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DeltaHedron Innovation Insight is a series of reports and newsletters exploring aspects of the technological future and technological innovation, with a specific focus on the strategic business opportunities, threats, risks and impact presented by emerging technologies and the dynamics of technological change

'Anticipating what can happen in the future is one thing, knowing what to do about it is quite another'

Developments in emerging digital health technologies

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Executive summary

This report examines the **impact** of ***recent trends*** in **technological change**, **innovation** and **emerging technologies** on the **digital healthcare industry**, from a vantage point of **exploring strategic business opportunities, threats and risks**.

- **Telehealth** and **mHealth** enable patients to **access healthcare remotely**. The resulting **'empowerment of the patient'** is **disrupting** the industry and **radically transforming** the **delivery**, **scope**, **quality** and **cost** of, as well as **access** to, **healthcare** in **developed** and **developing countries**. Development in digital health technologies is **dynamic** with **rapid changes** in their **performance**, **costs**, **applications** and **user bases**. The **industry structure** is **changing** as are cost curves, business models and the power and influence patterns amongst role players. Significant new value is being created and new outcomes enabled.
- Emerging digital health technologies should be **high on the radar** of companies as they **assess** strategic business **opportunities**, threats and risks. **Traditional healthcare providers** (including professional practitioners, hospitals and clinics), health insurers, funders, healthcare systems and producers of health technology products as well as **new entrants** and **new types of entrants** in the healthcare sector need to be **aware** of the **disruptive shifts** in the industry. **Opportunities** also **abound** for role players in other sectors that may, at first blush, not seem to be related or affected. Conversely, emerging digital technologies may also present **risks** and **threats** to role players in seemingly unrelated sectors. A strategic opportunity/threat/risk review is helpful to assess a specific company's or industry sector's technological innovation-related opportunities and vulnerabilities vis-à-vis emerging digital health technologies.
- The ability to **communicate wirelessly** via 3G and 4G (and soon 5G) as well as through routed wifi networks, position **mobile devices** (such as smart phones or smart watches) as **ideal mHealth platforms**. Many **sensors** and features that are useful in mHealth applications are already **imbedded** in the **mobile device** itself, including clocks, flash lights, microphones, cameras, geo-position sensors (GPS) and accelerometers. **Additional sensors** can be integrated into a **peripheral device** (such as a scale or blood pressure monitor) connected to and communicating with the mobile device, typically through **bluetooth**. Recent reports

mention mobile and portable sensors that can measure weight and body temperature, blood pressure and sugar levels, oxygen level and blood oxygenation, heart rate, rhythms and conditions, speech patterns, spectrometry, spirometry, dental parameters, cells structures of food, taste, blood alcohol content, sperm count, activity level and sleep quality; as well as ambient parameters such as pollution and noise.

- **mHealth**, either locally through an app in the mobile device or through remote access, provides the capability to **interpret** the inputs from these sensors and then to **identify** and **treat** a **range of clinical** conditions. This information can be made available **directly to the patient**, often in **real-time**. Diabetes, hypertension, heart conditions, cancer, skin diseases, seizures and epilepsy, pain management, male fertility, mental health and home care are amongst many conditions recent reported on. Related reports also cover a range of wellness and fitness issues (including fatigue and substance abuse, which have important applications in industrial settings).
- The **disruptive impacts** of emerging technologies often come from **completely different industries** than those they disrupt. The impact of a specific **emerging technology** can be enabled, enhanced and amplified (or alternatively hindered) by its interaction with other technologies, specifically also other emerging technologies. Recent reports refer to applications of artificial intelligence and machine learning, virtual reality, imaging, internet of things, robotics, chatbots, 3-D printing and drones interacting with digital health technologies.
- **Health information** is the **lifeblood** of **digital health technologies**, and significant effort is being directed towards capturing, communicating, storing, sharing, protecting, processing, interpreting and displaying the information. It is one the most **significant drivers** for strategic business **opportunities** and threats presented by emerging digital health technologies. The focus is on **actionable information** and **decision support to patients**, healthcare providers and other role players – **everywhere, any time and in real-time**. Recent reports focus on the use of **remote patient monitoring (RPM)**, big data and health analytics, data security (including **blockchain**), **patient generated health data (PGHD)** and electronic health records (EHR). **Interoperability** of datasets remains **problematic**.
- Many **challenges** and **uncertainties** remain to be resolved for emerging digital health technologies, as would be expected of any emerging technology. Apart from the technical and clinical challenges, issues pertaining to **ethics, liability, data security, policies and regulation** need to be addressed. The vexing problem of **business models** and the '**difficulties of making money**' from telehealth and mHealth are important, as are the related issues of **funding models and reimbursement of claims** for digital health provision. These difficulties are complicated by the fact that **traditional business models don't work** very well in a **platform-enabled, digital health world** driven by new types of information and empowered patients.
- As digital health, telehealth and mHealth become more ubiquitous, the **nature of health-related jobs** will necessarily also **change**. Inevitably **new types of roles** will emerge and current roles may **disappear**. One can, for example, imagine new and different roles for healthcare providers such as doctors, nurses and therapists. It is also necessary to consider how **curricula** for **training healthcare professionals** in the new digital health world should be developed and **proactively adopted** by universities and other education and training institutions. **Accreditation bodies** that regulate health **qualifications** and **register professionals** should also address this matter. It is important to ensure that the **next generation** of healthcare providers as well as the current practioners are prepared, able and willing to leverage the benefits of the new technologies. This will require not only an **understanding** of the **new technologies** and the **skills** to use them, but also a deeper understanding of the notion of the '**empowered patient**' and how that will affect the **relationships** between **patients and healthcare providers**. **Continuous professional training** in digital health technologies for **practising professionals** should be a high priority.

Contents

This report is not intended to be a historic review or an exhaustive discussion on the healthcare industry or technological developments in that industry. Instead it discusses a *selected number* of *relevant recent* developments which may be helpful in the assessment of strategic business opportunities, threats and risks posed by emerging digital technologies, innovation and technological change in the healthcare and related industries.

An analysis of technology-related strategic opportunities, threats and risks, needs to account for a range of factors, including evolving markets, industry structures, regulatory environments and economic conditions. This report does not emphasize all of these, but instead focuses on technological change as a driver of innovation.

1. Introduction

Digital health technologies are **radically transforming** the **delivery**, **scope**, **quality** and **cost** of as well as **access** to **healthcare** in **developed** and **developing countries**. They are **disrupting** the **healthcare industry** and present significant **opportunities** but also **threats** and **risks** to **traditional role players** in the healthcare sector (including practioners, hospitals and clinics, insurers and funders, managers of healthcare systems and producers of healthcare technology products) as well as **new entrants** in the healthcare and other industry sectors.

This edition of *DeltaHedron Innovation Insight* considers developments in a number of ***recent*** **emerging technologies** and trends in digital health, specifically regarding telehealth and mHealth. Recent developments in sensors and the ability to measure vital clinical signs, the clinical conditions and health applications which can be monitored and treated by **telehealth** and **mHealth** as well as a number of interesting mHealth devices are addressed.

