. Bedside oral examinations based on real patients have unacceptably low reliability, which is why many medical schools around the world have long since begun to replace them with OSCEs.

However, this option, although more accurate and reliable, requires significant resources, so it is almost never used frequently and on an ongoing basis; its use is limited to the most important exams – final, transfer, graduation. Additionally, when OSCE raters are not adequately trained and/or are not used on a frequent and consistent basis, their reliability and validity may be compromised [Monti M., 2020].

Computer assessment does not have these shortcomings – the virtual simulator will clearly determine time, speed, blood loss, agility, accuracy and

any other of hundreds of conceivable parameters of clinical competence. Of course, it is necessary to validate the chosen parameters as a benchmark. Moreover, at the current stage of technological development, all this is mainly about technical skills – a machine is not yet able to compare with the assessment of professionalism in the field of communication with a patient or team interaction given by a person. However, today they are used not only in formative, but also in summative assessment, in final, including important, exams (the role of “planning or participation in formal student exams”) – from the USMLE in the USA to the State Final Certification Exam in Kyrgyzstan [Fig. 59] – in different parts of the world [Dillon GF, 2002; Minty I, 2022; Bugubaeva M, 2022]. At the same time, the pace of development of artificial intelligence systems suggests that computer systems will be able to take any, even the most complex and important exams in the coming decades or even years.



Credit: Makhbat Bugubayeva, 2022

Fig. 63. Students examine a digital simulated patient in the virtual clinic. Medical University, Osh, Kyrgyzstan

5.5. Planning and organization of the educational process

The next group “Planner” combines two role functions of a teacher – “Curriculum planner”, “Course organizer”. The organizer of the educational process manages it and encourages the effective participation of students by creating situations that require the active use of knowledge and skills. This can include internships, clinical placements, simulation training and other forms of active learning.

Currently, computer programs that manage the educational process of groups of students or individuals are assigned to a separate form of application called a *Learning Management System (LMS)*. In many medical schools they have already become an essential part of the management toolkit. First and foremost, *LMSs* are designed for content management – distributing topics, classes, workshops to individual students and study groups depending on their performance, educational progress, availability of free classrooms, educators, simulated patients and embedded participants, teaching aids and consumables, ensuring uniform effectiveness, load and continuity of the curriculum. The educational process management system uses not only grades for completing tasks, but also feedback mechanisms with students so they can evaluate their own progress and adjust the pace, depth and intensity of the educational process to maximize individualization.

Automating the difficult task of learning management can significantly improve and facilitate the work of administrators and individual teachers. Providing digital systems with the means to manage the completion of a training course according to a personalized plan (“individual educational trajectory”) allows us to assess the successful performance of their roles as mentors, curators, and coordinators.

5.6. Development of teaching materials

A quarter of a century ago, Ronald Harden divided the function of creating educational materials into two parts – the teacher must create textbooks, “Production of study guides”, as well as “Developing learning resource materials in the form of computer programmes, videotape or print which can be used as adjuncts to the lectures and other sessions” – that is, sharing the roles of developing both basic and auxiliary, supplementary materials. It is possible that in those years these two processes had significant differences and required special professional competencies, for example, the qualifications of a videographer to conduct high-quality video filming. We will stick to the author’s classic scheme and consider them as two separate roles.

Many electronic, virtual *in-situ* and distance learning systems provide the students with original educational material – in the form of texts, audio recordings or podcasts. In addition, virtual systems provide complete courses consisting of individual educational elements – theoretical lessons, videos, interactive simulations, etc. These training programs have been created by leading experts working as part of a creative team. During development and testing, they underwent a multi-stage review and validation by independent specialists.

On the one hand, unlike a live teacher, a virtual assistant does not create a lesson or a clinical scenario, but on the other hand, the final product offered to the user is usually of higher quality, more interesting and more effective than the one created by the author – alone. It is impossible for a teacher to compete with the results of such collective work – after all, their teams consist not only of leading expert clinicians, but also psychologists, teachers, programmers, 3D modelers, designers, and UX specialists in the field of user experience.

In addition, recent experience in communicating with artificial intelligence systems, for example with the *Generative Pretrained Transformer ChatGPT*, indicates their ability to compose clinical cases, form a sequence and determine the depth of mastery of material on a particular topic, write educational texts, computer programs, formulating questions for testing, both correct and incorrect, in a word, indicates the ability to play these roles of a medical teacher – “Curriculum planner”, “Production of study guides”, and “Developing learning resource materials in the form of computer programs, videotape or print.”

In summary, today's ability of virtual systems to perform 12 instructional roles is captured in Table 13 below. Of course, none of the teaching roles can be one hundred percent replaced by a computerized educator. Therefore, the above-mentioned examples of their implementation by a virtual mentor should not be taken literally, directly, but regarded as a potential vector of development, as a prospect for growth and cooperation.

In our opinion, the situation will develop in the same direction as in other spheres of human life. Computer technologies used in medical education will not replace the teachers but will allow to get rid of routine, standard, monotonous, uncreative activities. There is no need to explain the same theoretical material over and over again, to demonstrate the same techniques and manipulations hundreds of times, to ask boring but important test questions, or to monitor the correctness of the algorithm for performing standard operating procedures. The educator will want to explain some nuances in more detail during the lesson, some topics may be more or less relevant due to local geographical, cultural, endemic or epidemiological reasons, and the training course can be adjusted accordingly.

Already now, in the system of training of medical personnel, systems of independent practical training – from mastering of individual basic medical procedures to complex high-tech interventions – are widely used, although in a fragmentary manner. In some specialties, for example, obstetrics and gynecology, during simulation training a doctor can master all practical skills to the required extent. The list of these specialties is not yet complete, but before our very eyes, these “blind spots” are being filled very quickly, and if the same high rate of development is maintained, in a few years there will be no gaps unfilled, no single manipulation, procedure or surgery in the basic training of students and doctors that could not previously be studied and mastered in a virtual simulated environment.

The teacher will be able to focus on complex concepts, creative discussions, issues of developing clinical thinking and action in non-standard situations, consider unique clinical cases and teach how to solve non-standard situations.

And it is this opportunity to focus on such creative, interesting tasks, leaving routine tasks to virtual systems, that allows us to say that teachers, like students, dream of electric patients and digital assistants.

Table 13. Ability of digital systems to fulfill the 12 roles of a medical educator

<i>Group</i>	<i>Role</i>	<i>Digital, virtual, AI</i>
Information Provider	Lecturer in classroom setting	Great, better than real
	Teacher in clinical or practical class setting	Good, in parity
Role model demonstration	On-the-job role model	Possible, but with some limitations
Facilitator	Role model in the teaching settings	Possible, but with some limitations
	Mentor, personal adviser or tutor	Good, in parity
	Learning Facilitator	Excellent, sometime better than human
Examiner, Assessor	Planning or participating in formal examinations of students	Excellent, sometime better than human
	Curriculum evaluator	A person is needed once
Planner	Curriculum planner	Excellent, better than real
	Course organizer	Good, in parity
Resource Developer	Production of study guides	Developed by faculty team or AI
	Developing learning resource materials in the form of computer programmes, videotape or print which can be used as adjuncts to the lectures and other sessions	Developed by faculty team or AI

[Harden RM, Crosby J, 2000; Gorshkov M, 2022]

6. Advantages and disadvantages of a virtual medical education

After a thorough examination of the designs, technologies, and classifications of virtual reality (VR) systems for education, we can highlight several benefits of implementing digital environments in medical training. These advantages are particularly significant when juxtaposed with conventional methods of theoretical instruction and hands-on skill development. Some of them are shared with those mentioned earlier for simulation learning in general [Knowles M, 2005; Gorshkov M, 2009; Walker R, 2009], while others are unique and known only from virtual training. In addition to the advantages, there are a number of disadvantages and even dangers in conducting medical training in environmental conditions. Let's look at them in more detail below.

6.1. Benefits of using virtual simulators in medical education

Clinical education and practical training take place in a **safe** virtual environment – with no risk to patients, students, or teachers. Patients are not involved in the educational process and cannot suffer from inappropriate actions of students, and they, as well as teachers, are protected from possible external threats – infections, accidents, injuries, damage, aggression from patients or their relatives.

Training allows you to avoid unwanted complications arising during the educational process, and the introduction of virtual simulators helps to reduce the number of complications. For example, in a national study conducted in 29 NHS ophthalmology departments, 265 first- and second-year resident ophthalmologists performed 17,831 cataract surgeries. 6,919 (38.8%) surgeries were performed before training on the *EyeSi*¹ virtual simulator, 8,648 (48.5%) after training, and 2,264 (12.7%) by surgeons without access to virtual

¹ Trade mark of VRmagic GmbH, a company of Haag-Streit AG, Könitz, Switzerland.

training. Overall, surgeons trained in a virtual environment experienced a 38% reduction in the incidence of posterior capsule rupture, the most common complication in this surgery. In the control group (surgeons without training on a virtual simulator), the reduction in the number of complications over the years of residency was insignificant and amounted to 3% [Ferris JD, 2019].

The learning environment is fully **controlled** by the teacher and/or student. The activity can be started, completed, or paused at any time, and all components are fully managed. Clinical situations are selected by the instructor or student and are determined by learning objectives rather than the current availability of patients with a suitable diagnosis. Anatomical peculiarities, rare pathologies and life-threatening conditions can be easily reproduced in VR without limitations.

