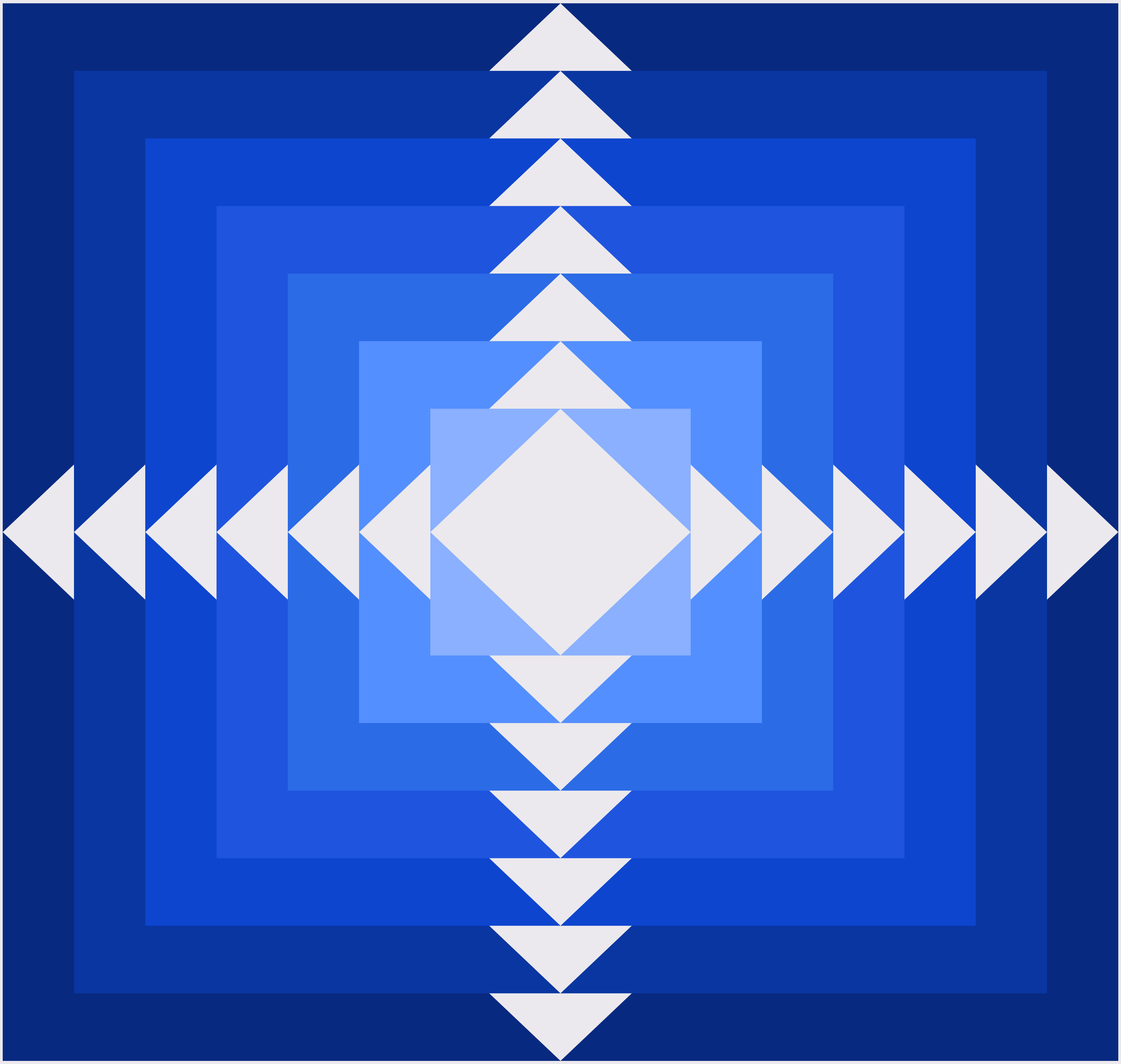
precisionOS presents

THE FUTURE OF SURGICAL TRAINING AND EDUCATION



Most medical students are trained for surgery using a variety of 'passive' and 'active' learning tools. Passive tools include textbooks, manuals, guides, and videos, while active training includes practicing procedures on cadavers or on real patients with a senior surgeon present. However, the future of training combines both.

Passive learning methods are important for building the knowledge-base required to perform advanced procedures, however their weakness lies in the surgeon's need to translate 2D images and text into real life dimensions. Passive tools lack alternate angles or any kind of tactile feedback, which are critical to the nuances of a procedure - and the patient's life.

