Working Group on Digital and AI in Health

Reimagining Global Health through Artificial Intelligence: The Roadmap to AI Maturity

September 2020

BROADBAND COMMISSION
FOR SUSTAINABLE DEVELOPMENT

Reimagining Global Health through Artificial Intelligence: The Roadmap to AI Maturity

September 2020

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About the Broadband Commission for Sustainable Development

The Broadband Commission for Sustainable Development was established in 2010 by ITU and UNESCO with the aim of boosting the importance of broadband on the international policy agenda, and expanding broadband access in every country as key to accelerating progress towards national and international development targets. Led by President Paul Kagame of Rwanda and Carlos Slim Helù of Mexico, it is co-chaired by ITU's Secretary-General Houlin Zhao and UNESCO Director-General Audrey Azoulay. It comprises over 50 commissioners who represent a cross-cutting group of top CEO and industry leaders, senior policymakers and government representatives, and experts from international agencies, academia and organizations concerned with development. Learn more at: **www.broadbandcommission.org**

About the Novartis Foundation

The Novartis Foundation strives for a transformational and sustainable impact on the health of low-income populations. In recent years, we reached over 30 million people with innovative healthcare delivery models. By measuring individual health outcomes and population health impact, we generate evidence to translate the successful models into health policy. In 2019, the Novartis Foundation sharpened its focus to concentrate fully on how data, digital technology and AI can improve population health around the world and transform health and care systems from reactive to proactive, and even predictive.

About Microsoft Corporation

Microsoft (Nasdaq MSFT @microsoft) enables digital transformation for the era of an intelligent cloud and an intelligent edge. Its mission is to empower every person and every organization on the planet to achieve more.

About Accenture

Accenture is a leading global professional services company, providing a broad range of services and solutions in strategy, consulting, digital, technology, and operations. Combining unmatched experience and specialized skills across more than 40 industries and all business functions – underpinned by the world's largest delivery network – Accenture Strategy works at the intersection of business and technology to help clients shape the future of their organizations and create sustainable value for their stakeholders. With more than 509 000 people serving clients in more than 120 countries, Accenture drives innovation to improve the way the world works and lives.

Foreword

Dr. Ann Aerts

Head, Novartis Foundation
Co-chair, Broadband Commission Working Group on Digital and AI in Health

For the past decade, the Novartis Foundation has embraced digital technologies to improve the health of low-income populations, powering initiatives that are people-centered, integrated, scalable, and sustainable. On our journey, we have seen first-hand how digital health and AI can transform global health.

AI is today's defining technology and the greatest opportunity to transform health systems from being reactive to proactive, predictive, and even preventive. AI allows us to reimagine how we deliver health and care to patients, improve outcomes, and accelerate universal health coverage. From global pandemics to health worker shortages, the world is facing growing challenges that call for extraordinary capabilities that only AI can offer.

Low- and middle-income countries have the most to gain from AI in health, and the most to lose. For example, the response to the COVID-19 pandemic shows how global health is now data-dependent. However, most countries still need to build these data, and governments who do not invest risk widening existing health inequities in their populations.

This is the third report of the Broadband Commission for Sustainable Development Working Group on Digital and AI in Health. Our 2017 report created a blueprint for how the technology sector, health leaders, and policymakers can collaborate to digitize health systems. Our 2018 report outlined recommendations for digital solutions that help address noncommunicable diseases. This new report builds on our previous work to offer a landscape analysis of use cases for AI in health.

We share the challenges and enablers for AI in health – insights that may be pivotal to respond to global health emergencies. One major challenge is integrating AI in health system workflows and operations, as without adequate deployment, even the best AI solution will not have an impact. On the other hand, we must address critical questions about ethics, data privacy, and security to ensure AI technologies deliver human benefits.

Our Working Group identifies five use cases for AI in health: population health; R&D; clinical care pathways; patient-facing solutions; and optimization of health operations. Yet, before assessing whether AI offers solutions, countries must identify the health problems they need to address. To realize the full potential of AI in health, countries must also nurture an enabling ecosystem with six interdependent areas: people & workforce; data & technology; governance & regulatory; design & processes; partnerships & stakeholders; and business models.

Thank you to the Working Group on Digital and AI in Health for their fantastic engagement and collaboration and for sharing your expertise so generously. It has been an honor and pleasure to work together to reimagine global health through Artificial Intelligence.

Paul Mitchell

Senior Director, Internet Governance, Microsoft Corporation; Co-chair, Broadband Commission Working Group on Digital and AI in Health

The arrival of COVID-19 has dramatically changed life on this planet. Moving swiftly to cover the globe, the pandemic has thrown into sharp relief the critical importance of broadband networks and ICTs to nearly every aspect of our modern lives: keeping in communication with family and friends, continuing school education without going to school, and keeping businesses and supply chains operating.

Work on this report began before the pandemic hit. It was intended to focus on the potential benefits AI might bring to the health sector. We did not forecast that a global pandemic would be first flagged by an AI and that less than four months later more than a third of the world's population would be locked down due to the novel coronavirus – a stunning example of the importance of this technology, and a wake-up call for the need to build strong foundations to harness the benefits of AI.

This report is packed with numerous examples of how AI is being used to fight against COVID-19, including diagnostic testing, predictive modeling, vaccine research, and more. It also details broader applicability to the sector overall.

As this report illustrates, data is the critical input. AI flourishes on data. By doing more to open up and share data, organizations can unlock value, share expertise and make data more useful for all, allowing everyone to benefit in ways they are not able to by going it alone. There is unprecedented collaboration and data sharing related to COVID-19 – we need to ensure that it doesn't stop there.

At Microsoft, we are joining with the global community to address the COVID-19 crisis with data including working with partner Adaptive Biotechnologies to decode how the immune system responds to COVID-19 and sharing research findings via an open data access portal for any researcher to use. Microsoft is releasing aggregated data to those in academia and research. We are also working with GitHub, which is hosting a range of collaborative COVID-19 projects[1], and many leading COVID-19 datasets.

We think it is valuable to define a clear set of principles when engaging with important and complex societal issues and we have adopted a set of principles to inform how we open and share data in a responsible way. We hope these principles will inform the broader conversation on open data and that others can build on and improve them.

One of these is ensuring that data is usable for everyone. Unless organizations are able to collect and categorize data in a standardized way, they will not be able to aggregate and analyze it in a manner that produces the transformative insights that shared data has the potential to unlock.

Finally, to leverage and bring AI capabilities to the next level for health systems, countries need to foster a robust enabling environment for AI. In this report, we call for global action to create meaningful legislation and robust policy frameworks that build and incentivize an AI-enabling environment.

Contents

Executive summary

The report holds that while low- and middle-income countries may have the most to gain from the radical potential of Artificial Intelligence (AI) to transform health systems, they may also have the most to lose.

AI is revolutionizing healthcare with game-changing capabilities

AI should not replace humans but rather enhance capabilities

AI-powered solutions are participating in more and more medical tasks traditionally performed by healthcare practitioners. AI capabilities can assist with tasks performed by highly skilled medical workers and tasks that go beyond human cognition (e.g., processing big data to diagnose illness), as well as tasks that support humans but are often subject to inattention, cause fatigue, or are physically difficult to perform. Across the entire care spectrum, AI capabilities in healthcare are performing hard work.

AI should not replace health workers, but the profession will undoubtedly evolve

As AI increasingly enters healthcare, good governance should ensure that physicians will see the upside of less administrative work and more patient-facing time. Humans and machines should work together to improve patient outcomes, strengthen health systems, and drive progress towards universal health coverage (UHC). AI will also create new jobs across sectors. Yet, the new jobs will not necessarily emerge within the same professional specialization or same geography where old jobs are being replaced by AI. Therefore, sequenced action and policy timing are crucial, with measures taken to ensure workforce disruption is accompanied by appropriate change management, social safety nets, and professional retraining opportunities.

AI addresses key global and national health issues

In low- and middle-income countries (LMICs), AI has the potential to address longstanding, systemic health issues with new advanced capabilities. Many LMICs are dealing with:

A shortage of health workers

The doctor-to-population ratio is markedly lower in LMICs, especially in rural settings.

Emerging threats

From COVID-19 to climate change and antimicrobial resistance (AMR), emerging threats present new challenges to existing health systems.

A dual burden of disease

Rising rates of noncommunicable diseases (NCDs) and infectious diseases combine to present a dual burden of disease in many LMICs.

Underserved populations

Over 734 million people live on less than USD 1.9 per day[2] and lack access to essential health and care services.

Rapid urbanization

Urbanization is increasing rapidly, with nearly 70% of people projected to live in cities by 2050[3], which is expected to widen health inequities.