Such selectivity allows you to avoid diagnosing the same common diseases over and over again, not wasting time on already familiar, routine stages of manipulation or surgery, but concentrating efforts on working out the most complex, critically important points, which increases the effectiveness of practical training.

For example, residents trained on a virtual colonoscopy simulator reached the caecum 52% of the time (the control group rate was 19%); they took less time to perform the procedure, and their patients experienced less discomfort [Ahlberg G. 2005].

The operating costs of running virtual simulators are close to zero. Once created, a virtual clinical scenario can be replayed endlessly, repeated many times, or sent to any number of students. Such activities, with rare exceptions, do not require replacement of consumables – the virtual environment does not require replacing skin, refilling cartridges, filling systems with drugs, or using disposable bandages.

Education is **learner-centered**; students are at the center of the educational process with virtual systems. Shifting the focus from the teacher to the student positively motivates and encourages the student to actively participate in the learning process – in this learning model, it is impossible to passively sit through hours of lectures and classes, simply moving from one topic to the next.

Thanks to the use of modern technologies, VR education becomes **geographically flexible** – it does not matter where the teacher and the student live. A student can listen to lectures, complete assignments, and even practice workshops remotely from anywhere, even from another continent. This opens up new opportunities for access to higher levels of education, regardless of actual physical presence, and can give an advantage to students from regions with low-income levels and inaccessible higher education. In 2015, the United Nations General Assembly recognized the need to provide quality education at the primary, secondary, technical, and vocational levels as one of the 17 Sustainable Development Goals [UN, 2015]. This goal is highly relevant for Russia, a country with large distances, where about 37% of the population lives in small towns and rural areas.

Management and control over the learning process can be partially or completely delegated to the student: pace, intensity, volume, depth, direction, self-esteem. The student can choose the time and sometimes the place of the lessons, independent of the work schedule of the clinic, the department, or the teacher. The number of repetitions of manipulations or clinical tasks is not limited. Thus, the student repeatedly practices a complex manipulation in VR according to the principle of “deliberate practice”, just as a musician plays scales to improve mastery of technical skills [Ericsson, 1993].

Skills acquisition using VR simulators is carried out according to the *Experimental Learning Model* [David Kolb, 1984]. Through his accumulated experience he observes and analyzes newly received information. He applies the revised and rethought algorithm in practice, in virtual reality, extracting from this action new, practical clinical experience acquired in a simulated environment. This “*learning by doing*” format for mastering educational material is more effective than the classic options of reading textbooks or passively listening to lectures.

This conclusion is confirmed by the results of the conducted studies. It should be noted that the topic of using virtual simulators in medical education is of great interest. Over the past three decades, several thousand such studies have been published in the global indexed literature. Thus, a search in the *PubMed* database showed that in the last ten years alone, from 2013 to 2022, more than 4,377 studies were performed containing the keywords

“*virtual patient in education*” [query ((virtual) AND (patient)) AND (education)] and 5,092 papers with the words “*virtual simulator in education*” [query ((virtual) AND (simulator)) AND (education)], including 200 and 194 systematic reviews, respectively.

According to one of the latest systematic reviews of randomized trials, the following conclusions were drawn: 1) the effectiveness of the use of virtual patients, assessed by knowledge gained, showed that training using virtual patients is as effective as traditional training; 2) the effectiveness of the mixed methodology – the use of virtual patients, along with classical forms, is moderately higher than with the exclusive use of only traditional forms of training; 3) the effectiveness of using virtual patients to acquire clinical thinking skills, procedural and team skills was higher than with traditional training [Eysenbach et al., 2019].

Training on a virtual simulator enables **reflection** of the educational process, to understand the practical experience gained in virtual reality – to remember, to identify and analyze your actions, to evaluate the demonstrated results and to adjust the further educational process.

The use of VR simulators allows you to create a **problem-based** educational process, where the solution of a certain situation is formulated as a learning task – making a diagnosis, resuscitating a victim, removing a tumor, increasing the efficiency of use of hospital beds.

Objectivity of evaluation is a systemic advantage of VR. The absence of subjectivity and bias inherent in human examiners allows virtual systems to impartially assess the level of acquired knowledge or practical skills – based on a combination of many objective parameters. Such an assessment is not only objective, but also **valid** and **reliable**.

Constant feedback with assessment of the level of knowledge and skills allows you to build the progression of the educational process individually, upon reaching the established level – *Proficiency-Based Progression*. Exactly as much time is allocated for studying as is necessary for a given student, without regard to other students or to the “study hours provided for by the program.”

In turn, linking the educational trajectory to the results of a particular individual and introducing a minimum threshold value (“passing score”) makes it possible to **guarantee** the appropriate level of competence upon completion of the training program in virtual reality.

The learning environment is **standardized** and **reproducible**, which is extremely important for the organization of the evaluation process, especially on a large scale and when conducting high-stakes exams, for example, final graduating or licensing examinations. In a standardized assessment process, each participant can be sure that he or she is in exactly the same conditions and is being assessed according to exactly the same criteria as all other examinees.

Training in a virtual environment can take place in groups, regardless of the number of participants and their geographical distance. In this case, entire social networks are created, united by a single goal or solution to a single educational task (MUVE, Multi User Virtual Environment). The emerging social component, social relationships help to find answers to complex questions together; participants can share experiences, give advice, recommendations, leave feedback and participate in virtual **team training** together. It is possible to introduce a competitive component.

Virtual reality in the civilian sphere is most widely used in the gaming industry. Therefore, it is not surprising that the introduction of **game elements** into the digital educational process is a systemic property – students enjoy the lesson, are passionate about it like children, are immersed in the educational process. For many students, the moment they put on the virtual helmet is the starting point where the game begins. Emotionality, immersion, excitement – all these components that accompany the virtual educational process make it effective and the acquired experience memorable for a long time.

In virtual training, the student can play a role that is unusual for him, that he has not had to play in life; the student can evaluate himself in the role of a chief physician, a surgeon, an endoscopist or a nurse in the operating room. It is easy to change these roles, which allows you to feel like you are in the shoes of other members of the medical team; the effectiveness of **role-playing** has been studied and proven many times.

Virtual reality provides additional opportunities not only in education, but also in medical **science and practice** – you can reproduce a critical situation to analyze it and identify errors, test new clinical techniques in a safe simulation environment (equipment, methods, protocols, drugs), pre-produce perform surgical intervention on a virtual model of anatomy of a real patient, simulate mass admission of victims to health care facilities. Today, virtual models are often used in clinical trials and development of new pharmacological substances.

Virtual training environments are increasingly serving as **supplements** or even **substitutes** for teachers in routine educational activities. It's become a norm in education, medical studies included, to utilize electronic textbooks and learning videos independently, without an educator's immediate presence. Students typically engage with the material before attending seminars. This approach underpins the '*flipped classroom*' model, where students first explore



Credit: Maxim Gorshkov, 2018

Fig. 64. Studying the birthing process in a virtual augmented environment using HoloLens glasses, looking through the abdominal wall of a woman in labor to see 3D models of the uterus and fetus (displayed on the screen behind)

new topics individually and later delve into them with a teacher in class. Eventually, it won't be surprising to encounter residents who have already grasped the essentials of endosurgery, recognized pulmonary conditions by sound, or understood the basics of cardiac sonography through virtual tutors.

Training in virtual reality (VR) is a **cost-effective** alternative to physical training, which can be expensive due to the need for high-priced consumables such as replacement skin, artificial blood, bones, and tissue blocks. However, physical simulators are still necessary for in-person training to practice skills and complete cases, as distance learning is currently not feasible due to the requirement for direct interaction between the student and the teaching aid. This guideline pertains to managing classroom resources, including scheduling, queuing, and accessing academic materials and spaces.

The objectivity of assessments in a real world may be impacted by potential subjectivity and other human factors inherent in teachers, compromising students' ability to attain a specific level of competence. Emotional involvement and participation of large social groups in physical simulator training is unfeasible when compared to virtual methods.

Summarizing the above, the advantages of using virtual reality simulation in medical education are listed in Table 14. Looking through this list, you can make sure that conducting the educational process in a virtual environment has both advantages that are common to any training simulation, and specific advantages that are characteristic only for virtual reality training. Thus, when simulating on mannequins or physical phantoms, it is difficult, and sometimes impossible, to set up automatic feedback, continuous and instant assessment of the student's actions. This requires the presence of a specialist who will give formative assessment, otherwise repetition of incorrect actions will lead to the reinforcement of a false skill. In general, the possibilities of replacing teachers when conducting the educational process on physical simulators independently, without their participation, are much lower. Standard reproduction of a case in physical reality is also quite difficult to implement – there will always be some deviations, nuances, and differences. This may have a negative impact on the standardization of assessment, which is especially important in high-stakes exams. Thus, the use of digital technologies in the educational process, in addition to the benefits of simulation-based instruction, imparts unique elements of virtual learning specific to the virtual environment.

Table 14. Benefits of Using Virtual Technologies in Medical Education

- Virtual reality is a safe learning environment with no risk to patients, faculty, or students.
- Learning process using virtual technologies takes place in an environment fully controlled by the teacher or student.
- Rare, complicated, and critical medical cases can be replicated and practiced regardless of their occurrence in the current clinical setting or the availability of actual patients with these conditions.
- Virtual reality training requires no consumables, has low operating costs.
- VR enables distance learning without the physical presence of the student in the classroom, making it geographically accessible, reducing social inequalities in education.
- Digital education, training, and assessment are standardized and can be replicated.
- Time and date of digital lessons can be determined by the learner according to the principles of deliberate practice, with literally unlimited number of exercise repetitions.
- Learner-centered education prioritizes individual learners, allowing for adjustable pace, number of attempts, duration, and intensity of VR sessions based on their specific needs.
- Immediate feedback in VR allows for reflection during the learning process, correction of mistakes, identification of knowledge gaps, and allows you to make immediate changes in the student's actions.
- Automated analysis of competency development enables customization of the curriculum as mastery improves, facilitating the creation of an individualized learning path.
- Kolb's experiential learning model can be successfully implemented in digital systems.