Active learning methods address the gap by giving students a chance to take their learning into the real world. However, today's most common active learning methods have limitations. For example, cadavers are very costly and inaccessible in some countries. Furthermore, practicing on real patients does not give students the opportunity to safely experiment and learn the limits of their abilities.

A virtual environment, on the other hand, serves as an active learning environment where learning from failure is permitted – even encouraged. Passive learning elements can be integrated into the software to support and enhance the active components. A virtual learning environment also gives students the chance to experience a variety of outcomes, which could help their ability to think and react swiftly under pressure.

The purpose of this report is to introduce three key technologies that are being applied to surgical training and education. We also discuss several key implications of these technologies for medical residents, practicing surgeons, medical device manufacturers, education managers and patients.

INNOVATION IN HEALTHCARE

Innovation in Healthcare

Innovation in healthcare has been relatively slow compared to other industries such as software and electronics. According to the Harvard Business Review, this is largely due to the complexity of the market which involves the need for FDA approval, the risk of costly failed innovations, and working with insurers. Investors are weary of funding new technology, as the time it takes to pass the mark in healthcare presents a risk to being superseded by even newer technology. There's no lack of investment in healthcare innovation, but rather a lack of successful penetration given the barriers to entry.

The consumer cost of medical and hospital services has inflated by over 200% over the past two decades (see Figure 1.0) as the total cost of delivering those services has increased, highlighting the need for more disruptive innovation in order to make healthcare more affordable for the policy makers and the public.

If hospitals do not innovate and adopt the latest technologies, they may not be able to address the rising costs for patients by either becoming more efficient or becoming more effective in their treatments. Additionally, innovative medical device companies may struggle to find a market for their products and further stifle successful innovation.

Price Change (Jan. 1997 – Dec. 2017)

Selected US Consumer Goods, Services and Wages (source: BLS)