The **disruptive impacts** of **emerging technologies** often come from **completely different industries** than those they disrupt. The impact of a specific emerging technology can be enabled, enhanced and amplified (or alternatively hindered) by its **interaction with other technologies**, particularly other emerging technologies. A discussion on the interaction of digital health technologies with a number of other emerging technologies explores these dynamics. The report is concluded with a summary and discussion.

The broader topics of digital health, telehealth and mHealth are covered comprehensively elsewhere [1]. Hence this edition of *DeltaHedron Innovation Insight* reports on a ***selected number*** **of** ***relevant recent*** **developments** that can impact on a company's assessment of strategic business opportunities, threats and risks.

In addition to the issues addressed in this edition, a **comprehensive analysis** of the **opportunities and strategic business risks** posed by digital health technologies should also **include** an analysis of other **relevant and related issues**, including benefits, economics, markets, business and funding models, regulatory, ethical and legal regimes, related industries and new role players, health systems administration and medical workflows in addition to clinical matters. A number of these will be addressed in forthcoming issues of *DeltaHedron Innovation Insight.*

An **appendix** provides a **brief discussion** on the **general characteristics** of **emerging technologies** and provides a context for the focus on digital health technologies, particularly from the vantage point of technological innovation and the **dynamics of technological change**.

2. Digital health, telehealth and mHealth

The notion of ***digital health technologies*** spans a **broad spectrum** and encompasses health-related processes, products, technologies and services that are inherently digital in nature. A number of subcategories can be identified, which overlap and are often used interchangeably.

Telehealth - **connected health** - is a particularly important component of digital health and is the focus of much of this report. It refers to products, processes, technologies and services that allow ***remote management*** of health and ***digital connection*** between patients, health service providers (including doctors and hospitals) as well as funders, insurers and regulatory bodies.

The nature of the ***digital connection*** can include communication, information exchange, monitoring (including remote patient monitoring (RPM)), biometric tracking, diagnosis, consultations, reminders and alerts, prescriptions, treatment and care (which can include procedures such as surgery) as well as education and training. On the basis of mode of delivery, telehealth services can be web-based, cloud-based or delivered on premise.

Digital health, in particular telehealth and mHealth, is **enabling new types** of **role players**, such as pharmaceutical and biotech companies, supermarkets, homecare providers as well as manufacturers of devices and products, to **enter** the **main healthcare markets** previously served by 'traditional' providers. It is important to keep in

[1] See for example Robert Wachter, *The Digital Doctor: Hope, hype and harm at the dawn of medicine's computer age,* McGraw-Hill, 2015; Bertalan Mesko, *The guide to the future of medicine: Technology and the human touch*, Webicina, 2014; Economist Intelligence Unit, *Power to the patient*, 2015; Economist Intelligence Unit, *Digital health: Total convergence*, 2017.

mind though that telehealth is a subset of digital health, albeit a very important one; and that there are many digital health applications that are not primarily telehealth in nature, but still digitally-enabled.

Mobile health (**mHealth**) refers to the mobile application of digital health technology which is enabled or performed through **mobile devices** such as smartphones, smart watches and tablets.

As the number of mobile phones globally approaches circa 5 billion, the **impact** of **mobile technology** is **disrupting many spheres of life**, far beyond the ability of people to just 'speak on the phone'. Although mobile phones themselves have enormous computing power, they can also **connect locally to other dedicated portable and mobile devices** (through wifi, bluetooth or cable, for example). These **peripheral devices** are part of the mobile ecosystem and can be used as **sensors** of one kind or another, often in the form of '**wearable devices**', multiplying the usefulness and effectiveness of the mobile device itself. Through connection to the internet, local peripheral devices and the ability to run user-selected apps, mobile technology has enabled an **'always-on' culture** with regard to communication and access to global information and services - driven by its provision of decision support to individuals **'everywhere, any time and in real-time'**.

Consumers (**patients**) are coming to **expect** the **same convenience**, **access** and **quality** of service with regard to their **healthcare** as they have in **other mobile empowered sectors**. eBanking, mobile shopping and mobile interaction with a range of other service providers have become ubiquitous and often the **preferred mode of interaction**. **Wherever** there is a **mobile signal**, there can also be **health provision**. This is true even where there is no electricity provision – a recent report describes a clinical trial where patients in a remote rural location were provided with mobile phones which were charged with solar panels.

'**Power to the patient**' and an emphasis on more **personalised healthcare** has indeed become a **characteristic of digital health**. The **relationship** between the patient and the healthcare providers is **changing**, with **patients** taking a much more **proactive role**. Not only is the patient's healthcare experience greatly enhanced, but the state of healthcare is being advanced with tremendous benefits delivered to healthcare ecosystems and infrastructures.

Health data and information is the **lifeblood** of **digital health technology**, including the ways in which it is captured, communicated, stored, shared, protected, processed, interpreted and displayed. Patient data, information about diseases and medical conditions, medicine, healthcare providers and costs as well as contextual information such as pollution or air quality information, for example, are all available. The **decision support** that **mobile technology** provides makes the **information accessible and actionable**, enhancing the ability of care providers and patients to not only '**know what and why**' but also to know '**what to do next**' – with support and guidance to actually do it.

The 'everywhere, anytime and in real-time' characteristic of telehealth and mHealth is an important element of information exchange between patient and healthcare provider.

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The **patient** can **access information** about their specific health issues, but also be **alerted** by the mHealth device in **real-time** if **danger signs** are **detected** and **what to do about it**, as well as being **reminded to take medication**. A preinstalled app on iPhones, for example, allows the user to press the 'Emergency button' which then dials emergency care and sends pre-recorded medical information to the provider [2].

mHealth is **enabling new sources** of health **information** to become available, specifically '**patient generated health data**' (PGHD). **PGHD** is providing very rich and useful new datasets never

[2] http://mobilesyrup.com/2017/04/01/how-to-set-up-medical-id-iphone-ios/

available before, not only about individuals but in aggregated format also about various larger cohorts, including on a national level. An individual patient can now record a range of clinical parameters and vital signs at home on a mobile device at very frequent intervals and transmit them remotely to a physician. This **information** can also be **very valuable** to **managers** of **national health systems**, policy makers, **funders** and **insurers** as well as pharmaceutical companies.

By **monitoring** their own health conditions, **patients** are positioned to take **more control** of **managing** their **own health**. The use of **electronic health records** (EHR), where each patient's complete health record is stored in one (cyber) location and accessible to all who need to use it when they need it, enhances this process. Due to the sensitive nature of the information, **data security** is an ever **increasingly important** focus area.

3. What mHealth can measure and what it can tell us about our health

The power of **remote patient monitoring (RPM)** as a driver for PGHD is vested in the **patient's ability** to **measure and monitor** a range of clinical and wellness parameters ('vital signs') **at home** using **mobile and portable devices**, and then **transmit** the information to a care provider for further **analysis** and **feedback** to the patient. In many cases the devices can also do local analysis and provide immediate feedback to the patient.