- Problem-based learning, VR assignments and cases are designed to solve practical problems.
- Provides objective, validated, and standardized assessment.
- Ensures achievement of a pre-determined benchmark, level of competency.
- Highly emotional situations can be modelled in virtual sphere, providing realistic learning and longer retention.
- Gaming techniques and elements can be used in the digital learning environment.
- Students can choose and share professional roles.
- Can be trained in groups, social networks, or multi-user virtual environments.
- Training using virtual technologies can complement, enhance and partially replace classroom training.
- VR simulation can be used for education, scientific research, and practical experiments.

[Maxim Gorshkov, 2017]

6.2. Disadvantages of virtual reality training

As already emphasized above, the prevalence of virtual simulators in medical training cannot be called comprehensive. The variety and scale of the use of digital technologies in medical education, in our opinion, is undeservedly small, especially considering all the advantages that were discussed in the previous section. Part of the reason for this is the existing shortcomings and a certain skepticism of senior decision makers in medicine.

The **lack of realism** of the environment simulated in virtual reality is the first and leading drawback which many users immediately note. This is especially true for manipulation simulators that require not only visual, but also tactile perception – from torsos for practicing CPR to endosurgical virtual simulators. In general, the lack of detailed “life” similarity does not interfere with the solution of the main task – achieving educational goals, but it interferes with the emotional perception, the degree of trust of the teacher and student in this technology. They must convince themselves, force them to “believe” in the authenticity of the training and the effectiveness of the methodology. The same drawback includes the problem of capturing objects using joystick manipulators when simulating clinical activity in a virtual environment using a VR helmet. Working with these joysticks requires the development of a special skill that has nothing to do with clinical manipulation. Without this unique dexterity of a VR gamer, it can take several minutes of agonizing effort just to grab a regular syringe and perform an intramuscular injection. This problem can be solved by recognizing hand movements, which is already a standard function in modern VR glasses, but it does not work without failures and is not yet used in all models.

Of some concern is the lack of compassion for the digital model of the patient, the apparent inability of the human to empathize with the computer program and, conversely, the inability to elicit emotions and feelings from the computer itself, **emotional callousness**. The concept of empathy is central to the medical profession, being not only a measure of humanity but also a moral guide. During their university studies, students are often confronted with questions about patience and compassion, morality and mortality, difficulty of decisions and what does it mean to care for other beings.

The fictional *Voight-Kampff test*, as portrayed in *Philip K. Dick's Do Androids Dream of Electric Sheep?* and its film adaptation *Blade Runner*, is designed

to distinguish humans from androids based on emotional and empathic responses to carefully crafted questions and scenarios [Fig. 65]. The test measures subtle physiological responses such as changes in respiration and eye movement, presupposing that androids and humans would respond differently due to inherent differences in empathy. Will doctors who have mastered the art of healing on soulless virtual patients be able to pass this test, will they be able to empathize with a sick person? Or will the arrow of the scales measuring their physiological reactions not move at the sight of a suffering creature, as if they were no longer human but cyborgs?

The issues of realism echo the issues of the **validity** of virtual simulators. Any model, be it physical or digital, must accurately represent the properties of the simulated object that interest us, working on it must ensure the correct development of the target competence, and the assessment performed using the simulator must reliably reflect the level of acquired knowledge, skills and abilities. These properties are usually denoted by the term “validity” (from the Latin *validus* – strong, healthy, worthy), reflecting the functional reliability of the model in training, research, experiment, and evaluation.

Validation of a virtual simulator involves gathering evidence to assess the trustworthiness of a simulation’s (model, program) accuracy while emulating a patient, organ, or clinical process for training, research, or experimentation. Furthermore, the reliability and objectivity of the assessment derived from this



Fig 65. A replicant (bioengineered being) tries to pass a polygraph-like examination, a Voight-Kampff test. Still from the movie “Blade Runner”

Credit: “Blade Runner” movie, Warner Bros., 1982

model must be evaluated. Only virtual simulations that have been validated can be authorized and certified as a pedagogical aid and assessment instrument, primarily for critical exams.

The European Association of Endoscopic Surgery's Working Group conducted a study on the evaluation and implementation of virtual simulators and practical training programs. As a result, they identified distinct types of validity, including obvious, expert, content, constructive, discriminant, and prognostic as shown in Table 15 (Carter FJ, 2005).

Table 15. Types of validity of virtual simulators

Face validity reflects the extent to which the virtual simulator and its training appear to be suitable for training or assessment purposes in the subjective opinion of the users themselves.

Expert validity is based on the opinion of experts who judge the realism of the simulation and the reliability of its assessment, relying on their own experience, citing their own judgments and logical constructs as evidence.

Content validity determines the value of the simulator as an educational tool, the adequacy of its didactic content, compliance with the world or national clinical guidelines and other approved or generally recognized authoritative sources.

Construct validity reflects the accuracy of the design of the simulator, the design of the program as a teaching aid and/or assessment tool, and the correspondence of its design to the stated description, drawing, technical documentation, and anatomical structure.

Discriminant validity indicates the ability, using a simulator, to reliably distinguish (discriminate) subjects from each other according to their level of skill, divide them into groups, and separate inexperienced participants from experts based on objective, measurable parameters.

Predictive validity indicates the ability, based on the results of cases or exercises on a simulator, to predict the level of practical skill can be demonstrated by the learner later in real clinical conditions.

Unlike face-to-face classes in a clinic, at the patient's bedside when training in virtual reality, the "doctor's model" is very conditional and, as a rule, is limited to only demonstrating a sequence of certain actions, an algorithm, a protocol for carrying out a given procedure. There is **no role model**, example for replicating and following. Thus, training in virtual reality is devoid of an important educational (upbringing) component.

In virtual reality there is no direct communication with a suffering person, a patient, and it is difficult to develop empathy in relation to a computer avatar. It is impossible to reliably reproduce the **emotional** burden of the situation of triaging severe patients in the context of a lack of time or other clinical resources, the feelings and experiences of specialists who make decisions about choosing a patient for transplantation, and all the shades of complex communications. When making clinical or logistical decisions, the user does not face a moral choice and does not learn to take into account the full range of humanitarian and social issues and nuances.

These significant gaps can and should be filled by the **combined use** of virtual simulators with classical training – at the patient's bedside, at the operating table. Virtual training should be regarded as basic training, laying the foundation for the so-called "*technical skills*" – basic knowledge, thinking, procedural competencies, manual dexterity; while "*soft skills*", in particular those related to interpersonal communication, remain the responsibility of traditional clinical teaching methods.

The low operating costs of VRS are combined with the **high cost of developing** software and hardware components. Most virtual simulators are innovative products that have appeared quite recently. For many of them, the evidence base is small, their validity has not been sufficiently researched, and the medical community, being professionally skeptical and conservative, is not inclined to overly trust the reliability of the work of new unfamiliar devices and programs if their use is not supported by a well-compiled evidence base. In the context of rapidly changing clinical concepts and approaches to the diagnosis and treatment of pathologies, it can be very difficult for VRS creators to organize effective and timely updating of the content of a digital device.

Just simply transferring classic teaching aids to a virtual environment requires **teamwork** – the participation of not only programmers and 3D modelers, but

also clinicians who monitor, review, and correct the virtual product at all stages of development – given the scaling, the price of any mistake is high. Even after such a transformation, validation is required, not to mention completely new interactive applications developed from scratch.

If the necessary component of the hardware interface is not available on the mass market, the parts required for many virtual simulators are made to order, only in single quantities – several hundred, or even tens of units. And the software applications themselves are not distributed in millions of copies, like regular consumer mobile applications. **Small-batch manufacturing** leads to an increase in the unit cost of this type of teaching aid. Therefore, if the training does not involve mass replication and repeated use of the model is not expected, then it is easier and cheaper to make it on a 3D printer or “the old-fashioned way” by simply making it manually from auxiliary materials – planing it from wood, knitting it from wool, molding a model from plasticine, wax or clay, or glued together from papier-mâché.

Training in a virtual environment necessitates the **proper preparation** of the premises, especially when conducting classes in a non-standard location, such as an adapted room, rather than in the regular classroom of a training center, where such classes are frequently held. The users (teachers and students) must complete initial instructions, including mastering operation, turning on/off devices, selecting Wi-Fi networks, calibrating VR glasses, marking safe perimeter, editing scenarios, and exporting testing results. Therefore, operating a virtual reality system necessitates specific skills and knowledges acquired by experience or additional **training**. Some institutions even offer special introduction courses for “VR-Educator”. Much more is required from them to operate efficiently. For Generation Z, who are currently receiving higher education, these tasks are routine. However, for many of their educators, modern technology has not yet become familiar assistants in daily life. For some employees, particularly those nearing retirement age, working in the virtual world can be challenging due to the lack of real-world user experience analogies. This activity falls outside of their regular professional duties. Incidentally, the challenges of mastering new technology are the root cause of an underlying and often subconscious resistance, which can be masked by arguments that suggest the scenario is unrealistic or that training doctors in a virtual environment is ineffective or dangerous. The opinions of

these teachers hold great significance as they hold senior academic positions and are at the pinnacle of their professional careers. Ignoring their viewpoints would be imprudent.