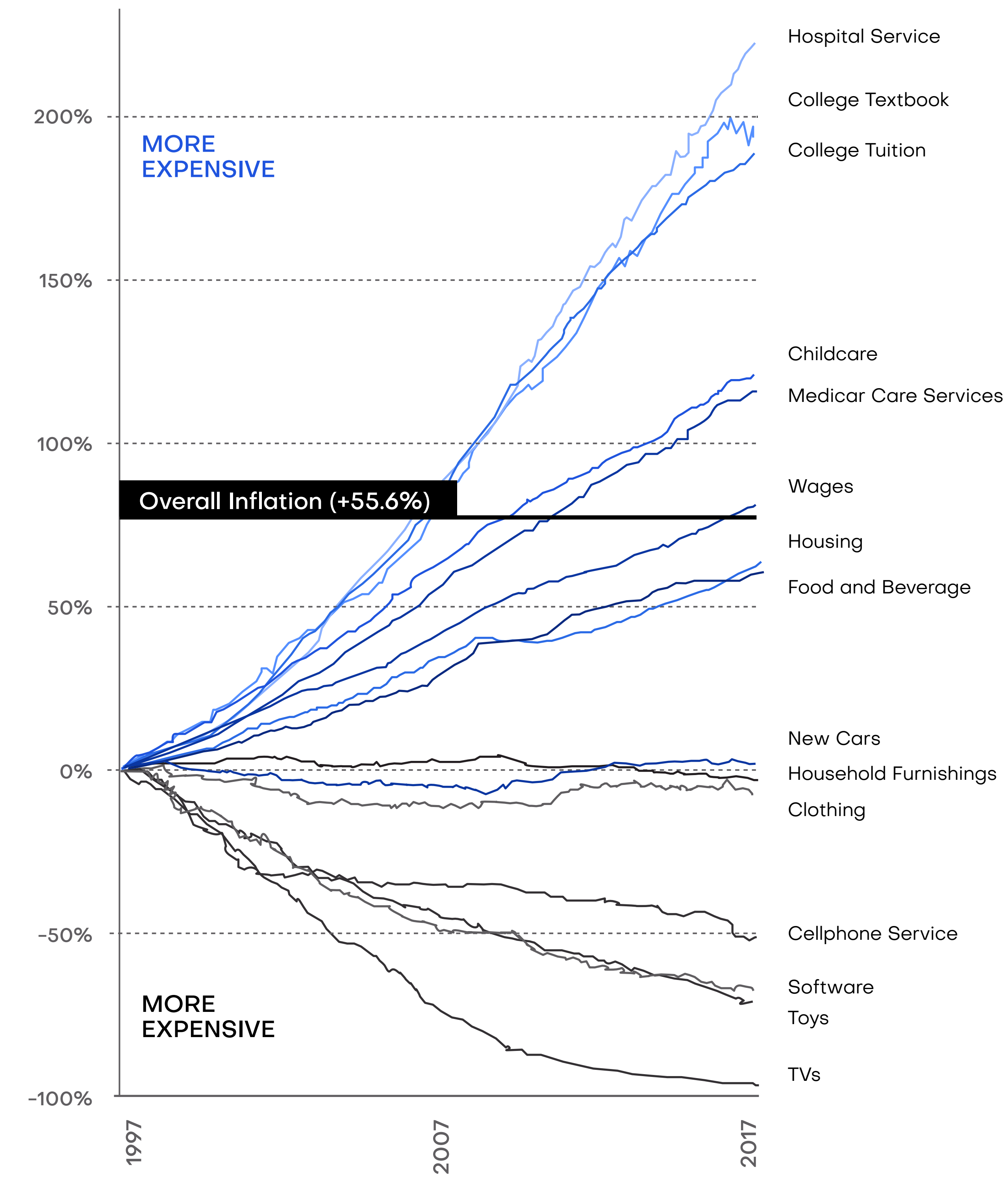


Figure 1. Price changes: Real-price inflation for consumer goods and services in the US, 1997-2017 (Corpe Diem, AEI)

Precision OS has found that innovation in healthcare and surgical technologies seems to be driven by medical device companies that have full innovation teams with healthy budgets for research and development (R&D). It seems that innovation in healthcare is pushed by medical device companies, instead of being pulled by hospital demand.

Despite the challenging environment, there have recently been some remarkable innovations in the field of surgery, such as HD scopes, smart surgical glasses, and surgical robots. For example, the development of small cameras, flexible materials, and advanced LED lighting has led to the introduction of HD endoscopes that grants surgeons visibility inside their patients to perform surgeries without making large incisions. Further innovation has iterated this design into more complex systems, such as MARVEL (Multi-Angle Rear-Viewing Endoscopic tool) developed by NASA and the Skull Base Institute. MARVEL provides a 3D, HD view and has a rotating tip that lets surgeons get a precise look at tumors. Its creators hope it will be used to perform minimally invasive surgeries (MIS) on the brain, resulting in fewer complications after surgery and faster recovery times.

Smart surgical glasses use a type of augmented reality (AR) called "mixed reality method" to aid with orthopedic and other types of surgeries. Smart glasses are essentially small computers with a head-mounted monitor and video camera: the camera provides the ability to observe from the surgeon's point of view, and the external monitor provides the surgeon with important images, charts, and diagrams for reference during a surgical procedure.

Surgical robots have been in use for at least 15 years. The da Vinci system represents the first wave of this technology, with the ability to perform movements with much greater precision than any surgeon could ever achieve. The second wave of surgical robots will likely apply artificial intelligence (AI) to collect and analyze data to improve surgical outcomes.

When cutting-edge science meets emerging technologies, innovation is at its most pivotal point. The remainder of this report will focus on the emerging technologies will play a crucial role in the future of surgical training and education: virtual reality, augmented reality and artificial intelligence.

EMERGING TECHNOLOGY #1: VIRTUAL REALITY

Emerging Technology #1: Virtual Reality

The purpose of virtual reality (VR) is to simulate the real world (or completely imaginary worlds) using high-powered computers and sensory technology like a headset and a handheld controller.

The technology has received a lot of publicity recently, with the release of the popular gaming console VR device 'Oculus Rift' and blockbuster movies like 'Ready Player One' – however, VR has been around for a long time. In fact, variations of VR have been used to train pilots in flight simulators for more than 80 years and is now being used by healthcare professionals to train surgeons and by scientists to visualize and solve complex problems like the structure of proteins.