3.1 Sensors – what we can measure

In order for the mobile or portable device to be able to measure a specific health parameter or vital sign, a **sensor** which converts the physical 'state' to data, is required. Many sensors are **imbedded** in the **mobile device** (such as a smart phone or smart watch) itself, but often the sensor is located in a **peripheral device** (such as a scale or blood pressure monitor) connected to and communicating with the mobile device, typically through **bluetooth**. In addition to their ability to communicate wirelessly via 3G and 4G (and soon 5G) as well as through routed wifi networks, mobile phones have enormous computing power and also are equipped with clocks, flash lights and embedded sensors such as microphones, cameras, geo-position sensors (GPS) and accelerometers. These sensors and features give them the **ability to measure and record** sound, noise levels and acoustic signals, images, physical location and the user's body motion, all which can be time, date and location stamped. In an mHealth setting, the camera can, for example, be used to take photographs of medical conditions, of retinas which can be used for diagnosing diabetic retinopathy and for spectroscopic diagnosis which can be sent remotely to physicians and also to enable video conversations. A **myriad of apps** allows each mobile phone to be customised by its user to perform specialised tasks, including health applications. It has been reported that even in 2014, more than 40,000 health related apps were available for mobile devices.

The **inputs** from the **sensors** can also be combined with **supplementary information** that can be obtained by the mobile device via the **internet**. For example, if the geolocation is known, the weather and height above sea level at that point can be downloaded. Mobile phones also have the ability to record air quality, pollution levels and radiation with the aid of connected peripheral devices.

Inputs from the mobile or portable sensors are processed and interpreted in terms of vital signs and clinical conditions, and the **information displayed** in an **understandable format** that **makes clinical sense**. Once the information is available, the patient can often view it in real-time and take appropriate action if necessary, with guidance and decision support via the mobile device. In addition to being stored on the device, the data is typically also transmitted, either immediately or later, to a database in the cloud where it becomes available to care providers. Feedback to the patient, either immediately from the device or after processing by a care provider, can alert the patient if the measurements exceed dangerous limits and provide recommendations on actions to take. The ability for the **patient** to **receive expert guidance** (EART) on '**what to do next**' is an important element of the patient empowerment experience that mHealth enables.

> "The ability for the patient to receive expert guidance on 'what to do next' is an important element of the patient empowerment experience..."

Because of the **personal nature** of mobile devices, **measurements** can be taken **very frequently** by the patient if required. Research indicates that patients who use remote patient monitoring (RPM) require fewer hospitalisations (with subsequent savings). One of the contributing factors is the ability of telehealth patients to make frequent measurements. **Daily monitoring** of **vital signs** presents a more complete picture of patient health. For example, if a patient with chronical heart failure (CHF) gains a kilogram or so in a single day, it can be an indicator of imminent problems which need to be addressed urgently. This can be missed if monitoring is infrequent, for example if the patient is only visited once a week.

A number of *recent* reports refer to the ability of mobile and connected portable devices to measure a range of clinical and wellness-related parameters, including:

- Weight
- Body temperature
  A peel-and-stick connected thermometer which enables continuously monitoring and recording of body temperature via a mobile app was reported.
- Blood pressure
- Blood sugar levels
- Oxygen level and blood oxygenation
- Heart rate, rhythms and conditions
- Speech patterns
- Spectrometer outputs (measuring the wavelengths of different colours), inter alia used for the detection of cancer.
- Spirometer, an apparatus for measuring the volume of air inspired and expired by the lungs, with the ability to identify obstructive and restrictive types of abnormal ventilation patterns.
- Dental sensors in a smart toothbrush with embedded artificial intelligence, detecting frequency of brushing, duration and areas covered.
- A sensor with the capability to scan the cells of food, enabling counting of proteins, lipids and carbohydrates. This is useful for the monitoring of nutrition and fitness.
- Taste. Researchers were able to remotely simulate the taste of lemonade by digitally transmitting the basic look and taste to a glass of plain water. Essentially the receiver only drinks plain water but with the combined light visuals and electrified sensation to the tongue, it feels and tastes like drinking a glass of lemonade [3].
- Blood alcohol content (BAC) sensors, which also track other substances in the blood like lactic acid and caffeine.
  A device specifically aimed at patients recovering from alcohol addiction has been reported. It uses facial recognition technology to confirm the identify of the user, and sends real-time data to the care platform if the patient tests positive for alcohol use, misses scheduled tests or performs a test with negative results [4].
- Sperm count [5].
- Activity level of a patient (such as motion, acceleration, steps taken, calories burnt) and sleep quality.
- Unique "breath prints" of diseases. The detection of the chemical signatures of 17 diseases using an artificial intelligence (AI) nanoarray and mass spectrometry, has been reported. Diseases including Parkinson's disease and eight kinds of cancer can be detected [6].

In addition to clinical and wellness parameters, ambient parameters can also be very useful in providing a bigger health and wellness picture. These include air quality and pollution, dust, exhaust fumes, chemicals, carbon dioxide and other gases. In addition to providing contextual information, by recording atmospheric readings in a patient's room, behaviour patterns (such as eating, sleeping or moving) can be better understood.

3.2 Wearables and hearables

In some cases, the health measurement of a specific parameter may only be required once a day. Here a **portable device** connected to the mHealth device may suffice, rather than something which the patient needs to have in proximity 24/7. Some information needs to be recorded continuously however, literally everywhere a patient goes. Devices that are worn on the patient’s person

[3] http://interestingengineering.com/can-now-send-receive-taste-lemonade-online/

[4] http://www.mobihealthnews.com/content/breathalyzer-maker-soberlink-map-health-management-launch-remote-patient-monitoring-pilot

[5] http://spectrum.ieee.org/the-human-os/biomedical/devices/smartphone-test-male-fertility/?utm_source=humanosalert&utm_medium=email&utm_campaign=040517

[6] http://newatlas.com/different-diseases-different-breathprints/47088/

(‘**wearables**’) are ideal carriers for these sensors. Wearables are also useful in situations where it is **difficult** to **physically provide devices**, such as in industrial settings or for the military. Fitness related wristband sensors and headbands are well known, and record movement and activity which can be processed to yield information on distance and number of steps walked and calories burnt, for example. Similar information can be generated by treadmills, exercise bicycles and other non-wearable digital enabled gym equipment. Data from these devices can be communicated to a mobile phone from where it is processed and communicated or linked directly to the cloud.

A number of recent reports mention useful information that can be gleaned from **in-ear measurements** and the development of ‘**hearable**’ devices. Hearables have the added advantages that audio feedback, other information and music can be sent to the wearer at the same time.