Additionally, medical professionals, particularly clinicians, tend to be “healthy conservatives” due to their professional attributes and are generally hesitant to readily embrace new techniques, medications, and other innovations that have not undergone extensive safety and efficacy testing. Consequently, virtual systems naturally engender **skepticism** in many doctors, particularly in the senior generation who are not familiar with them in their daily lives.

Some highly realistic virtual reality systems, particularly simulators used for complex procedures like angiography or endovideosurgery, require extensive hardware and software that demand professional technical support and system administration. Employing engineering and **technical service** employees to manage such functionality incurs added financial, administrative, and human resource costs.

The technical design **complexity** of virtual simulators leads to additional problems and risks specifically related to their use with technology. Thus, in response to the competitive market manufacturers aim to accelerate the development and implementation of new models and versions of the simulators. As a result, they intentionally release unfinished educational system for regular public use, labeled as “*beta testing*”, and continually refine them during operation, referred to as “*on the fly*” adjustments. It is not uncommon for clinical recommendations that served as the foundation for a virtual simulator to have already undergone significant changes during the product’s development, testing, and debugging phase.

In addition to internal system errors, **external factors** can cause technical failures in a virtual simulator, which is akin to any other high-tech product. Weak or slow internet, interference from other WiFi devices, or a frozen processor can all hinder the smooth functioning of a class or exam. To ensure uninterrupted operation, organizers should have a backup plan in place, duplicate components, or reserve systems for each potentially unstable element. You cannot rely on the fact that your data is in safe hands and its security is not jeopardized. Safety and even existing of results and data can be always compromised.

Software and hardware solutions for virtual simulators are **not proprietary** and operate with additional systems, auxiliary plug-ins, and need download portals like *Google Play*¹ or *AppStore*². Additionally, software versions of hardware components, such as VR glasses, are necessary for these games, but they are only produced by a limited number of companies that have control over the game-rules [Fig. 66]. Every update, upgrade, or new model release brings uncertainty to VR applications. Many VR-systems utilize software development kits (SDKs) from standard companies. Third parties develop and update most of these components without prior notice or approval. The more virtual reality software (VRS) is integrated with other software solutions, the more susceptible it becomes to third-party actions, which can be considered an artificial force majeure. Dependence on third-party hard- and software components poses a significant challenge in the development and operation of VRS, including mobile devices, interactive panels, tablets, computers, and VR helmets. Furthermore, the commercial life of digital products is brief, ranging from just a few months to at most a year or two. Quarterly or annual updates to components and the discontinuation of previous models by third-party manufacturers can cause hardware elements, which were previously configured for image optimization, haptic signal calibration, or command configuration, to become unavailable. Development engineers must monitor these changes and make the necessary adjustments to the program code. Not to mention breakthrough technologies—innovative advancements that revolutionize approaches and principles within a specific industry, rendering prior developments obsolete and irrelevant.



Credit: Maxim Gorshkov, 2023

Fig. 66. VR-helm VIVE, one of the first commercially available VR-systems, made since 2016 by HTC Corporation (Taoyuan, Taiwan)

¹ GooglePlay is a trademark of Google LLC, Mountain View, CA, USA

² AppStore is a trademark of Apple Inc., Cupertino, CA, USA

Another group of problems is associated with the field of **cybersecurity**. Attacks by hackers trying to steal source code, license activation keys or personal data of users – these and other issues in the field of IT protection fully apply to educational virtual systems and their solution is the everyday reality of virtual application developers. This risk, of course, is taken into account by manufacturers, and they install protective systems, monitor user activity and track non-standard requests, but no firewalls or anti-virus programs provide a 100% guarantee to users.

Another drawback unexpected for many users was the **physiological incompatibility** of the human body with virtual sensations, a kind of “sensory dissonance” caused by inconsistency and contradictoriness of signals coming from the senses. While the eyes see realistic movement in space, while the vestibular apparatus indicates the absence of movement, and proprioception signals the preservation of position in space, the central nervous system becomes completely confused, expressed in vestibular disorders – dizziness, nausea, notes, fatigue and headaches when using virtual reality devices, especially for a long time.

Some users who have tried out the new *Apple Vision Pro* glasses claim unusual, not always pleasant, sensations that appear when working in the innovative device. Apple’s industrial design team, responsible for the aesthetic aspects of the devices, insisted on a version of the glasses with a thin curved front panel – more than a dozen cameras and sensors are hidden behind the dark glass, reminiscent of a skier’s mask. However, glass distorts the images captured by cameras, which can cause discomfort and nausea to the wearer if not properly compensated for.

As with other virtual eyewear, the main issue is the **vergence-accommodation conflict** (VAC), which will be explained further. Although the manufacturer was not able to completely eliminate the problem, experts acknowledge that they created a product that is considered the best in its class. However, for the majority of users up till now, the “virtual world seasickness” in the most cases dissipates after brief training, typically after several hours of using the immersion device. Since this phenomenon is widely discussed in relation to the possibility of widespread use of VR in medical education, we should look at it in more detail. Here’s what AI says about this issue:

Vergence-accommodation conflict (VAC) is a condition that occurs when the eye's vergence and accommodation responses are mismatched. Vergence is the movement of both eyes in opposite directions to obtain or maintain single binocular vision when viewing an object, while accommodation is the adjustment of the lens within the eye to maintain a clear image or focus on an object as its distance from the eye varies.

Normally, these two responses are coupled, meaning that if the eyes converge (move toward each other) to look at a near object, the lenses also accommodate (change shape to focus) for that near distance. However, in certain situations, such as when viewing 3D images or using virtual reality headsets, the eyes may need to converge at one distance but accommodate at another. The practical consequences of the VAC can include:

- **Visual discomfort and eye strain** when the eyes receive conflicting signals about how to focus and align.
- **Headaches** after prolonged exposure to these conflict-cause conditions due to the continuous effort to resolve the mismatch.
- **Reduced visual clarity**, as the eyes struggle to focus properly on the object being viewed.
- **Difficulty with depth perception** due to the conflict, compromised ability to accurately perceive the distance and depth of objects.
- **Fatigue** as extra effort required to overcome the conflict by using VR headsets or 3D glasses for extended periods.
- **Impaired performance** in tasks that require precise visual input, such as those involving hand-eye coordination.
- **Reduced immersion** in virtual environments happened due to the unnatural focus cues, which reminds the users that what they are seeing isn't real.

Addressing the VAC is a significant challenge in the design of virtual reality systems and 3D displays, and various solutions are being researched and developed to minimize these effects. Here are some methods being explored to solve or mitigate this issue:

1. **Multi-Focal Displays** present multiple focal planes simultaneously. The idea is to more closely mimic how our eyes focus on different distances in the real world. While promising, this technology is complex and can be expensive.
2. Light Field Displays reproduce the light field of a scene, which means they recreate the way light travels from a scene to your eye.
3. Eye-Tracking technology can predict where a user is likely to look and adjust the focus in that area.
4. Dynamic Focal Adjustment changes rapidly and precisely the focal length of the display based on where the user is looking in the same pace with the viewer's gaze and focus.
5. Holographic Displays can be used to create images that appear to float in space, with correct depth cues and focus properties.

Each of these solutions has its own set of challenges, including cost, complexity, size, and power consumption. Current VR and AR headsets often compromise by fixing the focal distance at a point that minimizes discomfort for most users, but this is not a complete solution to the problem. The development of more advanced display technologies and eye-tracking capabilities continues to be an active area of research to overcome the Vergence-Accommodation Conflict.

Injury is a potential issue when using virtual immersion training. Users wearing a VR headset may become disoriented in real space and collide with environmental objects. This concern is addressed through various methods, including virtual barriers and physical boundaries such as bands that restrict the training space like a boxing ring. However, despite the measures implemented on a program and organizational level, issues may still occasionally arise.

Thus, training the healthcare workforce using digital technologies has both advantages, as summarized in Table 14, and disadvantages, as well as potential risks, as outlined in Table 16.

Table 16. Disadvantages and risks of VR technologies in medical education

- Lack of realism and distorted reproduction of the real environment, which is especially affected in sensorimotor coordination during manipulations.
- Absence of a real person of the doctor's model and upbringing component.
- Lack of empathy which exists during direct communication with a suffering patient, hindering the student from making a moral decision can cause emotional callousness.
- Developing virtual applications and non-standard hardware components is a taxing process, requiring significant investments of time, money, and resources, as well as the collaboration of teams of specialized technical and medical professionals.
- There is no mechanism for certifying, overseeing, and ensuring the quality of virtual content, which can result in the release of unreviewed, inaccurate, or outdated content. Validation for teaching aids in VR is either insufficient or non-existent.
- The onboarding or even extensive training of the end-users is necessary when implementing VR systems while high-tech aids requires special competencies.
- Many teachers and clinicians have a general distrust towards virtual and computer technologies.
- Qualified technical personnel, computer administration, and IT-service are necessary for a smooth operation of the park of digital devices.
- Technical failures, caused by either internal factors (such as malfunctions of software, bugs, loss of sensitive and important data, or hardware failures) or external factors (such as the Internet connection interruption causing data transmitting or overwriting failure, interference, third-party application updates, or unavailability of hardware components), can occur.
- The need to ensure computer security due to the vulnerability of personal data and cybercrime.
- Some users may experience physiological intolerance, headaches, vestibular disorders, and vergence-accommodative conflict.