Misinformation & disinformation

Adequately managing Ebola, COVID-19, or other outbreaks and diseases is often hindered by a deluge of misinformation and disinformation, causing unnecessary suffering.

To combat today's growing health challenges, we need to systematically integrate AI-enabled tools into the way healthcare is delivered and expand access for all. Without AI, UHC may not be achieved.

Yet, there are also risks associated with the use of AI in health, particularly for vulnerable populations, youth, and children. Successful integration of AI into health and care delivery depends on appropriate risk management processes that have been defined and operationalized for AI development, deployment, and continuous improvement.

To deliver on its promise, AI boasts an arsenal of capabilities

The report identifies five use cases for how AI is applied to address global and public health priorities, strengthen health systems, and improve outcomes for patients.

1. AI-enabled population health
   Solutions that use AI to monitor and assess the health of a human population, and select and target public health interventions based on AI-enabled predictive analytics.

2. AI-enabled preclinical research & clinical trials
   Solutions that use AI to assist drug discovery and design, omics technologies for highly personalized treatments, and AI tools for clinical trial design and execution.

3. AI-enabled clinical care pathways
   AI-based solutions that can be integrated into existing and new clinical workflows.

4. AI-enabled patient-facing solutions
   AI solutions that interact directly with patients, including personalized health coaching and life-style advice, the delivery of (mostly non-clinical) therapies, chatbots, interventions without the risk of harm, and information provision.

5. AI-enabled optimization of health operations
   AI solutions that optimize back-end processes in healthcare, such as procurement, logistics, staff scheduling, emergency service dispatch management, automated medical notes, and patient experience analyses.

The results so far are encouraging. AI has a proven track record across all five use cases, having improved or saved patient lives, augmented the capabilities of health workers, and strengthened health systems across the world. **Yet, we have only scratched the surface!**

Top 5 use cases for AI in health

Figure 1: Top 5 use cases for AI in health

Six areas for AI maturity in health

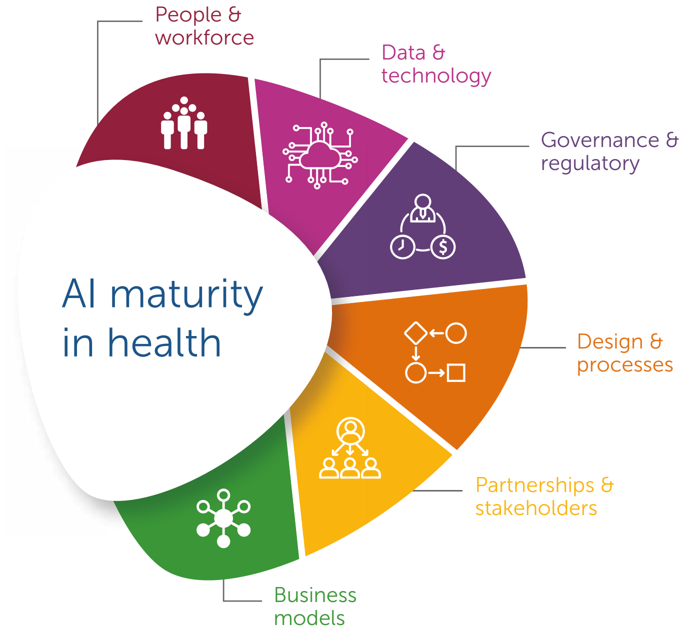


Figure 2: Six areas for AI maturity in health

To bring AI capabilities to the next level for health systems, UHC and patients, countries need to be proactive and foster a robust enabling environment for needs-driven AI.

To build and continuously improve a healthcare innovation ecosystem, the report identifies **six areas for AI maturity in health** that countries should prioritize to advance on their journey to AI maturity.

1. People & workforce
   Countries should prioritize AI and data science in their national health education curricula for pre- and in-service training and formal education. They should strengthen level-appropriate offerings for both technical and non-technical roles and prioritize the soft aspects of technology solutions: human-centric design and behavioral aspects.

2. Data & technology
   Countries should prioritize the foundations: robust technology architecture, connectivity, access to quality and representative data, data privacy and security layers, data stewardship, interoperability, fair and transparent algorithms and AI models, and explainability. Critical to achieving this are consent-driven policy frameworks, a strong data and AI strategy, robust technology implementation roadmaps, and the formulation of relevant best practices.

3. Governance & regulatory
   Leadership is critical to establish the robust governance structures and regulations necessary to ensure AI innovation targets national health priorities. Keys to good AI governance are: a national strategy and budget development, clear costing and implementation plans, privacy- and security-preserving regulations that put people first while balancing innovation, and the integration of human rights and a social contract. Likewise, regulators should continuously develop appropriate clinical and scientific validation pathways.

4. Design & processes
   Existing national health systems and clinical workflows are not always ready to integrate AI solutions. Relevant stakeholders may want to perform gap analyses for technical and user requirement specifications and collaborate broadly to ensure successful integration. Professional societies and academies, government agencies, and the private sector should collaborate to streamline the integration of AI into health systems. The localization of solutions into deployment contexts, performance measurements for outcomes-based validation, and human-centric design should also be prioritized to enable AI impact in healthcare.

5. Partnerships & stakeholders
   Countries should support effective, goal-oriented partnerships (e.g., multi-sectoral public-private partnerships, data collaboratives), coordinated prototyping, stakeholder engagement and participation in international working groups or task forces, and strong relationships with local partners and patient organizations. Perhaps most important of all, progress on the path to AI maturity requires the cultivation of high-level political support across ministries and the head of state.

6. Business models
   Innovative and sustainable business models should be a priority for countries and stakeholders across the healthcare, tech, and life sciences industries, and for the public sector. Countries should foster a diverse set of funding mechanisms guided by a long-term outlook for AI in health solutions. They can develop incentive mechanisms, experiment with novel pricing models and monetization strategies for assets, and advance the use of innovative financing mechanisms for social impact.

To create an AI-enabling environment, policymakers, donors, private companies, and other stakeholders should proactively invest in the six areas for AI maturity in health. The recommendations in the report's last chapter detail specific action points and recommendations for each stakeholder group, and can help navigate challenges, pursue best practices, and strengthen AI-enablers.

Policymakers, the private sector, international non-governmental organizations (INGOs), and other stakeholders have a wealth of experience and knowledge capital. To truly maximize the impact of AI on health, collaboration is essential to cultivate an AI-enabling environment that accelerates the achievement of Sustainable Development Goal 3 and health for all, and facilitates progress towards extending and improving people's lives and health.

Introduction

1

Background and purpose of the report

Introducing our digital health series

In 2016, the ITU-UNESCO Broadband Commission launched its first Working Group on Digital and AI in Health, resulting in a Call for Government Leadership and Intersectoral Collaboration for Digital Health. In 2018, it issued its second report, The Promise of Digital Health: Addressing Non-communicable Diseases to Accelerate Universal Health Coverage in LMICs, at the United Nations General Assembly in New York.

These reports were a call to action for governments, policymakers, and other stakeholders to build and scale digital solutions for accelerating universal health coverage in low- and middle-income countries.

They described market insights, case study examples, and lessons learned from digital health systems and solutions in LMICs and high-income countries (HICs). Each of the reports highlighted that if digital health is to deliver on its promise to create sustainable solutions that address priority health problems, governments and policymakers all have a major role to play and should start by leading and consolidating efforts for a genuine digital health ecosystem.

The 2020 report on AI in global health builds on its predecessors in three important ways

- **Underlining the importance of digital in health**
  Digital technologies can fundamentally change the cost-quality equation in healthcare. They can empower patients, health providers, governments, and other stakeholders with the information and tools they need to expand access and improve outcomes. AI solutions in healthcare can further advance this positive impact, and even fundamentally transform the practice of medicine and health. The foundations for successful and sustainable digital health solutions (quality data, connectivity, digital, etc.) are also the foundations for AI in health.
- **Reinforcing the opportunity for leapfrogging innovation**
  LMICs are often fertile ground for innovation due to relatively open regulatory environments, widespread mobile penetration, fewer legacy systems, and large unmet health needs. This combination provides opportunities to leapfrog and adopt newer solutions faster, both for digital health and for AI in health.
- **Broadband internet connectivity**
  Access to affordable mobile broadband and internet connectivity is a defining feature of the Broadband Commission's international development goals and is a prerequisite for many AI systems in health. While costs have dropped significantly, a large part of the world, including many least developed countries (LDCs), remains unconnected. After a decade of action, high-level advocacy, policy recommendations, numerous working groups with research reports and the incubation of several significant partnerships, the Broadband Commission is leading global advocacy for universal connectivity. Its goal is to ensure that broadband serves the broader social development that underpins the SDGs. The impact of COVID-19 on the entire global population demands that we build the world back better – including with broadband – to recover from this crisis and prepare against future shocks.