Interesting wearables and hearables that have been reported on recently include:

- Lightweight headgear with embedded electrodes for measuring EEG, eliminating the need for sensors attached to the patient’s scalp.
- A waterproof titanium-encased ring, which monitors sleep and fitness (steps, calories, distance and heart rate).
- Sensors embedded in earbuds to monitor heart rate, linked to a smartwatch.
- Earbuds equipped with an in-ear thermometer to measure core body temperature during activity, linked to a smartphone, smart watch or internet hub.
- Fully kitted out solution with physical condition monitoring system containing sensors for blood oxygen levels, heart activity, stress levels and body temperature.
- Wearable patch only a couple of square millimetres in size, that will noninvasively detect glucose levels from sweat and then also deliver the diabetes medication through microneedles in response to the sensor's readings.
- Real-time bio-sensing device reading antioxidant level changes on the skin from the palm of the hand.
- Heart rate sensors embedded into flexible, machine washable textiles. The intended use was in a hospital as a more comfortable heart rate sensor for paraplegic patients.
- Smart shoes generate data regarding the wearer’s balance and coordination via imbedded sensors that measure inter alia the forces on various part of a foot. This allows for estimation of balance, centre of gravity and weight shift, all in real-time. GPS sensors can also be integrated. The data can be transmitted to a smartphone or tablet, from where it can be inserted into the patient’s mHealth system. Smart shoes find application in sports, with golf being one of the main intended target markets, whereas ‘smart slippers’ can be used by stroke patients, for example.

3.3 Medicine compliance monitoring

In addition to measuring vital signs and clinical parameters, **mHealth** can also enhance patients’ **compliance** with the taking of **prescribed medicine**. It has been reported that circa 50% of US patients are noncompliant in this regard and that 30% of prescriptions given to patients are not filled, resulting in huge wasted costs and lives lost.

Encouraging proper use of medicines has traditionally relied on letters, websites, call centres and CRM software. Several mHealth technologies are enabling patients and care providers to monitor and improve adherence to prescribed drug regimes.

One development incorporates a very **small sensor embedded** in a **pill**, swallowed with other medication (‘digitisation of pills’). As the ‘pill’ dissolves in the stomach, the sensor is activated and sends an alert via a wearable patch connected to a smartphone app. Patients and clinicians can then determine the **extent** to which the patients are **adhering** to their **prescription**. This technology has also been found to be particularly useful in treating adolescent transplant patients.

Another interesting product is a medicine bottle that changes colour – it turns blue when it is time for the patient to take their medicine and red if the medicine was not taken, thereby alerting the patient and care providers.

3.4 Health status and clinical conditions

Once the clinical and wellness parameters have been monitored and measured, the inputs from a number of sensors can be combined and complemented by supplementary information to yield information, views and predictions regarding the patient’s general health, wellness and fitness, to the point where **specific medical conditions** can be **identified**. This can be done as a **snapshot** in time and/or presented as **trends** measured over longer periods. **Real-time alerts** to **dangerous conditions** that are arising as well as reminders to take medication, for example, can also be generated. Alternatively, the **patient** may have the **need** to **contact** a **healthcare provider urgently** in an **emergency** situation.

Recent reports mention a number of clinical and health conditions that can be identified via telehealth and mHealth, including:

- Type 2 diabetes
  The worldwide cost of diabetes is estimated at $825 billion each year. This huge cost spans treatment, medical intervention and the cost of treating serious complications, such as limb amputation. Early warning allows for proactive intervention, which can prevent further development of the condition. mHealth devices, including wearables, can be very effective in this setting, and a number of diabetes prevention programmes based on digital health technologies are being developed. Data from insulin-resistant participants suggest that a simple set of measurements, such as sleep patterns and steps, could be used to predict which other patients may be insulin-resistant. Glucose levels and physiological signals, such as high daytime heart rate that correlates with insulin resistance, can be measured. Systems are available where a cellular-connected blood sugar monitor takes blood sugar readings and sends the information to a monitoring service. If the reading is outside of normal bounds, the patient will be alerted and offered some kind of recommendation. If the reading is extreme, a specialist will call the patient and make recommendations. Development continues with regard to closed-loop continuous glucose measurement (CGM) and wearable injectors for automated insulin delivery.
- Hypertension
- Congestive heart failure (CHF) and cardiology problems, with embedded ECG measurements.

  More than 600,000 people die of heart disease in the United States every year. It is the number one cause of death for both men and women, causing more deaths than all forms of cancer combined.

  A portable electrocardiogram device using AI automatically flag abnormal ECGs, leading to early detection of common heart arrhythmias and helping to prevent strokes. The mobile device is about half the size of a credit card and only a few millimetres thick, allowing patients to get an ECG in about a minute [7].

  A foetal heart monitor which connects to an app via bluetooth has been reported. It also allows the mother to share the information on social media.
- Detection of skin cancer risk and dermatology (one of the largest applications of telehealth in the US in 2014).
- Neurology, including Alzheimer's disease and Parkinson's disease, with embedded EEG measurements.
- Seizures and epilepsy
  One reported study tracked epilepsy patients' seizures, focusing on triggers for the seizures. When patients sensed a seizure coming on, they activated the app, which then let a smart watch record heart rate data, accelerometer data (measuring the physical movement of the patient), as well as the gyroscope data in real-time while the seizure was happening. During the recording period, users were also prompted to test for reflex and awareness. After the seizure, patients can provide additional contextual information.
- Nascent inflammation
- Orthopaedics and bone health
- Metabolic conditions
- Pulmonary diseases (such as obstructive pulmonary disease), asthma, respiratory illness and lung diseases
- Cancer
- Anaemia
  The development of an app which can detect red blood cell levels simply by placing a finger over the camera and flash of a mobile phone, so that a bright beam of light shines through the skin, is being developed [8].
- Gynaecology and birth control
- Multiple sclerosis (MS)
- Cystic fibrosis

[7] https://www.forbes.com/sites/miguelhelft/2017/03/16/with-30-million-infusion-vic-gundotras-mobile-health-startup-unveils-ai-to-flag-heart-conditions/#2ed940c234f8

[8] http://www.telegraph.co.uk/news/2017/02/18/smartphones-become-pocket-doctors-scientists-discover-camera/

- Various mental health issues, including anxiety, depression, bipolar disorder, schizophrenia and suicide prevention.
- Emergency care
- Pain management
- Male fertility
- Lyme disease (a bacterial infection spread to humans by infected ticks).
- Insomnia
  One in three British people suffer with sleep problem and the average UK employee loses 8.5 days of work a year due to poor sleep. A new generation of automated digital therapies has been developed that aims to deliver cognitive behavioural therapy (CBT) at scale to address this problem.
- Obesity
- Physiotherapy
  A virtual physiotherapy platform has been announced. It will be offered to patients who are preparing or recovering from surgery such as joint replacements, and provides a better solution than the traditional paper-based exercise regimens. The platform has remote monitoring and compliance tracking, and provides patients with access to educational content. Physicians can choose from over 3,500 fully narrated exercise videos and more than 180 program templates to create a tailored prescription for each patient. The app also incorporates telehealth capabilities that enable video consultations and secure messaging [9].
- Fitness and wellness, including fatigue.
  Measurement of fatigue levels 'everywhere, any time and in real-time' have many applications in industrial settings, the military and for consumers (including drivers). 'Fitness to work and operate' is an important parameter in many work environments, which include alertness, competency and the ability to adhere to health and safety requirements. Think for example of pilots, professional drivers and operators of equipment in manufacturing settings. In addition to fatigue, other related parameters can also be measured using mHealth devices, including blood-alcohol levels and use of other substances. Monitoring can be done, for example, before a shift, trip or flight is undertaken and/or continuously and in real-time while it is in progress.