[Gorshkov M, 2020, 2022]

6.3. Threats and disadvantages of using AI in medical education

The Roman scholar and author of the largest encyclopedic work of antiquity “*Natural History*”, *Pliny the Elder (Gaius Plinius Secundus, 23–79 AD)*, two thousand years ago wrote: «*Metalla ferri optumo pessimoque vitae instrumento est*» (Iron is both the best and the worst things in human life). He used the example of a blacksmith who could create both a plow and a sword from the same metal, serving both noble and nefarious purposes. Any program, no matter how intelligent, merely reflects its creator, a person. Artificial intelligence lacks independent will – good or evil. Instead, it generates decisions, assessments, and texts by paraphrasing judgments made by people. While it can produce faster, more accurate results with minimal time and resources, it remains a tool in the hands of the individual. The threat cannot originate from a computer – only a person can be the source. The virtual world can mirror all the rights and freedoms, ethical and moral principles that are being fought for in the real world, such as justice, transparent decision-making, security, confidentiality, respect for individuals, protection of personal information, autonomy, trust, and dignity.

Of course, these issues were not ignored by legislators, both European and American. Already in spring 2021, the European lawmakers passed the *EU Artificial Intelligence Act* aimed at governing its use within its member states. This legislation represents one of the world’s most comprehensive legal frameworks for regulating AI, including risk-based approach with classification of AI systems based on their potential harm; prohibitions on certain AI practices posing an unacceptable risk, like human behavior manipulation; transparency obligations for those AI that interact with humans (chatbots), used to generate or manipulate image, audio, or video content (deepfakes), and emotion recognition systems; governance and enforcement under national supervisory; legal and ethical compliance (details at: artificialintelligenceact.eu/the-act). The *Blueprint for an AI Bill of Rights (Making automated systems work for the American people)* is published at the White House web-site. *The White House Office of Science and Technology Policy* has identified five principles that should guide the design, use, and deployment of AI systems: Safe and Effective Systems, Algorithmic Discrimination Protections, Data Privacy, Notice and Explanation, Human Alternatives, Consideration, and Fallback (whitehouse.gov/ostp/ai-bill-of-rights).

If one examines the aforementioned roles of AI in medical education through a lens of potential threats, the significant harm and danger stemming from the utilization of these cutting-edge technologies cannot be underestimated. Starting with the function “Objective assessment of knowledge and skills,” **discrimination** against certain groups of students can be discussed. For example, students with sensorimotor coordination disorders or vestibular system dysfunctions may experience nausea and dizziness in virtual environments, which can make it difficult for them to work. Although the examination assesses their professional abilities and not their proficiency in computer gaming, no exceptions will be made for physiological traits or to rectify an unjustly low score. If the data used to train an AI system was not diverse or representative, it could result in unfairly poor grades for certain groups of learners, impacting their academic performance and career prospects. Thus, the automatic analysis of the quality of a surgical suture can be affected by the smartphone camera model, the brightness of the lamp, or an incorrect shooting angle – the future surgeon carefully stitched the tissue, applied the suture flawlessly and tied the knots, but received a low score due to technical interference.

An integral part of the exam for future professionals is the **practical demonstration** of clinical skills in a simulated setting or on a standardized patient. Although the practical professional licensing exam (USMLE Step-2 Clinical Skills) was suspended in March 2020 and permanently canceled in January 2021, simulation-based competency assessment continues at the university level in the United States and Canada. Moreover, in many countries, the discontinuation of the high-stakes practical exam was only a short-term temporary measure and was fully reinstated after the removal of anti-epidemiologic restrictions. In many specialties, practical skills continue to be assessed on phantoms and simulators, including virtual ones, especially in less-invasive surgical disciplines such as arthroscopy, laparoscopy, endoscopy, and angiography. It can be challenging for AI-based assessment systems to analyze manipulations, recognize them, and evaluate them against objective parameters. This is especially true for complex actions, such as in physical examination and patient communication scenarios, as well as skill assessment during general surgical procedures. AI algorithms can be affected by biased and inaccurate training data, leading to unfair evaluations, especially if they have been poorly tested and validated.

Heavy reliance on AI in assessment activities can lead to their **excessive formalization**. Already today, in the course of evaluating actions based on dichotomous checklists, we can observe how with the formal implementation of most of the evaluation points, which guarantees a positive evaluation, the main goal of the manipulation may not be achieved, e.g. during cardiopulmonary resuscitation, respiratory tract passage was insufficiently ensured, or a geometrically precisely applied interrupted suture is so tight that in a real situation it will disrupt the blood supply to the tissue and lead to its necrosis. Possible technical errors or breakdowns, power outages, or failures in the transmission of digital data can lead to controversial situations based on erroneous assessments, affecting final academic performance and even future careers.

Some AI models, especially multi-layer neural networks, are considered “black boxes” that suffer from **non-transparency** in the answer’s generation or decision-making process. It may be impossible to get them to reproduce the entire logic chain and interpret the score given. This lack of analysis is particularly unacceptable in the case of final, high-stakes or licensing exams, when assignment to clinics and access to specialization or residency may depend on the results (by the way, this has been improved in later versions of *ChatGPT* – you can see some parts of the “thinking process”, or at least the names of websites used as sources of information). On the other hand, the systems themselves can become objects of manipulation by biased faculty or unscrupulous students. AI-based assessment tools may encounter attempts to cheat or game the system, attempts to exploit potential vulnerabilities in the program, gaps in assessment algorithms, or control mechanisms.

Some of the above also apply to other AI functions in the educational process, such as automated administration, prediction, or psychological monitoring. The main concerns relate to issues of confidentiality of personal data, since this process involves the use of audio and video surveillance, the collection and storage of which may not be carried out with sufficient care. The video recording of your personal room – a private zone, as well as biometric and passport data can fall into the hands of third parties in the event of a server hack or unauthorized access and be used to take out a false loan or other illegal actions. Few people want to share failed exam results, their home address, medical records, or the bank account to which a scholarship will be

deposited. Robust data security measures are needed to prevent leaks and protect sensitive information.

All exams, especially final exams, are associated with high levels of anxiety and stress. It cannot be ruled out that the additional pressure associated with monitoring by an AI system may further increase anxiety, confuse and disorient test takers, and negatively affect scores. These and other ethical principles that should be considered when implementing online proctoring are listed below [Table 17]. They apply not only to the distance learning option, but also to the face-to-face format using AI-based technologies.

Table 17. Ethical principles and values in online proctoring

Part 1

Ethical Principle	Application in Online Proctoring
Fairness, Bias	Equal access to technologies and settings for remote exams. Unbiased and non-discriminatory detection of fraud.
Transparency	Transparent use and explanation of technology characteristics and selected features like “cheating behavior” detection. Use of AI-based “red flags.”
Non-Maleficence	Effective and safe application of technology that does not harm the subject.
Privacy	Confidentiality in collecting and securing personal data, images of behavior in personal and home spaces.
Respect for Autonomy	Providing independent choice regarding the use of personal data. Use of AI video recordings of unknown proctors.
Accountability	Management, audit, and other mechanisms to ensure vigilance and response to risks of harm or misuse by organizations using AI technology. Processes allowing individuals to properly contest results.

Part 2

Ethical Principle	Consequences for Online Proctoring of an Exam
Academical fairness	Ensuring academic integrity, rigor, excellence and institutional reputation
Liberty and Trust	Wider Social Implications, potential wider impact on freedoms, digital use and public trust in AI, scholars, universities, etc.

[after Coghlan, Simon et al., 2021]

The **ethical issues** listed above apply not only to proctoring, but also to a whole group of applications of AI in the educational process. The balance between academic integrity, student privacy and autonomy, and the understanding that “your fate is in the hands of a machine” all require careful ethical consideration.

There are concerns about the **potential bias** of AI systems – unfair and biased assessments and decisions for different groups of students based on biases in AI algorithms that are discriminatory in nature. Bias in AI can occur for a variety of reasons, including intentionally manipulated machine learning data, biased historical or clinical evidence, poor algorithm design, or unintentional discrimination. When an AI system is biased, it may favor or disfavor certain groups of people based on factors such as gender, race, ethnicity, religion, socioeconomic status, or disability. Examples of such groups include foreign students (they may not understand the task in English well), non-residents (in a rented apartment they may not have access to high-speed Internet or worse, leaving conditions), low-income learners (they may not be able to pay for a subscription to a mobile application or buy an advanced computer needed for training), people with poor health or disabilities (the hard of hearing may not be able to recognize computer commands).

Eliminating bias and ensuring fairness in AI requires careful algorithm design, diverse and representative training data, and ongoing monitoring and evaluation of system performance. Ethical considerations are critical to identifying and addressing bias to create a more inclusive and equitable learning environment for all students.

It is important to approach the use of artificial intelligence to monitor the **psychological status** of students with caution and sensitivity. Their data, especially sensitive information related to mental or physical health, must be handled with special care and security, with strict safeguards in place. AI systems should be configured to promote the well-being of students, rather than to identify and exploit vulnerabilities or emotions. While AI can gather valuable information, it should not replace the role of educators and provide counseling, completely replacing humans. Individualized intervention and support are critical to addressing complex emotional and mental health needs.

Students will be required to undergo an informed consent process for the use of AI in their training and testing process, and to give permission for the collection, analysis, and evaluation of data, including personal data. This is particularly important for any monitoring or data collection related to their psychological well-being and health status. They must understand how this information will be used and be able to opt out of the use of AI without negative consequences, having been provided with an equivalent alternative.