Ensuring universal equitable access requires emphasis on digital infrastructure and technologies both during the pandemic response and recovery phases, and during the resiliency-building efforts.

Health systems that have strongly invested in digital health will be the first to realize AI innovation.

At the same time, creating an enabling ecosystem for AI in health goes beyond leveraging digital technology. AI technologies are fundamentally different than digital health solutions and – besides access to quality data – require complementary or new approaches.

Our methodology

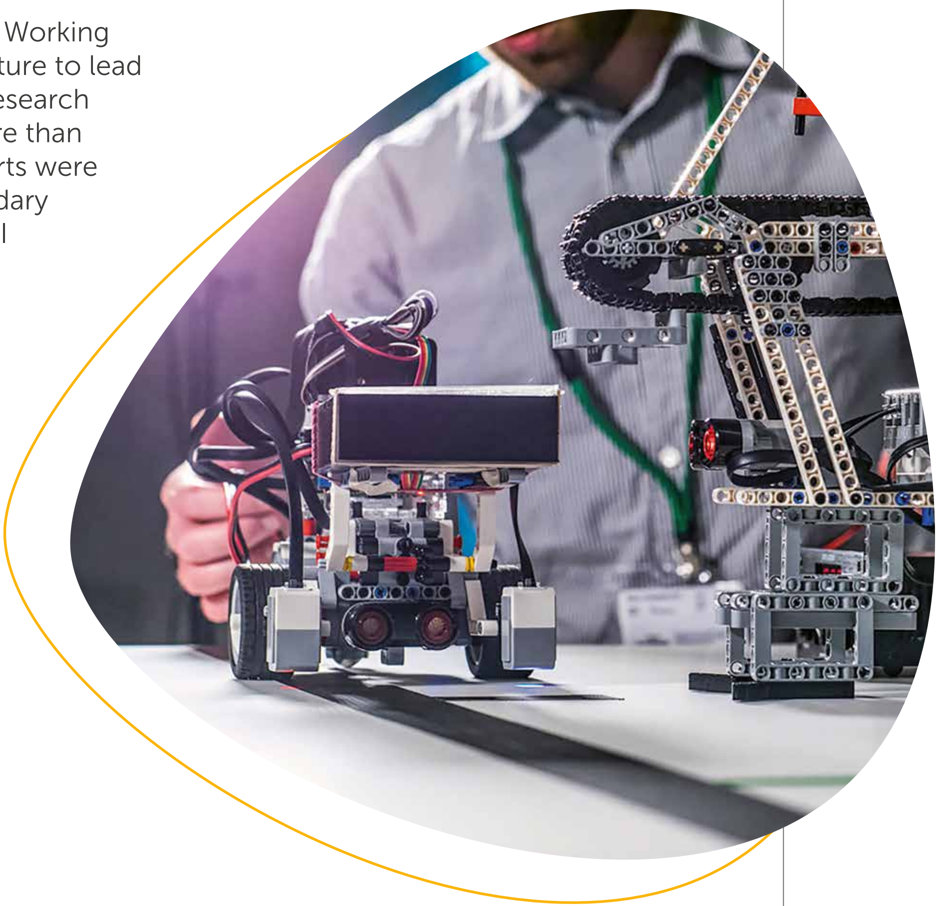
The Broadband Commission Working Group commissioned Accenture to lead the primary and secondary research for this report, for which more than 80 AI and global health experts were interviewed, over 200 secondary reports reviewed and 100+ AI solutions assessed.

Purpose of this report

The objective of the report is to generate knowledge on the challenges, lessons learned, and best practices for AI solutions in health, and to provide actionable recommendations for governments, policymakers, the private sector, non-governmental organizations, civil society, and other stakeholders within the digital and AI in health space.

Global action is crucial to build enabling environments for AI transformation. To support this, we have put forward a bold and pragmatic roadmap to AI maturity in health.

What are the big bets and key investments for impact? Our roadmap to AI maturity seeks to answer this important question.



2

What is Artificial Intelligence?

AI is disrupting everything, everywhere

Artificial Intelligence (AI) is everywhere, seeping into nearly all aspects of our daily lives. No longer are we at the cusp of a revolution – we are already in its midst, and we can expect that the current rate of change will only accelerate.

As AI becomes mainstream, so does its grip on society, culture, politics, and the economy. The unprecedented speed and scale of the digital transformation is fundamentally uprooting the global economy, shaking up the established order, and giving rise to new forces and players. The World Economic Forum (WEF) estimates that by 2022, 60% of the global Gross Domestic Product (GDP) will be digitized and that over the next decade, an estimated 70% of new value created in the economy will be based on digitally enabled platforms.[4] Research also shows that emerging digital ecosystems will account for more than USD 60 trillion in revenue by 2025, more than 30% of global corporate revenues.[5]

This high-speed transformation is driven by a confluence of forces that have propelled digital and AI into the global mainstay. These forces include the synergy between the falling cost of smart devices, Internet of Things (IoT), and wearables, the rise of emerging markets, and our ability to collect, use, and analyze massive amounts of machine-readable data about virtually everything.

Indeed, the digital footprints of personal, social, public, and business activities are increasing exponentially, with 90% of all of the world's data generated in the last two years alone.[6] Relevant health data includes medical images, electronic health records, multi-omics data (e.g., genomics, epigenomics, transcriptomics, proteomics, metabolomics, micro-biomics), public health data, vital signs data, staff and admission records, survey data, claims data, disease registries, clinical trial data, movement data, scientific literature, chemical data, language data, social media data, supply chain data (e.g., pharmacies, warehouses, etc.), environmental data, and meteorological data. The data comes from both new and old sources, and what we consider to be valuable data is rapidly changing. For example, we find value in data on actions we have always taken, yet previously never deemed valuable enough to record. Now, with the ability to digitize and draw inferences from old sources as new data points, we find new (and sometimes revolutionary) meaning in anything from the most trivial health processes to the most opaque systems. It is not just the quantity of data that is new, but also how data scientists and health professionals ascribe meaning and value to these data points and observations, and how these can be used to foster better patient outcomes and strengthen health systems.

> 90% of all of the world's data was generated in the last two years alone.

Digital and AI's undeniable footprint is also reshaping the geographic economy of the digital world. Consistently, one high income and one middle income country are leading the pack: the US and China. Together, these two countries account for 75% of the world market for public cloud computing, 75% of all patents related to blockchain, and most strikingly, 90% of the market capitalization of the world's 70 largest digital platforms.[7] Seven super platforms – Microsoft, Google, Alibaba, Amazon, Apple, Facebook, Tencent – account for two thirds of the total market value.[8]

AI is no longer confined to laboratory spaces. It has become a real-world application technology that is part of the fabric of modern life. It often functions quietly in the background, for instance when Google processes your search queries or suggests the best routes given the current traffic situation. AI is also at work when Amazon or Netflix provide recommendations, when you look for the best price on ridesharing apps like Uber and Lyft, or when your inbox filters spam or automatically categorize your emails. Put simply, AI is here, and here to stay. AI is reconfiguring societies, reshaping economies, and reshuffling the global pecking order. Wherever we are, these technologies are profoundly impacting ever more aspects of our lives and well-being.

But what actually is AI and what can it do?

Defining Artificial Intelligence

While AI's impact on the world is well-established, an exact definition of Artificial Intelligence has proven elusive – even though the field has existed for more than 70 years.

Microsoft's Eric Horvitz has described AI as "not really any single thing – it is a set of rich sub-disciplines and methods, vision, perception, speech and dialogue, decisions and planning, robotics and so on".[9] Crucially, Horvitz highlights that AI is ultimately about using these different disciplines and methods for a purpose: to "seek true solutions in delivering value to human beings and organizations".[10]

John McCarthy, considered to be the father of AI, described AI in 1955 as "the science of making machines do things that would require intelligence if done by people".[11] Our report uses McCarthy's inclusive definition and understands AI to be an umbrella term comprising several techniques (Figure 3).