3.5 mHealth applications in clinical trials

mHealth is finding increasing applications in **clinical trials**. Smartphones, smart watches and associated hearables are rapidly becoming capable of professional quality health assessments. A recent study commented that conducting some trials entirely via smartphones is **feasible, useful and scalable**, providing the necessary scientific rigour and allowing for large-scale participant enrolment [10].

As part of an asthma study in 2015, 50,000 smartphone users downloaded the app within six months. The added advantage of the smartphone was the ability to also **collect** other **useful** and unique environmental data such as geolocation and air quality, helping researchers to correlate daily asthma symptoms to environmental factors. In this case, it was found that wildfires in the areas contributed significantly to patients' symptoms.

Recent reports refer to concerns pertaining to the accuracy (or lack thereof) of the measurements that can be obtained with mHealth devices and sensors. As mentioned above, it is helpful to keep in mind that this is a technology which is developing apace and that accuracy will inevitably improve; and to consider the level of accuracy that is really required in these applications. This is another manifestation of a disruptive innovation entering at the low end of the market, but with the potential to compete with the mature technology in its main market in due course.

4. Digital health technologies interacting with other emerging technologies

Emerging technologies find applications in a wide variety of industries and sectors, including finance ('fintech'), education, manufacturing, transport, consumer, travel and of course, healthcare. From an opportunity/threat/risk assessment viewpoint, the analysis of digital health technologies as emerging technologies compels us to **investigate** their **interaction** with **other emerging technologies** (as discussed above).

[9] http://www.mobihealthnews.com/content/physitrack-lands-first-major-uk-payer-partnership-offer-virtual-physical-therapy-platform

[10] http://m.healthcareitnews.com/news/mount-sinai-work-apple-researchkit-shows-how-smartphones-surpass-traditional-study-methods

A recent report by PWC[11] refers to the 'eight technologies that matter now', viz. artificial intelligence (AI), augmented reality (AR), blockchain, drones, internet of things (IoT), robots, virtual reality (VR) and 3-D printing. We can also add other emerging technologies such as analytics, big data, machine learning, chatbots and APIs as technologies that are relevant to emerging digital health trends.

4.1 Big data - electronic health records (EHR), patient generated health data (PGHD), application program interfaces (API), analytics and genomic data

It was mentioned above that **health data and information** is the lifeblood of digital health technology, including the ways in which it is captured, communicated, stored, shared, protected, processed, interpreted and displayed. Major advancements are being made in this regard, but at the same time many challenges remain, including **interoperability**[12], **integration**, **scalability** and **data security**. The *21st Century Cures Act* gives a first codified definition of interoperability in the US. In a recent survey, 79% of health executive and 69% of clinicians answering the survey indicated that they were of the view that **interoperability** is one of the **top three barriers** to better use of patient data.

> "….interoperability is one of the top three barriers to better use of patient data"

4.1.1 Big data

The collected health data of patients certainly constitute '**big data**', with all its associated benefits, opportunities and also challenges. The effectiveness of **remote patient monitoring** (RPM) depends not only on **sensors** and **capable mobile devices**, but also on **secure, scalable and interoperable health data systems** that can deal with the big data. They need to be driven by **analytics**, ensuring that a patient's data is not a standalone measurement. The **challenge** remains to **turn big data into actionable data**, including enhanced decision support – everywhere, any time and in real-time.

4.1.2 Patient generated health data (PGHD)

As mentioned above, telehealth and mHealth now enable **patients** to **create** an **entirely new class of dataset** populated by the data they generate **themselves** (PGHD). In order for the interactive element of mHealth to be effective, quick response is required, emphasising the need for real-time two-day data exchange[13].

A new survey found that **57% of patients bring** along their **own PGHD** when they visit their doctor, even if they were not asked to[14]. Almost two-thirds of patients find that their **healthcare professional is more engaged** when they bring their PGHD to the visit, and two-thirds of healthcare professionals think that patients are more engaged when the patients bring their own health data. The survey suggests that more than **80% of patients** would **provide PGHD** if they thought **doctors will use it** to develop a treatment plan.

> "…patient generated healthcare data will be among the most useful data sources in 5 years…"

Another recent survey in the US indicated that 40% of surveyed doctors think that **PGHD** will be among the **most useful data sources** in 5 years as opposed to 30% listing it as a top source today. Clinical data, listed as a top source of data today by 95% of respondents, was estimated to decline slightly to 85% in five years.

4.1.3 Electronic Health Records (EHR)

Care coordination (the organisation of patient care activities between the healthcare professionals) is only possible if the **multiple stakeholders** across the industry can **contribute and share critical information**. Some information, specifically PGHD, may be held by the patient rather than in central databases. Ways need to be found to **integrate PGHD** and **other information** into an individual patient's **unique health record**. The problem is, of

11 http://www.pwc.com/techmegatrend

12 http://www.healthcareitnews.com/blog/allscripts-ceo-paul-black-3-health-it-trends-watch-2017

13 http://www.mobihealthnews.com/content/survey-four-ten-doctors-say-patient-generated-data-will-among-most-useful-data-sources-5

14 http://www.fiercehealthcare.com/it/6-barriers-keep-doctors-from-using-patient-generated-health-data

course, that a patient's health record may be kept by a range of different care providers, many of whom may not be aware of the others and even if they were, would not be able to access and share the information.

Electronic health records (EHR), where an individual patient's entire health record is captured in a single electronic file which is accessible to all care providers when and where they need it, remains a very **important issue**, but one that has yet to be fully cracked [15]. It has recently been reported that only 4 in 10 US hospitals have the necessary patient information electronically available from care settings outside their system, for example. In an ideal world, patients would like all care providers with which they interact to have access to all their records when and where required, but at the same time also have the data protected so that it is not revealed, used or published in any way that compromises the patient[15].

A recent study reported **inconsistencies** between **health problems and symptoms reported** by patients and what was **actually recorded** in the patient's EHR [16]. The reasons were not entirely clear, but it is suggested that physicians' experience, workload and use of a medical scribe were not significant factors. Instead the inconsistencies may be due to time constraints, system-related errors and communication lapses.

4.1.4 Application Programming Interfaces

As technology becomes more sophisticated, so does its users. **Patients** now **demand** timely **access** to their **health information**, and they want as few impediments to that access as possible. **Application programming interfaces (APIs)** can contribute significantly towards enhanced interoperability. Open APIs are not a new phenomenon - the financial, retail and technology industries are already utilizing APIs to revolutionise standards and expectations for consumers.

The use of **APIs** provides the key towards successful implementation of a **functional EHR system**. The development of a number of API-based software systems and tools for use in the healthcare environment was recently reported. There does, however, seem to be some **ambiguity** as to the **way forward**, including who should take the lead and what is really required. **Uncertainty** regarding **evolving business models** – '**who will pay**' – is contributing to the dilemma.