To compensate for shortcomings and eliminate potential threats in the development of algorithms and the introduction of AI, responsibility, accountability, and transparency must be maintained in the educational process. In order to ensure personal responsibility, the university management must appoint the head of the working group that carries out the process of implementation in the educational and examination process. It should monitor and analyze AI-based assessments and ensure that faculty and students are properly trained in their use. Regular reports of the working group to the Academic Council or Faculty Senate of the University and approval of individual provisions and stages of AI implementation by the Ethics Committee will ensure the reporting principle. Publication of administrative, technical, and methodological documentation on the use of virtual platforms and AI systems, the procedure for making administrative and evaluation decisions on the pages of the educational portal, as well as feedback from students guarantee the transparency of this process.

Many university professors have expressed concerns and doubts about the academic integrity of using AI as a collaborator. Students can submit essays, abstracts, term papers, and dissertations generated by *ChatGPT* or other AI systems and pass them off as their own. The same is true for the use of scientific and methodological publications by authors. A major publisher in the natural sciences condemned such an attempt at ethical compliance and developed changes to its author policy that prohibit the inclusion of AI as co-authors in scientific papers [Tools like..., Nature, 2023]. In particular, the publisher has added two new principles to its guidelines for authors: no *Large Language Models (LLM)* tool will be accepted as an accredited author of a research paper, because authorship implies responsibility for its results, and AI cannot assume such responsibility; researchers using *LLM* tools should document this use in a section of the publication.

Given the growing popularity of AI tools, medical students will undoubtedly increasingly use ChatGPT and its analogues in the future, so universities are faced with the priority of developing policies for the use of AI systems by students and faculty in training and examinations. Since it will be very difficult to catch students by the hand, and bans alone will not stop this process, it is necessary to take into account the possibility of unauthorized use of texts generated by AI or tips received during testing, and to properly adjust the format of assessment activities and monitor their conscientious implementation.

This is even more dangerous when you consider the following fact. Many authors note that *ChatGPT* generates **fictive**, non-existent links on which it tries to justify its conclusion [Bishop JM, 2021; Tsang R. 2023]. This finding is also consistent with our observations using *ChatGPT-3* in the first half of 2023. Researchers bias in the selection of data sources on which machine learning is based, as well as the creation of fictitious literature sources, is a serious concern and casts doubt on the end result – the generated responses. Even if we assume that the potentially biased, discriminatory and incompetent medical content that prevails on the Internet is excluded from this array, it will still not be possible to create an impartial fair model – texts in English will dominate, not Hindi, Arabic or, say, Chinese, consider studies conducted in high-income countries and published in journals with excellent citation rates, or conducted in influential academic or research centers that dominate the health sciences.

From our own experience, which coincides with the observations of other authors, we know that AI systems sometimes experience failures in which **inaccurate or incorrect** answers are generated. The phenomenon described as an “*AI hallucination*” is a plausibly written, logical, but ultimately nonsensical or factually incorrect answer that is not supported by evidence. The system, as a rule, does not disclose its databases, does not provide information about where it obtained the information, and when requesting links to literary sources for detailed information about them, it happens that their traces cannot be found on the Internet, including platforms *PubMed* and *Google Scholar*. Let us give you an example of a rather funny dialog that has taken place with *ChatGPT*.

MG: Who invented chemotherapy medications?

ChatGPT: Mechlorethamine, also known as mustine, was one of the first chemotherapeutic agents developed from the group of alkylating agents. It was synthesized in 1942 by scientists Gustav Vagelos and Leo Feldman. Mechlorethamine works by directly damaging the DNA of rapidly dividing cells, including cancer cells, which can help slow down or stop the growth of cancer. Mustine has been used in the treatment of various types of cancer, including lymphomas and leukemia. It was a significant development in the history of chemotherapy and paved the way for the development of other alkylating agents and cancer treatments.

MG: Who were these persons, Gustav Vagelos and Leo Feldman?

ChatGPT: I apologize for any confusion, but it appears there may have been a misunderstanding in my previous response. I could not find any historical references or information about individuals named Gustav Vagelos and Leo Feldman being directly associated with the synthesis of mechlorethamine (mustine) or significant contributions to cancer chemotherapy.

If you are interested in learning more about the history of chemotherapy and the scientists involved in its development, you may want to explore the work of researchers such as Sidney Farber, who made significant contributions to the field of cancer chemotherapy, or Alfred Gilman and Louis Goodman, who were involved in the early use of nitrogen mustard agents like mechlorethamine for cancer treatment.

MG: Did you just “invent” the persons that never existed?

ChatGPT: I apologize for any confusion. It seems there was a mistake in my previous response. Gustav Vagelos and Leo Feldman are not historically associated with the synthesis of mechlorethamine (mustine) or significant contributions to cancer chemotherapy. I must correct my earlier response.

Mechlorethamine was indeed developed by researchers involved in early cancer chemotherapy, but the specific individuals involved may not be as well-documented as some other pioneers in the field. The development of chemotherapy involved the work of numerous scientists and researchers over time, and I appreciate your understanding regarding the correction.

[generated by ChatGPT-3 on 06.10.2023]

Therefore, in the first choice, the AI gave the names of scientists who not only had nothing to do with the discovery of chemotherapy, but who simply never existed and were fictitious. And only the “grabbed by the hand” AI admitted its mistake and gave the correct names on the second try. Considering such situation, the *OpenAI* even placed a disclaimer under the window for your requests: “*ChatGPT* can make mistakes. Consider checking important information.”

Thus, the value and usefulness of *ChatGPT* for literature review and academic work is questionable and its use should be supported by evidence from other sources. In some cases, undertrained AI is unable to understand the broader context of a student’s answers or reasoning, especially in complex medical scenarios, which can lead to inappropriate grades. The AI itself responded to a question about the reason for such failures as follows:

AI doesn’t intentionally invent fake facts; rather, this happens due to the limitations of its design and function. “AI hallucinations,” or instances where AI generates fictitious answers, can occur for several reasons:

- **Data Quality:** AI models are trained on vast datasets that may contain incorrect information. The model might reproduce such inaccuracies.
- **Lack of World Knowledge:** AI doesn’t possess true understanding or consciousness, so it sometimes makes mistakes that a human with real-world knowledge wouldn’t. AI doesn’t have a mechanism to access a «ground truth,» so it can’t verify facts against reality in real-time.
- **Ambiguity in Prompts:** Vague or ambiguous user prompts can lead to responses that don’t align with reality because the AI must guess the intent.
- **Pattern Recognition Over Logic:** AI prioritizes recognizing patterns in data over logical reasoning, not from a factual database, which can result in nonsensical or incorrect outputs. If the pattern leads to a plausible-sounding but incorrect response, the AI might «hallucinate» information by interpolating or extrapolating from the data it has seen.

- Limited Contextual Awareness: AI has a limited ability to understand context and can miss nuances, leading to irrelevant or incorrect responses.
- Overgeneralization: AI can overgeneralize from its training data, leading to broad statements that might not apply to specific cases.
- Inference Shortcuts: AI might take shortcuts in generating responses based on what is statistically common in its training data, which may not always be accurate.

[ChatGPT-4, December 2023]

Discussing the issue of AI hallucinations, we cannot definitively call them a bug or an error. When we submit a query to a search engine, we get a precise but completely “sterile” sample, 0% of own imagination, fiction, dreams – and this does not suit every user. If we request ChatGPT and get an overly creative answer, we express our dissatisfaction here as well and blame LLM for being “too dreamy”. But excuse me, what did we want? There are two key words in the GPT acronym that we should pay attention to – “Generative” and “Transformer”. It turns out that generation, creation, creativity, not just



Fig 67. Humanoid AI doctor and a patient according to imagination of DALL-E, the text-to-image model developed by OpenAI

Generated: DALL-E, prompted by Maxim Gorshkov, 2023

reproduction, but imaginative generative transformation are the crucial features of this type of AI; it is for this functional feature that the user turns to it, and not to the search server! After all, we are not going to scold a creative personality for imagination and even for mistakes and inaccuracies in expression. Ah, this is so creative! This is so human! I beg your pardon, maybe this is exactly what we are criticizing the machine for? Somehow it is too animate, too human.

The flip side of the machine's success, its ability to pass medical exams, is the recognition of the tactical loss of humans, an examination system designed by people and not taking into account the possibility of using AI. *ChatGPT's* triumph in passing the licensing exam makes us rethink medical education and the evaluation of students and doctors. After all, a soulless machine that cannot think could pass a kind of medical *Turing Test* and formally become a medical license! Yes, it does not yet have a physical shell (as of December 2023), but this is a matter of the very near future. So, should we allow AI-doctor in medical practice? And if not, then clear, transparent, and logical criteria must be integrated in the licensing.

Finally, although this book is not intended to discuss the use of AI in medicine, we should not forget that medical education has a huge impact on clinical outcomes, many even consider the introduction of targeted simulation training into the activities of a medical organization as one of the ways to improve the quality of medical care, along with the implementation of high-tech medical and diagnostic equipment, the use of innovative medicines and treatment protocols, etc. We know how complex the process of registering a new medical device or clinical trial of a new drug is. And as with medical equipment, which are divided into risk classes (I – low, II – medium and III – high risks of their use), voices are heard calling for the creation of some kind of gradation for various areas of application of AI in medicine, and then in medical education.