Core concepts of AI

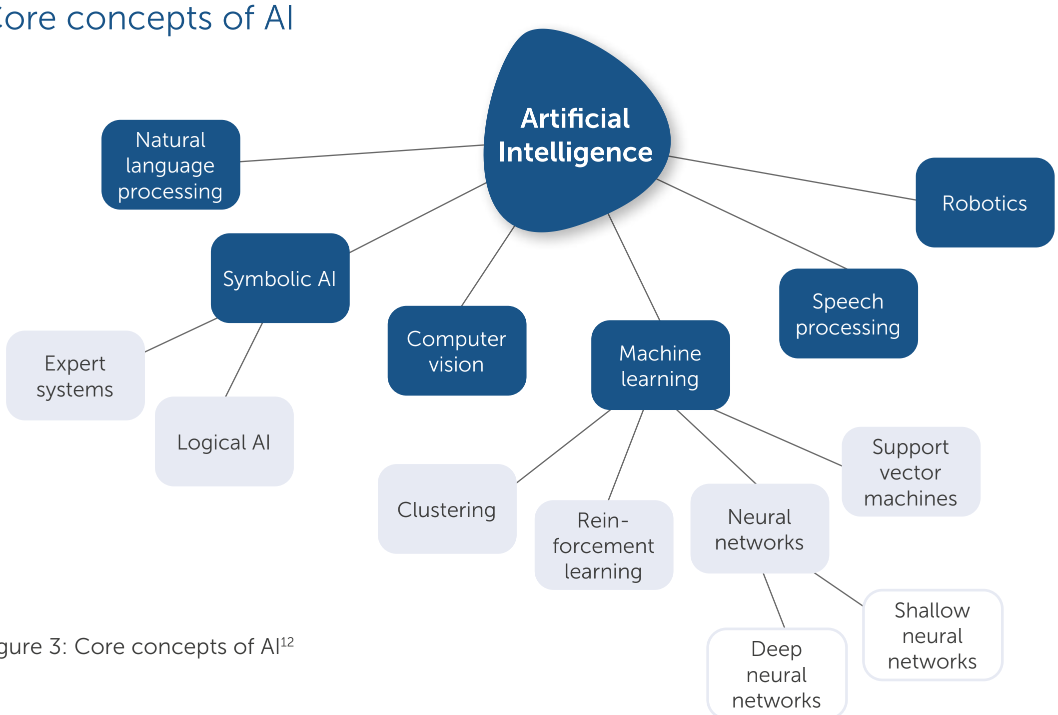


Figure 3: Core concepts of AI[12]

Related terms & definitions

Let's discuss two associated terms that have gained significant traction, machine learning and deep learning.

- **Machine learning** represents a fundamental paradigm shift in how computers can be used. Rather than humans manually programming machines with rules on what to do, machine learning is about feeding huge amounts of data into a system so that it can learn the rules by itself and produce new insights.[13] Put differently, machine learning gives computers the ability to learn without being explicitly programmed. Notably, machine learning is at the core of most of AI's current boom and the reason for most innovations – including in healthcare.
- **Deep learning** functions on the same basic principle as machine learning but can be more complex. Similar to how humans learn from experience, deep learning algorithms perform tasks automatically and repeatedly, each time tweaking their algorithms to improve the outcome (Figure 4).[14]

> AI is "the science of making machines do things that would require intelligence if done by people".
> – John McCarthy

Positioning of AI, machine learning, and deep learning on a timeline

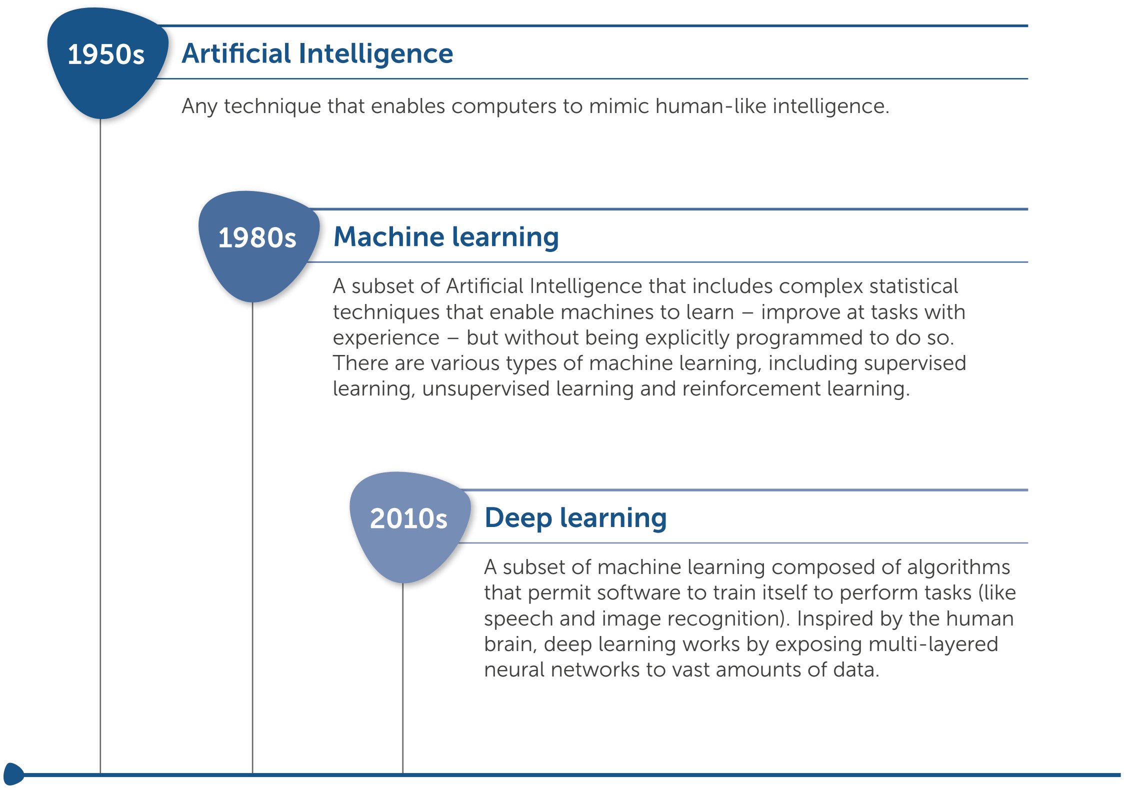


Figure 4: Positioning of AI, machine learning, and deep learning on a timeline[15]

What is the guiding purpose of Artificial Intelligence in health?

Artificial Intelligence has game-changing capabilities to revolutionize healthcare. In health, AI-powered solutions are participating in an increasing number of medical tasks traditionally performed by healthcare practitioners. Ranging from exercises commonly performed by highly skilled medical workers and those that fundamentally go beyond human cognition (e.g., processing big data to diagnose an illness) to routine tasks that can help reduce the workload of health workers, AI capabilities in healthcare stretch across a wide spectrum (Figure 5).

Illustrative AI in health capabilities

Prevention

- Personal monitoring and coaching can foster long and short-term health improvements (e.g., NCDs)
- Smartphones, wearables, home sensors can guide lifestyle (e.g., diet)
- Complications prevention (e.g., atrial fibrillation)

Intake and triage

- Reduce avoidable appointments and inappropriate referrals
- Triage reduces burden on health systems
- Reduce hospital-acquired infections via direct routing

Diagnosis & early detection

- Automate/refine diagnosis, enabling better doctor-patient relationships
- Bring expertise to remote locations
- Optimizing pathologist deployment
- Social determinants of health
- Precision medicine (e.g., oncology)
- Digital diagnostics for early detection

Treatment

- Robotic surgery (using robotics to perform complex procedures with more precision) and surgical support (e.g., real-time blood loss monitoring and supply)
- ICU monitoring and staff alert system
- Patient-drug matching
- Chatbot-based cognitive behavioral therapy

Health management

- Extend clinical resources beyond the walls of care delivery
- Long-term disease management (e.g., diabetes, dementia, epilepsy)
- Cost-effective, evidence-based coaching in low-skilled markets

R&D

- Biomarker and multi-omics for drug discovery and development
- Clinical trial associations between disease states, drug targets, and drugs
- Clinical trial design, trial start-up, trial conduct, and study close out

Population health

- Manage public health by integrating a variety of data for modeling of vectors and spread (e.g., COVID-19, malaria, dengue, Chagas disease)
- Risk scores
- Disease burden and cost predictions

Resource/process optimization

- Predicting surges in admission rates
- Staffing and scheduling
- Supply chain management
- Virtual assistants for physicians
- Patient involvement (participatory)
- Discovery of counterfeit drugs

Decision support

- Bring expertise to new environments, incl. last mile
- AI-guided tumor boards & guided P2P case knowledge exchange
- Link health observations with health knowledge to influence clinicians
- Improve care delivery by enhancing medical decisions with targeted clinical knowledge, patient information, and other health information

Figure 5: Illustrative AI in health capabilities

AI in health must support humans and improve health outcomes, not simply replace them in full automation.

Just like digital health, Artificial Intelligence is a means to an end

In considering the panorama of health applications, AI is not the only solution for health problems and cannot be a goal in and of itself. AI is an enabler and a means to achieve a health goal. Before deciding on an AI solution, a set of foundational questions should be asked and answered that consider the needs of the end-users (human-centric AI), the type of health and care system in which the solution needs to be integrated, and the socio-economic context in which it will be rolled out. The solution's development costs, deployment and maintenance costs, as well as its return on investment need to be considered; just like its ethical, security, and privacy considerations.