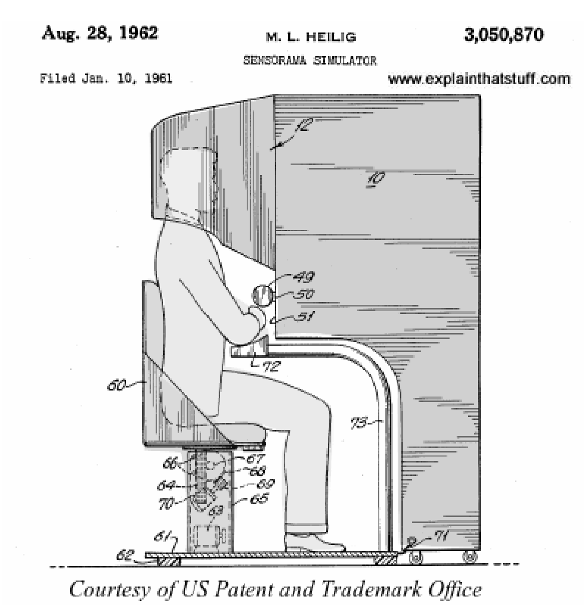


Figure 2. Sensorama Simulator: Cinematographer Morton Heilig started developing machines that produce artificial sensory experiences in 1956. He made the first 3D head-mounted display in 1957 and the Sensorama – a machine that immerses users in artificial vision, sound, smell, and vibration – in 1962. Image source: Google Patents database.

While innovators have been creating artificial or simulated realities since the 1950s (see for example the Sensorama and Ultimate Display), the term "virtual reality" was coined in 1989 by Jaron Lanier, founder of VPL Research and author of several popular books about technology. Thanks to rapid advancements in computing and related technology, VR is now common in both education and entertainment today.

There is more than one way to create a VR experience. Essentially, any 3D computer-generated world that users can interact with is considered VR. These experiences can be classified as immersive and non-immersive. Non-immersive VR experiences put users in front of a realistic virtual environment using something like a wide screen – for example 3D

modeling software used by engineers and architects. The fully immersive VR experience requires a detailed and convincing computer simulation, a powerful computer to process changes quickly enough to seem plausible, and immersive hardware such as a high fidelity headset, stereo sound, and sensory gloves or hand-held controllers. Flight simulators adopt all of this technology for a fully immersive VR experience

Demand for VR headsets in the consumer segment is starting to rise – when Samsung released its $99 'Gear VR' to the public, it sold out on Amazon.com and Bestbuy.com in just 48 hours. The market for headsets is predicted to grow modestly from 8.3 million shipments in 2017 to 8.9 million in 2018. However, sales of cordless headsets like the Oculus Go and Xiaomi Mi VR grew an impressive 429% in Q3 2018. It is these wireless devices that will likely continue to drive growth in the VR market, as they are less intrusive. Most devices are currently used for VR gaming – the PSVR, which represented approximately 50% of VR units sold in Q3 2017, has already sold about 10 million games for its system.