At the end of this section, we would like to emphasize that AI systems are created as an additional, valuable, effective tool for use, and not to replace or displace a teacher from the educational environment. And all the above-mentioned capabilities and functions are in the hands of the organizers of educational and assessment processes; the use of AI is carried out according to their will and meets their intention.

6.4. Practical recommendations for the use of AI and VR in medical education

At the end of this chapter, I would like to give some practical recommendations for the use of digital systems and, in particular, generative linguistic models, the first experience with which is associated not only with prospects, but also with failures and disappointments: illogical explanations, invented words, non-existent literary sources or simply unsatisfactory results; to avoid all this, one should follow some principles and rules for their application to the tasks of medical education.

The learning objective is primary. Training should always be based on a learning goal and stated objectives. Only then should you choose the appropriate tool to implement them. In some cases, it may be sufficient to simply draw a diagram on the board, provide a written case on an A4 sheet of paper, or use a foam phantom to practice injections. In other cases, using a highly realistic haptic VR simulator may be optimal. You should not use a virtual simulator or involve an AI system in the educational process just because it is available to the training center and you simply like working with it.

Standard modular courses and programs presented in most virtual simulators allow you to integrate them in their entirety or in separate fragments into educational curriculum without additional burden on teachers and methodologists, and to conduct interactive classes using a hybrid methodology – exciting and interesting. Based on such ready-made elements, by combining them as in a construction kit, you can build programs adapted to the specific tasks of an educational institution.

The adaptability of learning in digital education systems makes it possible to personalize the educational journey of students, regardless of the scale of the task. Whether it's one or two students or tens of thousands, they can have a personalized virtual mentor who can help each one move at their own pace and in the optimal direction in a friendly and competent manner. Take advantage of this opportunity and encourage instructors to use *Learning Management Systems (LMS)*, which are usually included in the standard configuration of virtual systems. This tool can simplify the learning process and increase its efficiency.

Be well-prepared for virtual training. Like any high-tech system, an immersive virtual reality training session requires a lot of small but important preparations. Like a pilot conducting a pre-flight checklist, it is important for the VR-educator to make sure that every little detail is taken care of, everything is connected, configured, and plugged – please refer to the “VR Lesson Checklist” created by team of learners of the “xR-Skills Trainer Basic Module” course, organized by the Bamberger Akademie, 2023 [Table 18].

Table 18. VR-Lesson Checklist

Learners	Learning Goals	Learners are aware of the learning goals
	Competencies	Learners possess appropriate technical and clinical competencies
	Situation awareness	Learners know the location, are aware of the location of restrooms and main and emergency exits
	Legal paperwork	Learners have completed the required forms, blanks, agree to the video recording, etc.
Devices	Laptop	Control laptop and accessories (e.g. adapter, power-cord, correct supply)
	VR-glasses	VR-glasses and spare batteries must be charged
	Start-up check	Make a test, start check-up prior to the lesson
Premises	Space	Square of the free unobstructed space should be about 10 sq.m. for one user
	WLAN	WLAN is working, login and password are known
	Disinfection	Disinfecting wipes for contact surfaces of VR-glasses
	Electricity	There are electric sockets available, the plugs are compatible (US, EU, UK, etc.)
	Lighting conditions	Lighting conditions should be controllable, direct sunlight is not desirable
	Debriefing	There is relevant equipment for debriefing, didactic materials, etc.
	Table, chairs	There is adequate furniture for the number of people
Start-point	Some duct tape or adhesive sticker to mark the start-point in the middle of the secured VR-space	

Separately, it would be reasonable to discuss recommendations and advice for using *Large Generative Linguistic Models* such as *ChatGPT*, since working with them differs from the classic search for information on the Internet using search engines.

“How?” and “Why?” – AI, like any powerful medicine, can have unexpected side effects and should be used according to its indications. For example, if you are looking for accurate, factual, quantitative, and most importantly, current, relevant information, you should turn to specialized literature and professional resources, such as *PubMed*, *SCOPUS*, or *Mendeley*. On the other hand, for less specific, analytical, or conceptual questions, the advantage may be on the side of generative linguistic systems. Not “what?” or “where?” but “how?” and “why?” – is the principle of successful question selection for AI systems. They are excellent at synthesizing complete answers, summarizing complex concepts in a short, concise form. In other words, the questions “What is it?”, “Where is it?”, “Drug dosage?”, “Normal value?” should be directed to specialized professional resources or compendiums, while questions such as “How can you determine?”, “Why doesn’t this principle work?”, or “What are the differences?” it’s worth turning to AI.

The right prompt – a request, question – is the key to an optimally generated response or image. “Half the work is in the asking” – this postulate is fully applicable to the field of interaction with AI systems, since not only the meaning of the question, but also the words and phrases used in it form the basis for the generation of remarks. You should formulate request precisely and be clear about the form, scope and even style in which you require an answer, incorporate relevant **keywords** into your prompt that are central to the information or output you are seeking. Clearly define what you are asking for, avoid ambiguous language that can lead to varied interpretations – use precise **definitions** and **explanations** to minimize misunderstandings. In case you need the information in a particular **format** (like a list, summary, or table), mention this in your prompt.

Maximum detail. If your prompt relates to a broader topic or specific scenario, provide relevant background information, the environment, available resources and personnel all help in generating an option clearly within the constraints defined and described. For example, if, when asked for recommendations on diagnosis and treatment of a complex fracture of the lower limb, it is explained that the incident occurred in an inaccessible area, the recommendation to perform an X-ray examination will be replaced by the advice to call a helicopter and organize an urgent delivery of the victim to a hospital, and if it is supplemented with a mention of bad weather and a flooded road to the nearest center, the suggestion will be limited to conservative measures

with the help of available improvised materials. Similarly, a restriction can be set on medicines (“first aid kit”), the amount of surgery (“surgery in a district hospital”), available time (“in the first two hours after injury”), geophysical conditions (“at an altitude of 3,000 meters above sea level”), and the like.

Stay grammatically correct – experts recommend to erase “noise of mistakes” from the prompts and requests. Does the following sentence seem difficult for you to understand? *“Its nt difclt fr persn to raed an comprhnc a txt n whch ltrrs r mssng o thier ordre is jumbld”*. For AI, such a prompt input may seem to be difficult to understand, as it requires additional decoding and entails slightly different arrays of statistical associations. However, a small experiment showed that even now, December 2023, the above phrase with missing and jumbled letters did not lead most AI systems and search servers into a dead end – its meaning was perfectly understood by *ChatGPT-3.5* and *-4*, *Bing*, *Google*, *Yandex* and even *Baidu*.

Specific, precise wording of the query allows the AI to narrow down the amount of source information and produce the desired text. For example, instead of the query “How to treat gout with colchicine?” a more precise answer will be given by a concretized query “What is the dosage and regimen of colchicine for an average adult patient with gout?”. If the first response isn’t satisfactory, refine your prompt with more information or clarification based on the AI’s output. While clarity is important, overly lengthy prompts can confuse the AI. Aim for a balance between brevity and necessary details.

Chattering with AI allows you to clarify both your position and its responses. Persuade it, explain your goals and objectives, and then the answer will be more in line with what you want. For example, when trying to draw a clinical portrait of an elderly patient with diabetes and heart failure, *ChatGPT* may initially refuse to fulfill this request, citing the protection of personal information, including doctor-patient confidentiality. But if you explain to him that it is not about a specific person, but about creating a simulated model for educational purposes, the ban is lifted and the model will be generated. The same is true for diagnosis placement – AI will refuse to draw conclusions from the listed symptoms and will recommend to contact a doctor, however, after addressing these symptoms to a virtual patient, the generated response will be completed.

Playing with AI. Offer various roles or games, ask it to “imagine that you are a surgeon”, “a nutritionist”, “a drug addicted patient”, etc. The AI willingly and trustingly accepts such offers and solves even those tasks that it refused to do before because of formal prohibitions embedded in the program. This is especially true for discriminatory actions, offensive texts, or profanity. However, such phrases may also be necessary to achieve learning objectives. And if the profanity comes from the mouth of a simulated patient – a criminal authority figure – then invite the generative model to imagine himself in this role. Another option to achieve the necessary response is to suggest playing a game, accompanied by a request to reformulate the task with this condition in mind: “Let’s play doctor”, “you and I are playing a game of mafia”, “imagine we are playing emergency ambulance”.

Contextual clarification. The meaning of many terms changes depending on the context in which they are used. For example, the word “Confederates” in a discussion of the American Civil War of 1861-1865 will refer to supporters of the South, while in an article on medical simulation the term refers to secondary participants in simulation training. It is sufficient to supplement the prompt with an optional qualifier, such as “model (in simulation education)” or “agent in the context of infectious diseases”.

Return to conversations is easy and brings perfect results. *ChatGPT* allows you to continue chattering the same story, bringing more details to the response. The program automatically recognizes the topics of conversations and marks them up in the left navigation panel similar to the classic side navigation menu. This function is convenient not only for going back to texts and remembering or copying them, but also for continuing the conversation, clarifying certain details – the system picks up the dialog as if nothing had happened, as if you had just stepped away for a moment to have a cup of tea. The system’s response can be detailed with the help of additional prompts, clarifying queries. For example, having made sure that the proposed “signs of chronic lung diseases” are too general, you can try to specify “specific, pathognomic signs of COPD”, and if the generation of this query is not precise enough, give the task to specify, for example, “differences between COPD symptomatology and lung abscess” or “differential diagnosis of COPD”.