The purpose principle for AI in health

All AI in health applications should be guided by this purpose principle: AI in health must support humans and seek to improve health outcomes, not simply replace humans in full automation. Expressed as a formula, this means: **Humans + AI = Better outcomes**.

The AI purpose principle should guide us everywhere, always. From AI-powered disinfecting robots for hospitals fighting COVID-19, to AI-guided surgical interventions, AI solutions run the risk of overriding humans. It is important that when AI can substitute medical expertise, make health system processes more efficient, or return much-needed time to health workers, the workflows should have human-in-the-loop processes in place to identify errors and provide accountability.

Four common misconceptions about Artificial Intelligence

1 "AI, the magic bullet"

AI is not a magic bullet. There is no master robot that will outperform a human physician in all tasks. AI's accuracy depends on the quantity, quality, and representativeness of the data it learns from.

AI should never be advanced for technology's sake alone. There must always be a clearly identified positive health goal and clear evidence that AI is working in its narrowly-defined field. "AI fills gaps, and while humans are good at asking intelligent questions, commonsense reasoning, and value judgments, machines are much better at pattern detection, statistical reasoning, and large-scale mathematical reasoning. This is where AI is proving its value."[16] (AI for Good Global Summit 2017, ITU, Prof. Francesca Rossi)

2 "We need more data"

While data is indeed crucial for AI, and specifically for robust machine learning and deep learning, what is really needed is high-quality, structured data, available from open data repositories, and effective and privacy-preserving sharing frameworks. Data quality and data validation processes are central to mitigate potential risks associated with poor data – a view that is in line with the World Bank's forthcoming World Development Report 2021 on Data for Development, which provides a clear basis for thinking about data quality and governance along the full value chain (e.g., collection, storage, transformation, analysis, and implementation of data).[17] Similarly, metadata, data standards, and tools to understand key data characteristics (e.g., representativeness) are critical. One crucial attribute for quality data is interoperability. Today, too much data sits in silos across and beyond the health system, and policymakers as well as data scientists are struggling to pull this data together for public good. Even when data is available, the lack of a clear data architecture and data interoperability often results in inefficiencies, redundancies, patient dissatisfaction, and medical errors. The issue is not too little data, it is its low quality and lack of interoperability that make efficient use for the public good difficult.

3 "Health workers will be replaced by AI"

AI performs crucial health work, from image analysis to early disease detection and long-term health management. In most cases, AI does not and should not replace humans, but acts to enhance capabilities and can help health workers get back much-needed time to spend with their patients and families. Some tasks required from health professionals, such as analyzing scientific literature and presenting knowledge maps to action, can be performed faster and more accurately by machines. The amount of medical literature doubles every three years: if doctors were to stay abreast on new knowledge in the field every day, they would need to read 29 hours per day... and increasing.[18]

AI-produced knowledge maps/graphs allow physicians to digest information and take action more quickly. While AI should not replace health workers, the profession will undoubtedly evolve, and digital and AI skills will be central to healthcare. Physicians will see the upside of less administrative work and more patient-facing time.[19] Humans and machines can work together, improving patient outcomes and strengthening health systems – this should be both the present and the future of medicine. However, special attention is needed on this transition, as the new jobs created by AI are not necessarily created where old ones are being replaced. Context-sensitive policy timing can ensure that workforce disruption is accompanied with appropriate change management, social safety nets, and professional retraining opportunities.

COVID-19 has highlighted the need for robots to reduce human interactions in times of an infectious pandemic. While these technologies are often ready or near-ready, major workflow and regulatory obstacles can hinder their deployment. This report will discuss this point in detail.

4 “AI is the future of healthcare”

AI is a crucial part of healthcare's future, yet this future is already here – at least partly. AI is having real-world impact on patient lives, medical outcomes, and health systems. Yet, while core capabilities are already in place, AI adoption can be slow, especially in clinical settings.

Obstacles to adoption include clinical workflows, regulatory unpreparedness, and security and privacy concerns. To enable AI-driven solutions to have an impact on health, it is critical that they are thoughtfully and robustly integrated into the health and care systems. COVID-19 highlights how quick and targeted government action can enable the deployment of AI-driven solutions in health, as shown by the rapid success of these technologies used in some of the first countries hit by the pandemic.

3

Why AI in health matters

Looking ahead: the health needs of the next decade

Healthcare is big... and it's getting bigger

Global spending on healthcare will roughly double over the next 20 years from USD 10 trillion to USD 20 trillion by 2040. For most countries, healthcare is one of the largest and fastest growing sectors, frequently consuming over 10% of GDP in HICs, with many LMICs starting to follow suit as they cope with rapidly rising healthcare spending.

The world faces growing and unresolved global health challenges

Globally, healthcare systems are experiencing growing pressures: we just witnessed how COVID-19 propelled health onto the world's center stage, showing how increasing healthcare costs are compounded by the constant threat of emerging new diseases, and by changing demographics, increased longevity worldwide, burdens of disease, and rapid urbanization, which often leads to a widening of health inequalities.

In LMICs specifically, the global disease burden (GDB) risks compromising already fragile health systems. Today, crucial health needs already go largely unmet: for instance, Sub-Saharan Africa represents 12% of the global population but faces 25% of the world's GDB. Meanwhile, it only houses 3% of the world's health workers and spends only 1% of the world's total health expenditures.[20]

1. A shortage of health workers

The world is faced with a shortage of 16 million[21] trained health professionals, mostly in LMICs. This shortage is projected to increase to 18 million by 2030. The doctor-to-population ratio is unevenly spread around the world, with roughly half of the world's countries having less than 1 doctor for every 1 000 inhabitants. Senegal, Mozambique, Cameroon, Cambodia and Haiti are among the many countries with ratios of less than 0.2 doctors per 1 000 inhabitants, whereas the US and Canada have ratios around 2.5 and Germany and Switzerland around 4.2.

This shortage is particularly pronounced in rural settings. For example, Nigeria holds 0.14 physicians per 1 000 people in urban settings but only 0.01 in rural settings.

2. The dual burden of disease

Simultaneously, LMICs are facing a rising tsunami of chronic and noncommunicable diseases (cardiovascular diseases (CVD), cancer, diabetes, and chronic respiratory disease)[22] combined with the ongoing burden of infectious diseases. Many of these health problems are interconnected and require a concerted effort from national governments, local communities, private sector, and the international community.

3. Emerging threats

From outbreaks of vaccine-preventable diseases, increasingly drug-resistant pathogens, and growing rates of obesity and cancer, to the health impacts of environmental pollution and climate change, the top threats to global health are often more dangerous for LMICs than for HICs.[23]

COVID-19 and global pandemics

Health and humanitarian emergencies put tremendous strain on health systems and can disproportionately impact LMICs, which are often more vulnerable due to poverty and weakened health systems. Almost all countries were caught off guard by COVID-19 and ill-prepared for adequate prevention, disease detection, response, and recovery from the pandemic. Given this recent experience, few in the world still doubt that new, highly infectious diseases will emerge again, the question is simply when and how prepared health systems will be.

The rapid spread of COVID-19, its virulence, infectious risk, and mortality have left health systems scrambling, revealing significant health system weaknesses. The outbreak has crippled global economies and supply chains, and flooded misinformation into the public sphere. In LMICs, the impact of COVID-19 may further exacerbate existing inequalities and have a severe toll on human life due to already limited health system resources, a high prevalence of existing comorbidities that could potentially increase COVID-19 mortality (HIV, tuberculosis, malnutrition, diabetes, immunocompromised illnesses) and disruptions in food supply chains. The virus' economic impact will undoubtedly continue to depress economies in LMICs and around the world. The United Nations Conference on Trade and Development (UNCTAD) estimates that almost half of all jobs in Africa could be lost, and that income losses for LMICs could exceed USD 220 billion, and a USD 2.5 trillion rescue package may be needed for the world's emerging economies.[24]

Pandemic preparedness capacity, planning, execution, revision, and implementation of international, national, and subnational preparedness plans should be a top priority for governments and health systems.