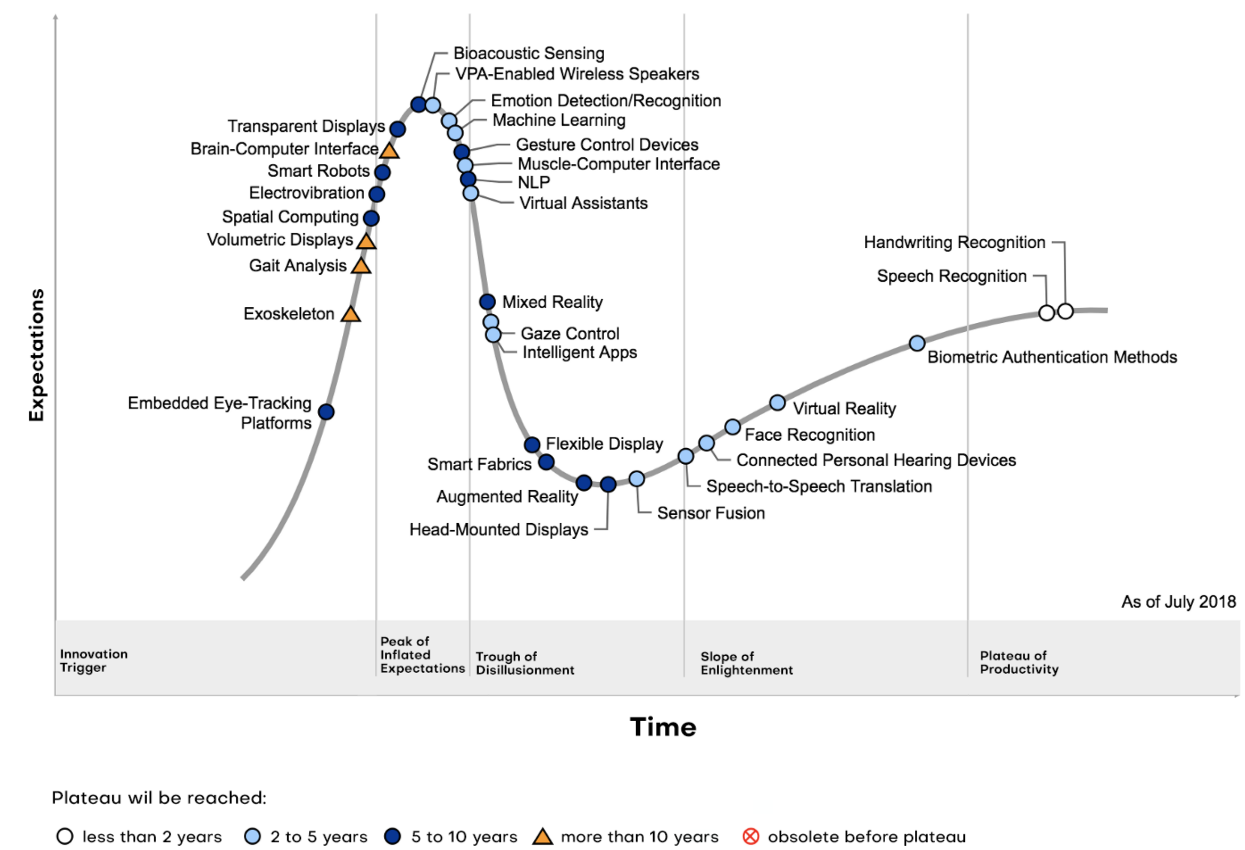


Figure 3. Expectations over time for immersive technology innovation (Gartner, 2018)

Commercial Applications

The consumer segment for VR is largely focused on entertainment, however commercial innovation has potentially profound implications for industries and society at large. Many industries are using or testing VR to find new efficiencies; particularly in the fields of automotive, architecture, education, retail, tourism, real estate, manufacturing, construction, scientific research, banking, and healthcare.

As technological barriers to entry are reduced, there will likely be a much wider adoption in commercial VR technology – particularly for training purposes.

VR is already being used to train for difficult or dangerous jobs like flying, or performing complex procedures in space. Architects and industrial designers use cost-effective VR computer models to let their clients interact with and explore their creations before they are built. Ford, for example, uses Microsoft HoloLens VR technology to design new cars and experiment with changing or altering features in real-time. This lets their engineers and designers test various designs without having to create multiple prototypes.

VR is also well established in surgical training; a 2008 survey of 735 surgical trainees from 28 countries revealed that 68% of respondents felt the VR training they were exposed to was "good" or "excellent" (only 2% found it "unsuitable"). As already mentioned, the combination of active and passive learning in VR technology has paved a path for efficient and effective training for surgeons without affecting patient risk.

VR training modules give surgeons the opportunity to practice a complete surgical workflow, with or without guides, and provide valuable feedback and performance metrics to improve performance. Surgeons can practice the same procedures repeatedly until their metrics meet a performance threshold indicating they have reached the necessary skill level to move forward. In VR training, learning and decision-making skills are enhanced through repetition: students follow a module, evaluate the outcome, and repeat to improve results.

The Importance of Volume in Surgical Training

Research has shown that volume is critical in training for surgery. In fact, the highest-volume surgeries tend to yield the best outcomes for patients, while low-volume surgeries are associated with longer hospital stays, longer operating room times, increased hospital complications, and higher costs. Michael Porter has studied the effect of surgery volume on outcomes and value in healthcare and proposed a "Virtuous Circle of Value" based on the volume of care.