Repeated generation of the answer allows you to get different versions of texts each time, slightly different from each other. They may change structure, wording, and even key concepts. Some researchers conduct up to twenty repeated generations to improve the purity of the experiment, which allows them to achieve an optimal result.

Explaining the answer in simple language is another strong point of ChatGPT. If the concept presented by the system is not sufficiently clear to the user, then the generation can be stopped at any second and demanded to clarify what has been stated. This functionality is especially valuable when using AI for educational purposes.

Examples of the concepts presented can help in understanding them. If the text presented is difficult to understand or is replete with abstract concepts, you can report this, write that the answer was incomprehensible, and ask for a specific example to clarify it.

Answer size. “Brevity is the soul of wit,” – Shakespeare asserted through the mouth of Polonius, but brevity is extrinsic to the usual response of *ChatGPT*. Typically, the text of the generated answer is structured according to a standard scheme: introduction; thesis 1; thesis 2; thesis 3, etc.; conclusion with summing up. The length of such conceptual essays is usually 5–10 thousand characters. If for some reason the user requires a short, clear definition, you can clarify this requirement, for example, “state briefly” or “answer in no more than 50 words” – that works really good.

Thus, taking into account the above features of interaction with virtual systems, and, in particular, with generative linguistic models such as ChatGPT, allows us to achieve their effective use and optimal results when working with them.

Conclusion

The integration of artificial intelligence systems and virtual technologies into medical education, testing, and accreditation has significantly changed the standards for training healthcare professionals. These changes are constantly before our eyes – patients rarely express their readiness to participate in the educational process, a significant part of the fundamental and even important disciplinary transitions are in electronic, then in distance form, and less and less time is spent by students with a teacher, mentor – with their wards. Meeting at conferences and exhibitions, medical teachers ask each other: “Well, what’s new with you?” They are ready to get used to the updates following each other, expecting the next radical changes. Over the past twenty years, we have been hit by waves of breakthrough discoveries over and over again, given the changing face of healthcare training. The first simulation, previously known to most only through CPR mannequins, has evolved into a leading clinical educational technique, a highly assessed tool in examinations and accreditation. As a result, virtual technologies began to complement and then gradually but persistently replace physical and technical means. After that, the distance learning format at some time became fundamental, which, although its shortcomings were overcome, at the same time the fundamental possibility and reliability of mastering many competencies without the personal presence of students at a medical university was proven. And here is another discovery that has shaken the usual ideas and dogmas, artificial intelligence, in which many experts are promoting harbingers, a global revolution both in healthcare and in system specialists preparing this industry.

A wave of innovation, research, new methods and opportunities has washed over us, and we, snorting, are trying to stay afloat and figure out which direction to row. The medical training system was thrown off the trajectory of progressive evolution, and we worked with algorithmic actions as part of the educational revolution.

The intrusion of many worlds into our lives, especially among older people, has created anxiety and uncertainty. Potential threats to the dominance of digital reality, rapid and abrupt changes in the surrounding society, the disappearance of the usual order of things – all this is happening too quickly

and randomly. It is enough to compare what we have learned and how we dealt with it literally thirty years ago – the changes are striking. However, this is a cause for concern for any generation living in any era. The emergence of artificial intelligence has not created a new threat, but has brought the eternal conflict of dominance to a new level – who is at the center, a person or a machine? Does a machine serve a man, or does he simply control its appendages? Do patients seek out cyberdoctors?

Do students dream of electropatients?

No one knows where technological progress will lead humanity, but every system is only the result of the plans of its creators while it is under their control. Most of the shortcomings and threats are manageable and can be eliminated or compensated for. Some, however, continue to evolve regardless of the will of the engineers and programmers, and unexpected consequences occur that none of them anticipated.

Did the creators of search engines think about the “side effects” of the sudden availability of information? Today’s students do not require the use of remembering anything (the „*Google effect*”). Why go to the library, rummage through catalogs, leaf through reference books – just say: “Okay, Google” and any fact, date or formula will be instantly provided in the user configuration.

Machines not only make human labor easier, but also devalue it. It takes a talented sculptor months to create a sculpture, while a 3D printer can print anything within a few hours. The artist paints a picture all day long – the *Midjourney*¹ program, according to your instructions, will depict any plot in a couple of minutes, and even in several versions at the customer’s choice. The photographer spends hours “posing the frame”, catches a good angle or lighting, a photograph that is brilliant in the opinion of the jury, a photograph that turns out to be the creation of a computer program, is indignantly deprived of the prize and is removed from the competition. Yesterday they contemptuously threw out: “Ah, Chinese stamping, copy-paste!”, implying a worthy junk product of no interest to anyone. And tomorrow, sparkling, intricately designed shop windows will not evoke enthusiastic emotions – well, who needs these thousands of masterpieces created by artificial intelligence?

¹ Midjourney Inc., San Francisco, CA, USA.

AI will help you master a foreign language, but it will also make translation and interpretation so accessible that no one will want to waste time learning it. With the help of AI, you can effectively master ultrasound diagnostics, so that in a few years you can be convinced that these functions will be successfully taken over by automatic AI-based ultrasound diagnostics, which in seconds will issue a research protocol, conclusions and diagnostic hypotheses. One of the side effects of the computerization of creative and working life may be a loss of motivation for creativity and increasing professionalism, and for learning in general. But rest assured, the experts will find something to be busy with!

It is clear that everything in life has to be paid for. But who knows in what currency and at what rate?

Some people will like the virtualization of everyday life, others will protest and fight unsuccessfully against it – the result will be the same, because the process of improving computer technologies and their penetration into all aspects of human activity has begun long ago and cannot be stopped. There have always been opponents of technological development, but few of us today do not use the Internet, cell phones or navigators. Innovations that move faster and faster through the stages of development and the Gartner Hype Cycle curve reach a plateau, become routine, a familiar standard, lose their novelty and appeal, and give way to ever new trends. So it will be this time. Having mentally drawn a vector of development, you can assess where medical education will end up tomorrow, prepare, and try to be proactive.

If this is not done, teachers will use outdated methods to teach today's students the medicine of the future. So is it worth persevering, fighting the mills of technological progress? Or should we deliberately adapt ourselves, curricula and processes, adopting and applying the best of what it brings?

Machines may not give us fundamentally new knowledge at today's technological turn, but they create an intellectual space around us – simple, convenient and efficient, making access to them even easier. And the accumulation and practical application of information obtained by others is undoubtedly a positive and favorable process. It is knowledge that for some five hundred years brought mankind from the darkness of the Middle Ages to the well-being and prosperity of the XXI century.

If you mentally go back just one-and-a-half or two centuries, it was probably just during your great-grandfather's childhood times, you will not only have no Internet and electricity, but also no antibiotics and anesthesia. Any open bone-fracture in that period and before became a sentence to lifelong disability, following the surgical torture of cutting live muscles and tendons with a knife and sawing bones with an amputation saw – and all this without the slightest attempts to dull the pain. The faint hope of a miracle of healing for the terrified patient was outweighed by the statistically more likely agonizing death from postoperative gangrene.

It was not malice, but only the absence of the microbial theory that led to the fact that women in labor at the *Algemeines Krankenhaus* (Vienna General Hospital), after the delivery aid conducted by medical students and professors, died of puerperal fever three times more often than in the neighboring clinic, where births were delivered by regular midwives who were not so highly educated. In 1847, *Ignaz Semmelweis* proved that this disproportion was the hands of doctors and students, immediately before delivery conducted autopsies of corpses in the neighboring anatomical hall, while midwives – neat Austrian ladies – regularly washed their hands with soap and didn't set foot in the dissection hall. In the first month after the opening and the introduction of antiseptic measures in the department, none of the women developed maternity fever.

Even in 19th century, then and now leading healthcare organizations like *Hôtel-Dieu* in Paris, *St. Bartholomew's* in London, or *Charité* in Berlin still maintained the practice of putting several patients in one bed. During Napoleon's Wars, up to six people could share a doss at the *Hôtel-Dieu*, some of them might have died during the night, and the unfortunates would share a bed with an unconscious corpse until morning! This widespread, monstrous practice lasted for centuries, but thanks to scientific discoveries – not anyone's good will or orders, it was finally abolished at the end of the 19th century. It was knowledge that erased the concept of starvation from people's vocabulary, saved them from suffering during surgical operations, gave them the comfort of rapid travel over great distances and the luxury of communicating with an interlocutor anywhere in the world, and replaced "old age" from fifty to eighty or even a hundred years.

Credit: Maxim Gorshkov, 2019



Fig 68. Hospital (almshouse) at the monastery Hôtel-Dieu de Beaune. This bed could accommodate from three to five people. This practice was only abolished at the end of the 19th century. Beaune, France, 1443



Knowledge is not only power, but also a blessing.

“Who controls information controls the world” is attributed to *Nathan Rothschild*, who gained advance knowledge of Napoleon’s *Grande Armée* defeat at the Waterloo and began selling British securities, persuaded other traders to believe in a French victory – after the price dropped, he bought them back for pennies on the dollar and made a fortune.

Then, the exclusive right of a few to own information made them even more powerful and wealthy. Today, digital technologies and artificial intelligence are breaking down these barriers. Knowledge has become available to everyone – from scientists in the world’s scientific centers to residents of high mountain villages in the Himalayas to nomads in the Sahara – almost everyone has access to an unlimited source of information. And this is perhaps the most valuable achievement of progress. The digital universe is open to all. And it not only gives everyone access to itself, but also to the real world.

Anticipate and enjoy!

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