The rise of noncommunicable diseases
NCDs, such as heart disease, diabetes, cancer, and respiratory diseases, cause more than 70% of global deaths, or 41 million casualties each year. The largest burden of these diseases lies in LMICs, where people with these morbidities exhibit them at earlier ages and face worse outcomes. Of all premature deaths from NCDs (i.e., between 30-69 years of age), 85% occur in LMICs.[25]

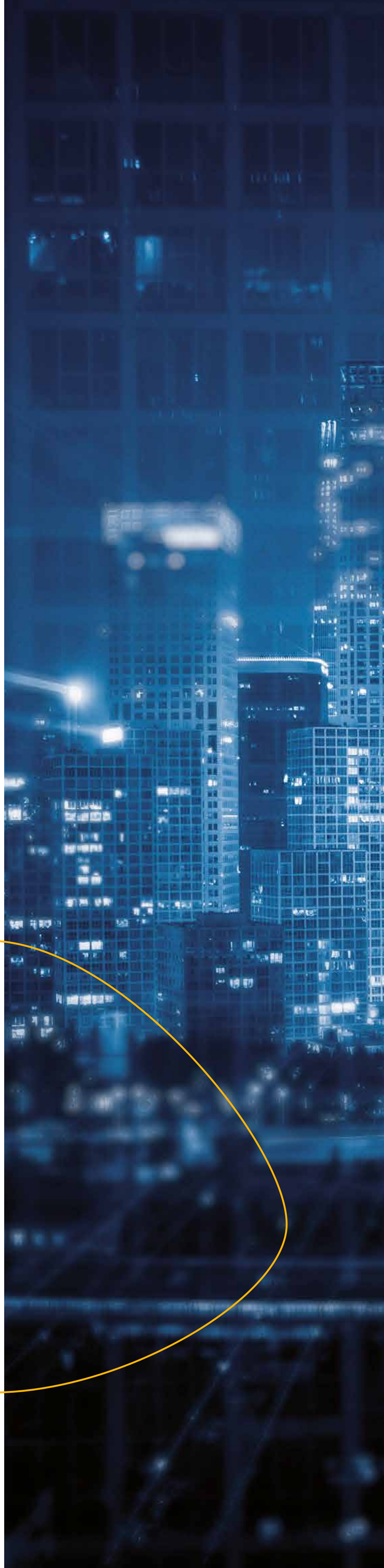
Climate change and air pollution
The World Health Organization (WHO) reports that nine out of ten people worldwide breathe polluted air every day. It states that "Microscopic pollutants in the air can penetrate respiratory and circulatory systems, damaging the lungs, heart and brain, killing 7 million people prematurely every year from diseases such as cancer, stroke, heart and lung disease".[26] About 90% of these deaths occur in LMICs, which have high volumes of emissions from industry, transport and agriculture, as well as high degrees of indoor air pollution due to the widespread use of dirty cookstoves and fossil fuels.

Antimicrobial resistance (AMR)
Much of the advances in life expectancy have been enabled by the development of antibiotics, antivirals, antifungals, and antimalarials. Yet, resistance to many of these medicines is rapidly increasing and the threat of AMR has the potential to cause once easily treatable infections such as pneumonia, tuberculosis, gonorrhea, and salmonellosis to become deadly again. If we do not identify and detect new therapeutic options, AMR will also seriously compromise medical procedures such as surgery and chemotherapy due to potential infections resulting from surgery or compromised immune systems. Every year, 6 million people die due to a lack of antibiotics while drug resistance causes more than 700 000 deaths yearly.

4. Underserved populations
   Over 734 million people live on less than USD 1.9 per day[27] and lack access to essential health and care services. Furthermore, over half of the world's population today lives in cities, with this figure projected to increase to 70% by 2050.[28]

5. Rapid urbanization
   Rapid urbanization can widen health inequities, and related exposure to unhealthy lifestyles increases the risk of heart and lung diseases, cancer, and diabetes.

6. Misinformation and disinformation
   Whether it is fake news, pseudoscience, censorship, or spin – misinformation and disinformation are responsible for cutting too many lives short.[29] Misinformation (incorrect information shared without malice intent) and disinformation (incorrect information shared with the intent to mislead) that is disseminated online or through mobile phones can have devastating impact and fuel epidemics – as we saw with Ebola and COVID-19. Beyond facilitating disease transmission, misinformation and disinformation spread mistrust and public antagonism towards health systems and health workers. For frontline health workers (and journalists), this can have catastrophic consequences such as derailing efforts to help prevent and curb outbreaks.[30]



The promise of AI in health

AI is at the forefront of digital technologies, gaining momentum as one of the greatest technology revolutions the world has seen.

AI is transforming the future of healthcare, and a panorama of AI solutions has already been unleashed. AI has the potential to radically reimagine and reconfigure the way health and care are delivered, and as the world doubles down on the AI revolution, LMICs should capture the opportunity to act now and avoid being left behind.

AI is breaking records

The size of the global AI health market is expected to reach more than USD 31 billion by 2025, growing at 41.5%.[31] AI health startups are topping all other industries in deal activity for AI and have raised USD 4.3 billion in funding since 2013.[32] The acceleration of investments is unprecedented and AI's impact on health systems and patient lives has taken the technology far beyond the hype.

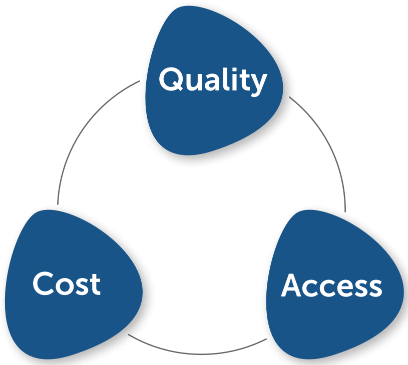
CEOs in life sciences and healthcare are equally doubling down on Artificial Intelligence.

- 94% of healthcare executives report that AI, blockchain, and other emerging technologies have accelerated the pace of innovation over the past three years.
- 41% of healthcare executives report that AI is the technology that will have the greatest impact on their organization over the next three years.
- 80% of companies report that AI is in production in their organization in some form. AI-driven results can be found across industries, and health care and delivery have already seen a significant impact.

AI is tackling the iron triangle in health and care

AI is demonstrating that it can create a positive impact greater than the sum of its individual parts. From a health systems perspective, AI is affecting three interlocking factors known as the Iron Triangle of Health:[33]

1. Reducing healthcare costs
2. Improving quality of care
3. Expanding access



Recent studies show that AI is boosting access and improving outcomes while also cutting costs significantly.[34] AI can re-engineer health systems from being reactive to proactive, predictive, and even preventive. For physicians and other health workers, clinical decision support systems are facilitating better decisions by using predictive or real-time analytics, thereby increasing quality of care and improving patient outcomes. AI is also helping doctors to approach disease and patient biology and pathology more comprehensively, laying the groundwork for precision medicine and precision public health. Finally, life sciences research and development (R&D) benefits from AI's ability to process tremendous amounts of multidimensional data to create new hypotheses, speed up drug discovery and drug repurposing processes, while cutting both costs and time to market through in silico methods.

Reimagining global health and care delivery

Beyond AI's ability to positively strengthen national health systems, its capabilities can also directly address today's growing global health challenges. For example, health worker shortages can be mitigated by AI-powered patient-facing symptom assessment tools, and decision support tools for health workers can bring medical expertise to the most crowded and most remote areas of the world.

AI also better enables value-based healthcare, with the potential to eliminate waste in the health system. The dual disease burden of infectious diseases and NCDs in LMICs is partly abated by integrated health management tools that help patients manage complex diseases, including through AI-enabled lifestyle coaching and real-time biomarker monitoring.

AI-powered targeted outreach and information campaigns are key to health education and its positive impact on population health.

In the fight against AMR, AI tools are helping physicians reduce over-prescription while empowering patients to increase adherence. Machine learning is also identifying new antibiotics through novel algorithms, bringing new drugs into clinical trials after years of neglect.

While supply chains are often partly to blame for vaccine shortages and wastage, AI-enabled predictive and real-time tools are ensuring that ever-more children and adults are receiving the vaccines they need.

In mental health, AI tools have proven their value in helping vulnerable and underserved populations, even in fragile and conflict-affected settings, most recently for Syrian refugees suffering from depression and other mental health challenges.

Finally, AI systems have proved able to assist across the entire spectrum of pandemic preparedness, response, and recovery during the COVID-19 outbreak. In short, there are few problems in health where AI does not have the potential or track record to provide new solutions.

The case for AI

The case for AI in health presented here is rooted in health and social benefits. The economic case is being built and still requires more research. Initial findings and forecasts give reason for strong optimism, and we are likely to substantiate these economic claims over the coming years. Yet, the positive health impacts and social benefits of AI are already clear and are transforming health and care delivery – enabling countries to reimagine health systems.

The global community has the opportunity to actively re-engineer health systems by reimagining how digital and AI capabilities can strengthen health and care delivery. This is particularly relevant for leaders in LMICs, given the potential to address the specific needs of diverse LMIC populations.