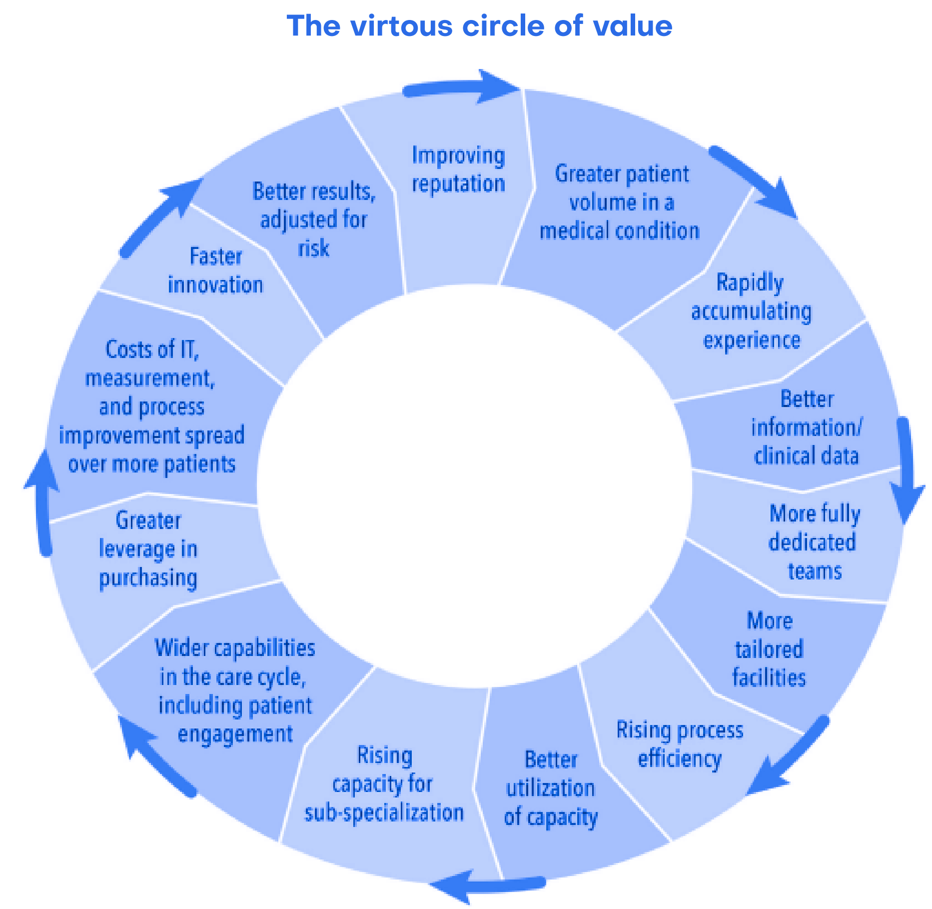


Figure 4. Virtuous Circle of Value proposed by Michael Porter. Source: Volume and Outcome: 100 Years of Perspective on Value From E.A. Codman to M.E. Porter, reprinted from Porter and Kaplan's "How to pay for healthcare".

In the Virtuous Circle of Value, a higher volume of surgery drives a positive feedback loop of improvements starting with more experience, better data, rising efficiency and so on. However, many types of surgeries are low-volume simply because there are not enough cases for surgeons to practice and gain more experience. Training modules in VR environments will give surgeons the ability to practice almost any kind of surgery, with no limitation on volume. This will drastically improve outcomes for patients undergoing low-volume surgeries.

VR also has surgical applications beyond training - it also presents an opportunity for useful pre-operative planning, where surgeons can upload patient-specific 3D models to a VR system and observe the are of operation before beginning surgery. For example, Precision OS technology allows surgeons to view and interact with periarticular fractures in a VR environment to plan their approach for surgery. They can even perform a complete virtual surgery and analyze the resulting data. This technology replaces the typical trial-and-error method used for fracture care, which can be dangerous for patients.

Finally, it is important to note that VR surgical training modules can be accessed anywhere there is a computer and an internet connection. This makes it an accessible and practical solution for training surgeons in lower income countries and rural areas, where trainees may not have access to the same training tools, mentors, or volume of cases as other regions.

EMERGING TECHNOLOGY #2: AUGMENTED REALITY

Emerging Technology #2: Augmented Reality

Augmented reality (AR) is a technical term for the superimposition of useful information or digital images onto the real world (as seen only by the user).

AR is an additive technology that augments reality, whereas VR acts as a total substitute for reality. A popular example is the AR smartphone game 'Pokemon Go', which asked users to find virtual characters hidden in real world locations.

The first functional AR system, Virtual Fixtures, was developed in 1992 by the U.S. Air Force's Armstrong Laboratory. Since then, AR technology has been predominantly popularized by gaming and entertainment applications. However, AR is starting to see more commercial applications such as education, construction/fabrication, and healthcare. For example, when Google Glass was unveiled in 2013, Google gave the devices to a small number of hospitals for testing. Surgeons used the glasses for projecting CT scans and MRIs onto their field of vision so they could refer to the images during surgery. Similarly, the Microsoft HoloLens AR glasses are widely used for their remote assist function, which lets technicians and remote experts work together to solve complex problems in the field while saving time and reducing travel costs.