4.1.5 Health analytics and machine learning

Health analytics will be a very powerful healthcare decision support instrument and complements other emerging technologies in healthcare, including **artificial intelligence**. '**Descriptive analytics**' assist physicians (and mHealth devices) to diagnose medical conditions and health status, when provided with the symptoms. In a sense this is a reactive mechanism, as it deals with a medical condition that has already been manifested. '**Predictive analytics**' can assist by predicting which conditions can develop in the future, given symptoms or 'vital signs' measured now. However, **actionability is important** in health settings, and knowing what may happen in the future is not the same as knowing what to do about it.

Studies have shown how **difficult** it is for a **physician** to **stay abreast** of all the **new information**, procedures, protocols and treatments being developed. It has been suggested that this gap in knowledge can contribute to variation in care and suboptimal outcomes. Enter '**prescriptive analytics**', which can **assist** the physician by **identifying and recommending options** for action and prescriptions for medicine, providing actionable decision support at the doctor's fingertips. The benefits of prescriptive analytics in mHealth applications are also obvious [17, 18].

It is foreseen that advanced sources of analytics such as **IBM Watson** [19] can complement human expertise with **artificial intelligence** and machine

[15] http://uk.businessinsider.com/electronic-health-records-innovate-2016-8?r=US&IR=T

[16] http://www.fiercehealthcare.com/practices/all-patient-symptoms-don-t-make-it-into-ehr-study-finds

[17] https://www.forbes.com/sites/teradata/2016/11/04/prescriptive-analytics-just-what-the-doctor-ordered/#493007223330

[18] https://hbr.org/2016/12/how-physicians-can-keep-up-with-the-knowledge-explosion-in-medicine

[19] https://www.theguardian.com/healthcare-network/2017/mar/11/artificial-intelligence-nhs-doctor-patient-relationship and https://www.forbes.com/sites/jasonbloomberg/2017/03/24/eight-vendors-driving-disruption-in-the-ibm-ecosystem/#2fca034b2e9a and https://www.forbes.com/sites/jasonbloomberg/2017/03/22/ibm-bets-the-company-on-cloud-ai-and-blockchain/#f7cab29776d5

learning to synthesize a large knowledge base in various clinical conditions (such as cancer and heart disease). It can **suggest treatment options** designed for a **specific patient**, all in real-time.

4.1.6 Genomic data and precision medicine

Genomic information presents the potential for precise diagnosis, optimised treatment and predictive aspects to healthcare, as well as enhancing treatment of patients that are already ill. **Traditionally**, medical knowledge and therapies are **tested on broad populations** and **prescribed** using **statistical averages**. The result is that, **on average**, **treatments** ultimately **work** for **some patients** but not necessarily for all. **Precision medicine**, on the other hand, use the **genomic data** to **personalise treatment** (including medicines) for **individual patients**. A number of service providers can analyse an individual's genomic data and provide a report to the patient and their healthcare provider.

4.2 Data security and blockchain

By the very nature of the **privacy concerns** and personal sensitivities involved with healthcare, data **security** is a very **high priority**. It has been reported that more than 16 million patient records were breached in 2016 in the US, with a 320% increase in hacking of healthcare providers' data year-on-year [20].

In addition to the privacy issues involved, a large scale malicious **cyber attack** on a national level, for example, on the personal health records of patients can be **catastrophic**. It is not surprising that significant effort in data and cyber security is aimed at the health sector. Whereas security regarding the **personal health records** of patients are obvious, there are also concerns regarding the **data security** of **distributed devices** that are part of the '**internet of healthcare things**'. Many recent reports indicate **concerns** from **hospitals** regarding the **security** of their **internet connected devices**.

> "….concerns from hospitals regarding the security of their internet connected devices"

Blockchain is an emerging technology that can be used with great success to address these challenges. Although blockchain is well known as the driver of the bitcoin cryptocurrency, it can also be used in a number of other applications. The technology enables sharing of data in a manner that is highly **secure** and **tamper-proof** by decentralising the storage of **encrypted data**, enhancing security, authentication, accountability and data sharing. Indications are that there will be an **increasing** use of **blockchain in healthcare** [21], where it can be deployed in applications such as patient records, supply chain application and clinical trials.

4.3 Imaging

Imaging per se may not be an emerging technology in own right, but its importance in healthcare settings warrants an inclusion in this discussion, particularly given the imaging enhancement potential of other emerging technologies. Whereas a **significant amount** of **medical data** (some suggest 90% [22]) come from **imaging** (including X-rays, MRI scans, EEG scans, ECG scans, sonars, retina scans and photographs), reports also suggest that at the same time the **ability** of **electronic health records** to accommodate and **integrate imaging data** is **problematic**.

Significant value can be added to a wide range of medical imaging specialties, such as radiology, if **patient images** were **automatically attributed** to the **clinical context** in which they are captured. **Artificial intelligence** and deep learning technology can contribute significantly towards image processing and **interpretation** of the images.

It is important to recognise the value of also **including videos** rather than just static images in a patient's **health record**. This can include sonar scans, for example and also be useful in 3-D interpretations.

4.4 Artificial intelligence (AI)

AI provides **tremendous opportunities** in healthcare, not necessarily as a substitute for healthcare practioners but by **providing decision support** and **augmenting human intervention**. Combining AI with other technologies can assist not only healthcare practioners as well as patients to **diagnose themselves** with a **range of conditions** (in

[20] http://medcitynews.com/2017/02/move-beyond-the-buzz-in-digital-health/

[21] http://www.theverge.com/2017/3/10/14880094/deepmind-health-uk-data-blockchain-audit

[22] http://www.chinadaily.com.cn/business/tech/2017-03/16/content_28573832.htm

some cases even before they show symptoms) and to **better understand symptoms** and effects of treatments. Recent experiments have demonstrated cases where **AI-driven algorithms** using deep learning have **outperformed human doctors** with regard to **diagnosis** of some medical conditions.

4.5 Virtual reality (VR)

VR equally has **great potential** to **enhance healthcare**, in part due to its relative low costs and ease of use. It is highly interactive and flexible, can be personalised to the individual patient and used with patients varying in age, sex and medical conditions. A recent study investigated the use of three **VR applications in inpatient settings**, viz as a distraction for **pain reduction**, to **improve body image** in patients with eating disorders and as a mechanism for **cognitive and motor rehabilitation**. The reported **user experience** was **positive** with **high patient satisfaction**. Pain distraction was one of the most promising areas. Eating disorder studies employed the technology to modify subjects' self-perception by using avatars in virtual environments to help train patients to make better lifestyle decisions. Improvements in body conditions were reported in all studies, with patients using the VR technology additionally reporting improved body image perceptions, and after one year, performing better at improving or maintaining weight loss.

4.6 Internet of Things (IoT)

IoT is **widely used** in **various healthcare settings**, often referred to as the 'internet of healthcare things' (IoHT) – although some suggest it should rather be referred to as the 'internet of patients' (IoP) to emphasise a focus on patients' needs. A recent study suggests that after manufacturing, healthcare will be the largest application domain for distributed devices. Much effort is directed at addressing **interoperability** issues and **integrating PGHD in the IoHT**. Improvements in **data security** and cybersecurity are high on the agenda, with a number of reports highlighting the apparent ease with which IoHT devices can be hacked and the damage that can be done [23].