Healthcare AI total revenue by segment

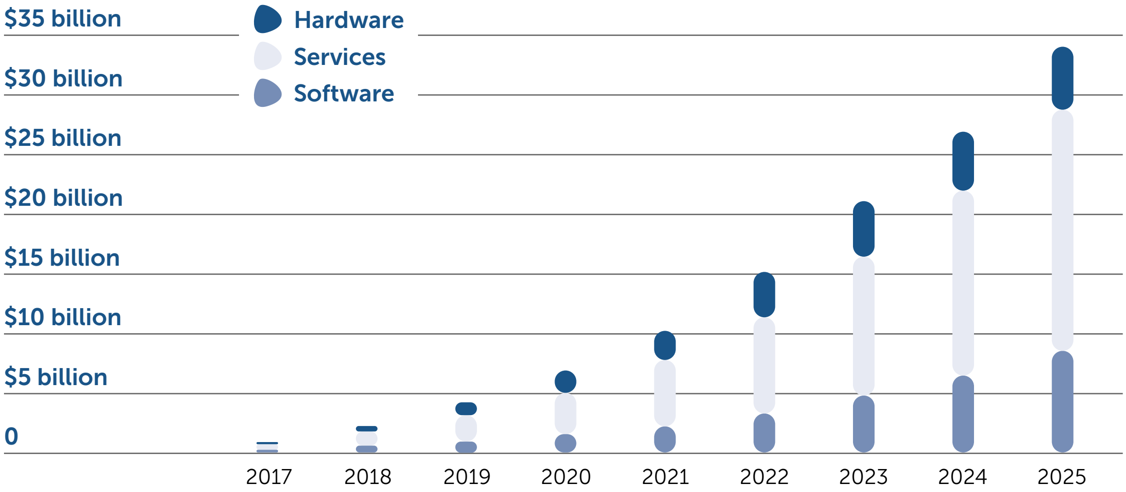


Figure 6: Healthcare AI total revenue by segment[35]

Creating real impact and savings for HCPs and governments: AI's exponential growth

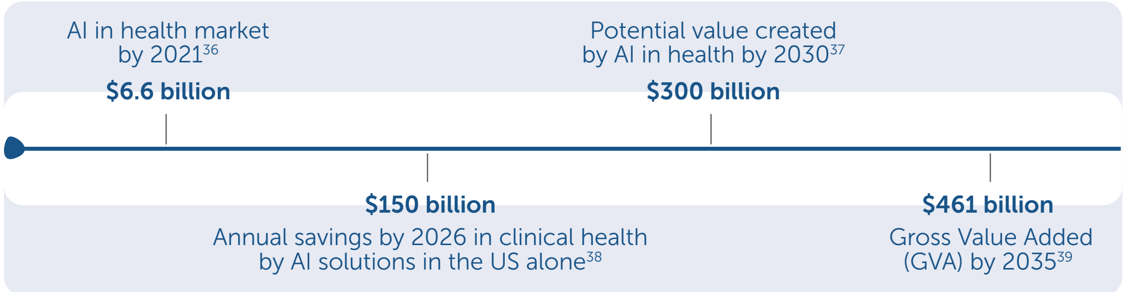


Figure 7: AI's exponential growth[36-39]

AI has moved beyond the hype: what business leaders think

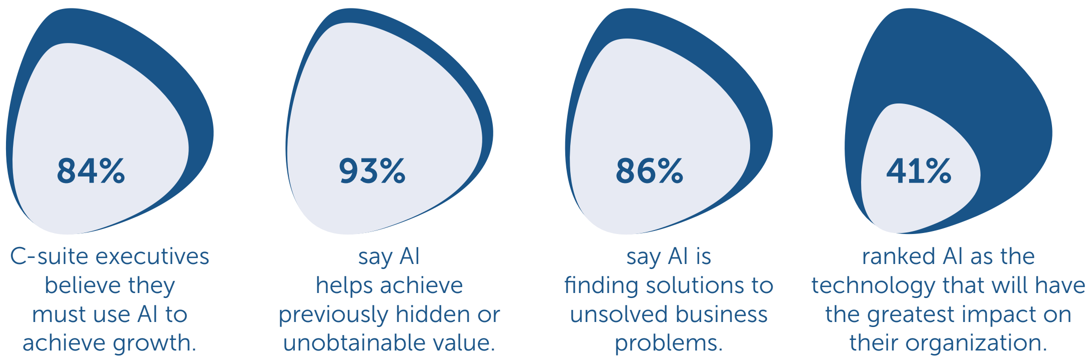


Figure 8: AI has moved beyond the hype: what business leaders think[40-41]

From hype to mainstream

Last year's buzzword technologies have real-life use cases that are changing the world.

AI is more than hype. It is real, it is achievable, and it is coming whether you are ready or not. AI is a true leapfrogging technology, set to transform health systems and save countless lives. Like all technological advancements, innovation will happen for all countries if they take the opportunity to start or continue investing in quality data and building the environment and infrastructure necessary to support this new era.[42]

The time to act is now

While LMICs may have the most to gain from AI's transformative potential, they may also have the most to lose.

In this technological revolution, who stands to benefit and who may lose out? As seen in past technology advancements, not everyone benefits equally.

For example, access to affordable mobile broadband and internet connectivity is a foundational enabler for AI applications to be deployed, as reflected in the Broadband Commission's international development goals. Most AI systems need at least some level of connectivity to work. While the costs for broadband and connectivity have dropped significantly, it is still prohibitively high in some LMICs, and especially in the LDCs, posing a crucial barrier to accessing digital and AI in health services.

The 2018 Broadband Commission report, The Promise of Digital Health, identified a number of actions for governments and network operators to accelerate connectivity, including public access points, stimulating competition and providing incentives for operators to enter less attractive markets (e.g., remote areas), promoting infrastructure sharing, and managing radio frequencies efficiently. Policymakers and other stakeholders should prioritize making connectivity available and affordable to all and identifying specific measures for underserved population segments. In the absence of targeted inclusion measures for such populations, they are likely to miss out on the benefits of AI in health.

The reality for many LDCs is that they lack the basic information and communications technology (ICT) and digital infrastructure needed for many AI applications to be scaled nationally. In addition, health systems suffer from significant technology underinvestment, and weak education systems and digital learning outcomes remain barriers to increasing AI skills and talent.

Another critical enabler for needs-driven AI in health is representative, unbiased data. If LMICs do not start investing in data and infrastructure, and if the global community does not prioritize fairness, there is a real risk that LMICs will be left behind in the AI in health revolution and that their needs – such as the shortage of health workers, dual disease burden, and emerging threats – are not met. At the same time, COVID-19 and the rise of chronic diseases are revealing that HIC governments also need to modernize their health systems and better integrate AI technologies. Concerted global action is urgently needed to address these realities and foster the equitable use of AI in health. The risk of inaction is so large that it is imperative for governments, policymakers, investors, and global health stakeholders to come together and co-create an ecosystem in which AI solutions can be developed, deployed, and continuously improved.

Inequalities in data representativeness, access, biases, and other disparities may be further exacerbated if not addressed when data strategies and architectures are defined and built. Similarly, algorithms and models are susceptible to unfair, unequal, and discriminatory practices resulting from the data they are trained on.[43] The non-neutrality of technology can create long-lasting disadvantages for LMICs that are not equal partners in co-defining which health priorities to address and co-developing appropriate solutions. Co-creation must be a guiding principle in both LMICs and HICs.

Other biases may come in the form of neglecting certain disease areas, a reliance on more costly technology, or intellectual property impediments.

The cost of inaction would affect virtually every aspect of life, society, and economy. It would result in an underutilization of AI's potential to address the world's growing health challenges, particularly in LMICs. It would also give away an economic opportunity to scale innovation and erode one's voice in helping to set standards, protections, and designs that are relevant for local populations.

Yet, LMICs can build on some key advantages. For example, LMICs feature fewer digital legacy systems than HICs. This may make it easier for LMICs to implement and scale innovation nationally and generate large, structured data from the beginning. Given AI's tremendous potential for helping to solve crucial health challenges and strengthening health systems in all settings, one thing is clear: the time to act is now.

> "Digital tools are ultimately accelerants… the biggest risk of digital health technologies is that, rather than accelerating movement towards equity, they instead accelerate movement toward disparity."
>
> – Skye Gilbert, Executive Director of Digital Square, PATH

4 Landscape review

Key opportunities

Around the world, global health stakeholders such as INGOs and International Organizations (IOs), national agencies, local hospitals and innovators are working to leverage AI technology for positive health impacts across various use cases. The previous chapter established that AI in health is happening now: there is a plethora of AI solutions that stretch across the entire spectrum and lifecycle of healthcare needs and applications. Recent report collaborations and academic studies have illustrated this, providing detailed information on impactful use cases for AI in health.