EMERGING TECHNOLOGY #2: AUGMENTED REALITY

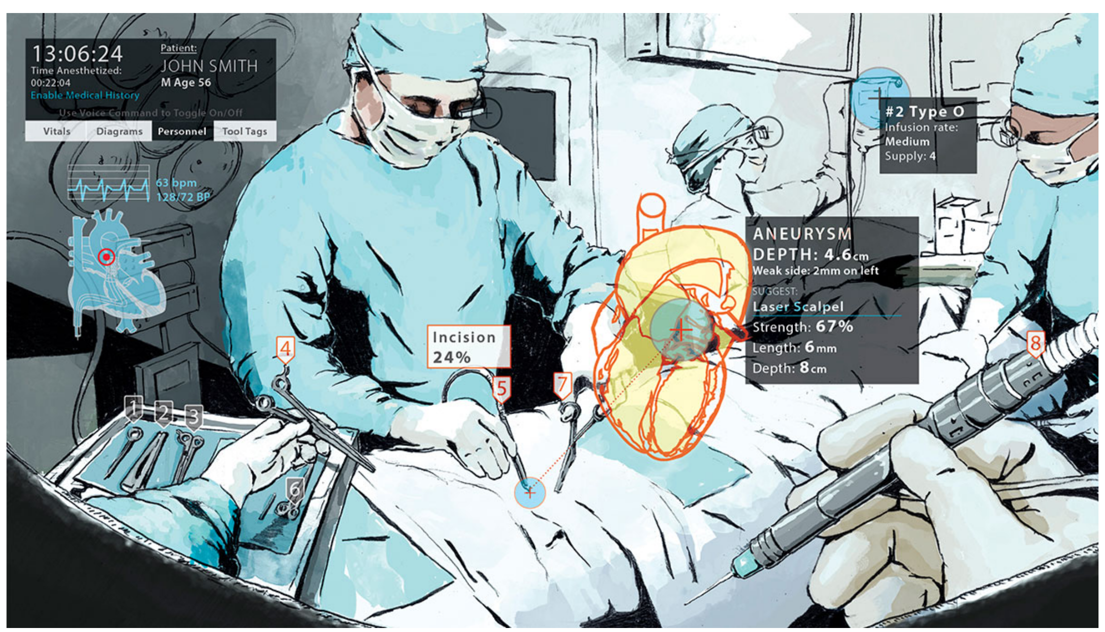
e. *HoloLens users can manipulate a computer interface and 3D images only they can see with simple hand gestures. (Source: Thyssenkroup)*

AR for Surgery

The major application of AR for surgery is addressing the shortcomings of medical imaging. Traditionally, MRIs and CT scans produce HD digital images that surgeons can analyze and manipulate on screen to plan surgery before beginning the procedure. After they have finished analyzing the images, surgeons have to mentally piece the information together and use their experience and intuition to bring that knowledge to the operating table. It is very difficult to properly visualize exactly where problem areas are on the body from memory alone. AR technology provides a bridge between medical imaging and the surgical execution, guiding surgeons during the operation by contextualizing images within their field of view or, including the ability to superimpose images on the patient's body.

This kind of AR application in surgery is being prototyped at the Maryland Blended Reality Center's "Augmentarium" and at similar facilities at Stanford, Duke, and John Hopkins. Using an AR headset like the HoloLens, surgeons can see digital images such as an echocardiogram overlaid in their field of view, with supporting vital signs and other data.

These overlaid MRI or CT scan images help surgeons accurately choose incision points, drill angles, and identify trauma in the patient's body. This added information and precision can help manage the unknowns of surgery and reduce the number of unexpected errors. AR technology has already been successfully applied to neurosurgery, otolaryngology, and maxillofacial surgery, and shows promise for orthopedic, cardiovascular, thoracic, and general surgery. But the technology could be even more beneficial for bedside procedures (outside the OR), which are usually carried out by a single doctor and nurse as opposed to a full team of experts. Most hospital rooms are not designed for emergency surgical procedures, and procedures might have to be carried out late at night when only a junior trainee is available to perform the procedure. An AR display that brings together multiple image and data displays could improve bedside procedure outcomes and reduce complications.



f. Source: The Augmentarium at the University of Maryland (illustration by Brian G. Payne)

EMERGING TECHNOLOGY #3: ARTIFICIAL INTELIGENCE

Emerging Technology #3: Artificial Intelligence

Artificial intelligence (AI) is defined as the simulation of human intelligence processes by computers.