4.7 Robotics

In addition to the use of **robotics** in **surgery**, including **remote surgery**, a number of products using **robots** as '**paramedical staff**' and **aides/companions** for the **elderly** have recently been reported, some of them in nursing-related roles [24]. Such a robot may also have integrated sensors, so that it can record 'their' patient's heart and breathing for example, and take appropriate images for transmission to remote care providers.

A child-sized humanoid robot (named Kaspar) is taking part in its first clinical trial with the UK National Health Service [25]. Kaspar uses realistic but simplified human-like features to **help children** with **autism** explore basic human communication and emotions, and learn about socially acceptable physical interaction. The robot can talk, comb its hair and play the drums. It has skin sensors on various parts of its body, including on its cheeks, torso, arms, palms and feet, which allow it to respond to touch. Kaspar has pre-programmed autonomous responses, as well as responses that can be triggered remotely by teachers, therapists, or other children. These responses enable Kaspar to encourage certain tactile behaviours and discourage inappropriate ones.

The use of **robo-pets** for healthcare purposed have also been reported, in one case presented as reducing the behavioural and psychological symptoms of **dementia**.

There are many **ethical** and **user resistance** issues to address regarding the use of robots in healthcare, but the technology itself is **promising**.

4.8 Chatbots

A number of **healthcare applications** integrating commercial **chatbots** used in mobile smartphones have been reported. These include the ability of the patient to ask the bot to explain their physical condition or to create personalized exercise routines. Voice interaction with these bots are synergistic with the use of hearables.

A specialised radiology chatbot for use by non-radiologists in a clinical setting ('cyber-radiologist in app format') was recently reported [26].

[23] http://www.healthcareitnews.com/blog/commentary-digital-health-reform-and-underserved-where-will-2017-lead

[24] http://www.bbc.co.uk/news/business-39255244

[25] http://www.mirror.co.uk/tech/humanoid-robot-developed-help-children-10134984

[26] https://www.inverse.com/article/28737-artificial-intelligence-chatbot-doctor-hospital-radiologist-ucla-ai-deep-learning-app

4.9 3-D printing

Healthcare is one of the **fastest growing 3-D printing industries**, driven in part by the demand made by the **uniqueness** of each patient's condition and anatomy.

A number of **3-D printing applications** in **healthcare** have been reported recently, and include:

- The printing of customised orthotics, prostheses and anatomical models, printed titanium vertebrae [27], hip and jaw implants, blood vessels that deliver nutrients and self-assemble like they would in a human body [28], bioresorbable splints to help save the lives of babies suffering from tracheobronchomalacia (TBM) [29], customised wheelchairs [30], 3-D printed veins, vascular tissue and calcium-plastic bones with hyperelastic qualities.
- A 3-D printed heart-on-a-chip module that is capable of replicating the heart's reaction to substances was reported. Lab-on-a-chip research can potentially be useful research testbeds that do not require animal testing.
- A prototype using bio-inks printed a totally functional human skin [31], deemed adequate for transplanting to patients as well as for use in research or the testing of cosmetic, chemical, and pharmaceutical products.
- Personalised, 3-D printed pills have been reported, in one case with personalised time-release supplements.
- An online community that shares open source, customisable designs for prosthetic hands and arms has been reported.

Reimbursement codes for claims remain one of the hurdles pertaining to the use of 3-D printing in healthcare.

4.10 Drones

There have been a number of recent reports indicating the use of **drones** in **healthcare settings**, particularly with regard to **first responder** deliveries and **rescue operations**. The deliveries can include medical supplies as well as equipment to enable video discussions from the emergency site with remote physicians, hospitals or emergency response centres. A case is reported where drones are used to **transport blood to hospitals** [32]. The use of pilotless taxi drones has been reported as well as military evacuations by drone [33]. Pilotless drones for patient evacuation will be available soon.

5. Discussion

As an emerging technology, **digital health technologies** (including **telehealth** and **mHealth**) are **not only enhancing** the healthcare of **individual** patients and **healthcare systems**, but as is the case with many other emerging technologies, it is also exhibiting '**creative destruction**' characteristics in addition to the **performance benefits** it delivers. The emerging healthcare technologies are **disruptive and dynamic**, with **rapid changes** in performance, costs, applications and user bases. There are **changes** in **industry structure**, shifts in **power patterns** and **cost curves** as well as the **entry** of **new types of players**. Significant new value is being created and new outcomes enabled.

Emerging digital health technologies should be high on the **radar of companies** as they **assess strategic business opportunities**, **threats** and **risks**. **Traditional healthcare providers** (including professional practitioners, hospitals and clinics), health insurers, funders, healthcare systems and producers of health technology products as well as **new entrants** and **new types of entrants** in the healthcare sector need to be **aware** of the **disruptive shifts** in the industry. **Opportunities** also **abound** for role players in other sectors that may, at first blush, not seem to be related or affected. Conversely, emerging digital technologies may also **present risks and threats** to role players in seemingly unrelated sectors. A **strategic opportunity/threat/risk review** is helpful to assess a specific company's or industry sector's technological innovation-related opportunities and

[27] http://www.3ders.org/articles/20170217-india-first-3d-printed-titanium-vertebrae-implant-helps-32-year-old-woman-walk-again.html

[28] https://www.engadget.com/2015/12/06/scientists-3d-print-live-blood-vessels/

[29] http://iq.intel.com/3d-printing-better-healthcare/

[30] https://3dprintingindustry.com/news/review-recent-medical-advances-using-3d-printing-3d-bioprinting-102971/

[31] https://phys.org/news/2017-01-spanish-scientists-d-bioprinter-human.html

[32] http://spectrum.ieee.org/the-human-os/biomedical/devices/when-drone-delivery-makes-sense-when-youre-flying-lifesaving-blood-to-hospitals/?utm_source=humanosalert&utm_medium=email&utm_campaign=040517

[33] http://thetechnews.org/bae-concept-for-integrating-drones-and-fighters-that-split-into-multiple-vehicles/#.WOANlIWcHcs

vulnerabilities vis-à-vis emerging digital health technologies.

Health information is **the lifeblood** of **digital health technologies** and the benefits they can bring. Significant effort is being directed towards capturing, communicating, storing, sharing, protecting, processing, interpreting and displaying the information. It is one the **most significant drivers** for **opportunities** and threats with regard to **emerging digital health technologies**. The focus is on **actionable information** and **decision support** to patients, healthcare providers and other role players – **everywhere, any time and in real-time**.

Many **challenges** and **uncertainties remain** to be resolved for emerging digital health technologies, as would be expected of any emerging technology. These can of course be both **opportunities** and **threats**.

It has been said that you can teach someone to remove an appendix in a week, but it takes many years to teach someone what to do when something goes wrong. Also, there aren't universally agreed-upon therapies and treatments for conditions ranging from depression and chronic pain to stroke and Parkinson's disease. These **dilemmas** need to be accounted for as the world moves towards AI diagnosis and machine generated advice to patients and prompts to take action themselves. **Interoperability** and **cyber security** (including for IoT devices) remain **problematic** issues.