These processes include learning (the acquisition and retention of information and rules for using the information), reasoning (using learned rules to reach definite or approximate conclusions), and self-correction (revisiting conclusions in light of new evidence). There are two categories of AI: weak and strong. Weak AI, sometimes called narrow AI, is designed and "trained" for a particular task. One example is virtual assistants (think Siri or Alexa). Strong AI, also called general AI, has generalized human cognitive abilities. Strong AI can find solutions to new problems without human intervention. Strong AI has not yet been achieved.

AI is powered by a type of algorithm called 'deep learning'. Deep learning algorithms take input data (provided by humans) to train, then use this training to make generalizations based on the training data. Deep learning algorithms are designed to reason by induction: applying insights from specific information to more general cases. Therefore, the quality of the input data is critical to the algorithm's success.

Deep learning is a subset of "machine learning", which is the science of getting a computer to take actions without new programming. There are three types of machine learning algorithms:

A. **Supervised learning:**
Algorithms are used to detect patterns in structured data sets and use these patterns to draw conclusions from new data.

B. **Unsupervised learning:**
Algorithms are used to find patterns in data that is not structured with labels, but sorted according to similarities or differences.

C. **Reinforcement learning:**
Similar to unsupervised learning, but the AI system is given feedback after an action (or several actions) are performed.

Data for use in machine learning can be captured in many ways. Some of the more advanced techniques include machine vision, which allows computers to capture visual information from the environment (an important function for self-driving vehicles), and natural language processing, used to

recognize, interpret, and translate human speech.

AI is already being used successfully in business, where algorithms are used to analyze data from CRM platforms to learn how to increase value for customers. In education, AI is being tested for automated grading and adapting to an individual student needs. AI tutors, for example, could provide students with the right resources at the right time to enhance learning. In finance, personal finance tools like Mint and Turbotax automate the sorting of financial data for tax purposes, and machine learning algorithms are used on Wall Street for advanced trading. Finally, AI is having a major impact in healthcare where machine learning is already being used to improve diagnoses. For example, IBM Watson can respond to questions from patients and look at patient data to come up with a hypothesis, which can then be verified by a specialist. However, it is perhaps in the field of surgery where AI could have the biggest impact.

AI for Surgery

A comprehensive review of AI used in surgery found that machine learning, artificial neural networks, natural language processing, and computer vision are all being applied to surgical practice and together have the potential to revolutionize the way surgery is taught and performed. Specifically, AI tools can already be used to diagnose and treat cancer; detect, diagnose, and treat strokes; and for various purposes in neurology and cardiology.

AI could therefore increase the average skill level of all surgeons by helping them perform better. For example, Digital Surgery is using big data analytics to uncover important insights from the immense data set created by robot-assisted surgical devices. Surgeons can use this data to sharpen their skills. Another example is the Caresyntax qvident, a surgical risk and quality management tool that gives surgeons access to new data processed by AI. In 2017, Maastricht University Medical Center used an AI-assisted surgery robot to suture blood vessels as small as 0.03 mm across. This kind of surgery requires very high precision, so it is an ideal use case for AI where margin for error is minute. The robotic system, created by Microsure, is controlled by a surgeon whose hand movements are translated using AI into more precise movements carried out by a robotic hand.

In the future, AI could be used to interpret the data provided by advanced imaging tools and robotic diagnostic tools to improve diagnoses and give surgeons a better understanding of what is happening inside a patient's body before operating.

A Look into the Future

A major study by Goldman Sachs on the potential impact of VR and AR found that there are about 8 million physicians and EMTs throughout the world who could use VR/AR technology in their practice - a significant user-base worth about $16B. Combined, the three technologies evaluated in this report (VR, AR, and AI) introduce powerful tools to improve surgical education and address the key limitations of minimally invasive surgeries (MIS), such as limited field of view, absence of haptic feedback, loss of depth perception, long learning curves, longer operating times, and higher costs.

CONCLUSION

However, despite the remarkable accomplishments so far, these technologies have not yet reached their full potential. The healthcare industry as a whole still needs to solve crucial funding challenges, get more decision-makers to buy in to new technologies, remove barriers to innovation, and upgrade entire systems to leverage the benefits of VR, AR, and AI. To start, a paradigm shift is needed in the educational curriculum to move away from traditional, limited training methods toward technology-focused learning tools that enhance the learning experience.

Researchers, academics, entrepreneurs, technologists, hospital managers, and medical device companies need to work together to apply new technologies in hospitals, especially in the OR. If the overall goal is to improve surgical outcomes, then failing to explore the full potential of VR, AR, and AI technology could be leaving lives on the table, which taken to its full extent could mean a clear breach of duty for healthcare professionals.