One of the major **cross-cutting** issues that requires further investigation is an examination of the **factors driving or inhibiting** the **adoption** of digital health technologies and **affecting the rate of adoption** of the new technologies. How and why the technologies are adopted and at what rate ? Which new and unforeseen uses are users themselves finding for the new devices and how can these be captured ? It has been suggested that **barriers** to **adoption** include **reimbursement regimes** and the '**conservativeness of the healthcare industry**'.

Many opportunities, threats, risks and uncertainties are in the technological, scientific and clinical domains. However, emerging digital healthcare technologies also pose **challenges** with regard to **ethical issues, accountability, health and safety, legal and liability issues, data security and regulation**.

The **vexing problem** of **business models** and the '**difficulties of making money**' from **telehealth** and **mHealth** are important, as are the related issues of **funding models** and **reimbursement of claims** for **digital health provision**. These difficulties are **complicated** by the fact that **traditional business models don't work** very well in a **platform-enabled, digital health world** driven by new types of information and empowered patients.

As digital health, telehealth and mHealth become more ubiquitous, the **nature of health-related jobs** will necessarily also **change**. Inevitably **new types of roles** will **emerge** and **current roles** may **disappear**. One can, for example, imagine new and different roles for healthcare providers such as doctors, nurses and therapists. It is also necessary to consider how **curricula** for **training healthcare professionals** in the **new digital health world** should be developed and **proactively** adopted by **universities** and other education and **training institutions**. **Accreditation bodies** that regulate health **qualifications** and **register professionals** should also address this matter. It is important to ensure that the **next generation** of healthcare **providers** as well as the **current practioners** are **prepared, able and willing** to **leverage** the **benefits** of the **new technologies**. This will require not only an **understanding** of the **new technologies** and the **skills** to use them, but also a deeper **understanding** of the notion of the '**empowered patient**' and how that will affect the **relationships** between **patients** and **healthcare providers**. **Continuous professional training** in **digital health technologies** for **practising professionals** should be a **high priority**.

6. Appendix

The dynamics of technological change, technological innovation and the nature of emerging technologies

In order to assess the strategic business impact, opportunities and risks of emerging technologies, it is helpful to understand the dynamics of technological change and the characteristics of emerging technologies.

Any innovation, irrespective of its other characteristics, has **two important components**, viz. an **'invention' component** and an '**acceptance in the market' component**. Innovation encompasses the creation or invention of new products, processes or services *and* their successful adoption by users – it is where '**technology meets the market**'.

Technological innovation is not only an **inherently risky business**, it is also a **dynamic process** – things change with time, including the performance of the technology, costs, use and applications as well as adoption by users and diffusion patterns. The dynamics are often depicted in terms of S-curves, learning curves and the familiar Gartner hype cycle to name but a few, which are all helpful in interpreting the trajectories of the technology over time as well as the interaction amongst technologies.

A **mature technology** has many advantages, established over a long period. These include proven reliability, established user bases and distribution networks as well as intellectual property protection. However, these advantages can eventually become hurdles impeding change. The **bulk of innovations are of an incremental nature**, continuously improving existing products, processes and services, typically over a long period through the contributions of many role players all across the globe. Incremental innovations enhance existing products, processes and services by making them '**faster, cheaper and better**'.

From time to time, however, **radical and disruptive innovations** come along. They bring about a **step change in performance and benefits**, and are typically based upon one or more **emerging technologies**. Radical innovations tend to **upset the industry hierarchy**, often accompanied with the introduction of new business models, changes in the industry ecology as well as changing regulatory environments, new policies and new legislation. **New types of companies** (rather than just new companies) become the **new industry leaders**. As is often the case with disruptive technologies and radical innovations, a **shift** in behaviour patterns of role players and the 'centre of the gravity' in the **value chain in terms of power and influence relationships** between role players often come about.

Technological innovation, particularly radical and disruptive innovation, is known to bring about '**creative destruction**'. New products, processes and services as well as new companies, new types of companies and industries, business models and customer bases emerge, enabled and fuelled by the new technologies. At the same time the mature and established orders fall by the wayside as they are replaced by the new. Emerging technologies often have the '**attacker's advantage**' [34] and it can take significant effort and ingenuity for legacy players to reinvent themselves in order to survive, prosper and be competitive in the new world. Start-up companies and ventures based on emerging technologies do not need to rely on legacy infrastructure investments that can become obsolete and may be difficult to dispose of; and they can exploit new engineering and scientific principles.

New technologies can be very disruptive, creating new markets and industries, accompanied by changes in business models; and sometimes new social cultures and norms. Emerging technologies often create '**disruptive innovations'**. They initially address the low performance end niches of a market segment [35] and are often perceived as 'non-threatening' by mature technologies. However, as the (soon-to-be disruptive) emerging technologies develop, they improve to a point where they supplant the mature technologies in the latter's main markets, often leading to the demise of the mature technologies as mentioned above. All of this happens over time, hence the importance of understanding the dynamics of the innovation processes that are playing out.

Very often the emerging technology causing the **disruption comes from a very different industry or sector in which the disruption is caused**, and/or the disruption is the result of a **number of emerging technologies having a simultaneous impact** rather than a single intervention. This is one of the major reasons why technological opportunity and threat analysis should track a wide spectrum of emerging technologies from diverse sectors in different stages of development; and why it is important to consider the impact a combination of technologies may have as well as the competitor, symbiotic and predator-prey influences that they may have on one another [36].

[34] See for example Richard N. Foster, *The Attacker's Advantage*, Summit Books, 1986.
[35] See for example Clayton M. Christensen, *The innovator's dilemma: When new technologies cause great firms to fail*, Harvard Business School Press, 199; and Clayton M. Christensen and Michael E. Raynor, *The innovator's solution*, Harvard Business School Press, 2013.
[36] C.W.I. Pistorius and J.M. Utterback, "Multi-mode interaction among technologies", *Research Policy*, Vol 26, 1997, pp. 67-84. http://www.sciencedirect.com/science/article/pii/S004873339600916X

As **new technologies** emerge, they are **not optimised** in many regards. When decisions are made at an early stage to investment in or adopt emerging technologies (or not), it is easy therefore, to fall into the **trap of neglecting to account for the dynamics of change** when comparing the performance, costs and reliability of emerging technologies with more mature technologies. Emerging technologies are often judged in terms of benchmarks that apply to the mature technology, as the new technology has not yet had the opportunity to reveal its usefulness or new applications that it enables. As a new technology develops, **learning dynamics** come into play and the new technology becomes cheaper, better, faster and more users adopt it. It is important to **consider what 'could be' and probably 'will be', rather than just 'as is'**. In their early stages, the performance of emerging technologies may not (yet) be what the main market requires at the time. Initially emerging technologies may be **inferior** to the mature technologies they are challenging in many respects, they may be relatively expensive, sometimes unreliable and may not have established user bases. But **things develop and emerging technologies become more competitive over time**, often when competing mature technologies have little scope to improve further.

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