The past two years in particular saw the release of several important reports, such as:

- Artificial Intelligence in Global Health: Defining a Collective Path Forward (2018), by USAID, the Rockefeller Foundation, and the Bill & Melinda Gates Foundation
- Advancing AI in the NHS (2018), by the UK National Health Service (NHS)
- Ethical, Social, and Political Challenges of AI in Health (2018), by Future Advocacy and the Wellcome Trust
- Artificial Intelligence in Healthcare: the Hope, the Hype, the Promise, the Peril (2020), by the US National Academy of Medicine (NAM)

Combined, these reports catalogue more than 300 different real-world examples of AI in healthcare and identify over 40 (overlapping) AI in health use cases.

Use cases may be classified according to the primary users or stakeholders, such as patients and families, clinical care teams, population and public health program managers, healthcare business and administrative professionals, and R&D professionals.[44] Clinical decision support systems for health workers and care teams, frontline health worker virtual assistants, patient virtual health assistants, and AI-enabled population health solutions are just some examples.[45]

Alternatively, use cases may be defined by their function or purpose, e.g., personal health management, decision support, patient monitoring, triage, diagnosis, population health, clinical care pathways, treatment, health system management with supply chain and resource management, workflow process optimization, and medical and preclinical research.[46] This report defines its use cases by function and purpose, identifying five use cases for AI in health, which also build on previous reports.

A common misconception

A common misconception is that LMICs do not have the same potential as HICs to capitalize on and leverage AI in health and care. Our landscape analysis shows that AI in health is not beyond reach for LMICs and that impactful innovation is happening across the globe. LMICs may even have an advantage over HICs, as having fewer legacy systems in place can enable them to leapfrog AI solutions in health.

There are more real-world examples of AI in health than there is space to present in this report. As a result, we showcase only a selection of examples – each with the potential to positively impact health systems and health outcomes, and each being at a different stage of maturity and with varying degrees of impact. Solutions range from fully scaled platforms to pilots, and from tangible tools in the hands of patients to those that are purely software running in the background.

Our research: a selection of global examples for AI in health

Building on the report Artificial Intelligence in Global Health: Defining a Collective Path Forward (2018), by USAID, we complemented the example catalogue by specifically identifying real-world solutions from around the world. Starting with an inventory of more than 100 solutions, we shortlisted 44 for further analysis. Eleven examples were selected for presentation as in-depth case studies in this report (full list of AI-driven health solutions in appendix).

Evaluation criteria for the solution selection included three overarching areas, with diverse underlying criteria:

- **Innovation** (technological validation, scientific validation, data utilization, device(s) required)
- **Impact** (health outcomes, general impact, impact countries, scalability, lessons learned, stakeholder enablement)
- **Relevance** (LMICs relevance, LMIC vs. HIC balance, complexity and cost, human resources, mix of maturity levels)

It was particularly important that a fair number of the presented solutions were developed or co-created in LMICs to illustrate the innovation potential, insights, and best practices that work in these settings. We also believe that it is this diversity of innovations and solutions, coming from big industrial players, university research labs, and small-scale innovators that best captures the maturity of the AI in health landscape.

Top 5 use cases for AI in health

The report identifies five top use cases for how AI is applied in health to address global and public health priorities, strengthen health systems, and improve outcomes for patients. The current examples we identified mainly speak to health as a biomedical paradigm. However, as the systems paradigm of global health expands, AI tools also begin to address health by factoring in more complex, system-related features of health, such as the fact that most diseases are inseparable from poverty, inequalities, stigma, and social disadvantage and environmental and climate factors.[47] Some of the examples outlined have begun this journey, but AI in health use cases will undoubtedly expand as systems views on global health gain traction.

AI-powered population health tools, for example, are starting to look at non-traditional health data to quantify anything from climate and the environment to poverty and inequality levels. For example, innovators mine large meteorological and environmental databases, integrate all sorts of health and non-traditional health sensory data, and use remote satellite data to determine affluence through house/land plot sizes, access to public infrastructure, neighborhood characteristics, proximity to recreational areas and schools, and others. Patient-facing AI solutions are starting to incorporate culture and gender into their designs and analytical functions. Other solutions are finding innovative ways to lower the effects of disease-related stigma, such as, for example, for leprosy or Ebola. Symptom assessment tools for doctors and patients are bringing clinical decision support and medical expertise closer to where people live and help reduce the workload of overburdened health providers. The multifactorial data on which their analytical engines are based merge traditional health data with those from non-traditional sources to improve healthcare delivery across the entire health ecosystem. AI has the ability to fundamentally transform health systems from being reactive to becoming proactive, predictive, and even preventive.

The present report builds on the functional use cases identified in the report, Ethical, social, and political challenges of AI in health, by the Wellcome Trust and Future Advocacy (2018), aiming to deepen the current understanding of AI use cases in health and help drive concerted efforts in the field along with other ongoing initiatives.

Use cases inspired by ethical, social, and political challenges of AI in health

1 Population health

AI solutions to monitor and assess the health of a human population in order to select and target public health interventions based on AI-enabled predictive analytics.

2 Preclinical research & clinical trials

AI technologies, especially neural networks and deep learning, to assist drug discovery and design, use omics technologies for personalized therapy, and deploy AI tools for clinical trial design and execution.

3 Clinical care pathways

AI-enabled clinical care pathways are novel technologies that fit AI-based solutions into existing and new clinical workflows, such as for diagnostic or prognosis purposes.

4 Patient-facing solutions

AI-enabled patient-facing solutions that use AI to interact directly with patients and other users, including the delivery of non-clinical therapies, chatbots, personalized health advice, interventions without risk for harm, and information provision.

5 Optimization of health operations

AI-enabled optimization of health operations refers to the use of AI to optimize back-end processes in health systems such as procurement, logistics, staff scheduling, emergency service dispatch management, automated completion and analysis of medical notes and other documents, patient experience analyses, and many more. Optimization of health operations is a transversal use case throughout health and care, and can touch the back-end optimization of the previous four use cases as well as in its own right.

Figure 9: Use cases inspired by ethical, social, and political challenges of AI in health[48]

COVID-19: AI's impact on an unfolding global health pandemic

The COVID-19 health and humanitarian emergency presents a serious threat to people across the planet. It has brought global economies to a halt and disrupted almost all aspects of life. According to the United Nations, the Coronavirus outbreak has engulfed LMICs already vulnerable to poverty, food/water shortages, and weakened health systems.

The COVID-19 outbreak has catalyzed a cascade of AI innovation across diverse application areas – from pandemic modeling and prediction to containment and early response, as well as R&D and vaccine development. Ever since the first reports emerged of a major infectious disease outbreak in Wuhan, China, the world began to race to leverage the power of AI and big data models. AI is being used to forecast COVID-19 spread, predict infection rates, guide emergency response, perform lung image analyses, drive quarantine monitoring, and, ultimately, find an effective vaccine and cure.

Flagging the threat first

On December 30, 2019, AI platform BlueDot picked up on a cluster of unusual pneumonia cases happening around a market in Wuhan, China, and flagged it.[49] It had spotted what would come to be known as COVID-19, nine days before the WHO released its statement alerting governments and people to the emergence of a novel coronavirus. BlueDot uses natural language processing (NLP) and machine learning to sort data from hundreds of thousands of sources, including statements from official public health organizations, digital media, global airline ticketing data, and climate data – all in 65 languages.[50]

Modeling the disease's path

Tencent is a Chinese multinational conglomerate and one of the world's largest video game/social media companies. It champions advancing research on computer vision for medical diagnosis. Using data from its app WeChat, Tencent was able to model the virus and accurately project how travel restrictions from Wuhan could slow the virus spread by almost three days.[51] It also correctly predicted COVID-19 would spread first to Bangkok, Seoul, Taipei, and Tokyo, in the days following its initial appearance.[52]

Preventing the spread

Baidu, another large tech company in China, is using AI infrared technology to measure the body temperature of railway and airport passengers in Beijing and Shenzhen. Its thermometers detect temperatures within a range of 0.05 degrees Celsius, and alert public health officials of any anomalies.

South Korean in-vitro diagnostics company Seegene has developed an AI-based testing kit and platform that speeds up diagnosis by two weeks. Seegene's test kit was approved for emergency use by the Korea Center for Disease Control and Prevention. The test identifies the target genes of COVID-19 in a single tube and automatically analyses and interprets data in real-time.

Another South Korean company, Vuno, has developed an AI deep learning tool that examines lung x-rays and CT scans within three seconds. It was swiftly adopted into clinical workflows at Korean hospitals to assist radiologists in screening and diagnosing COVID-19.

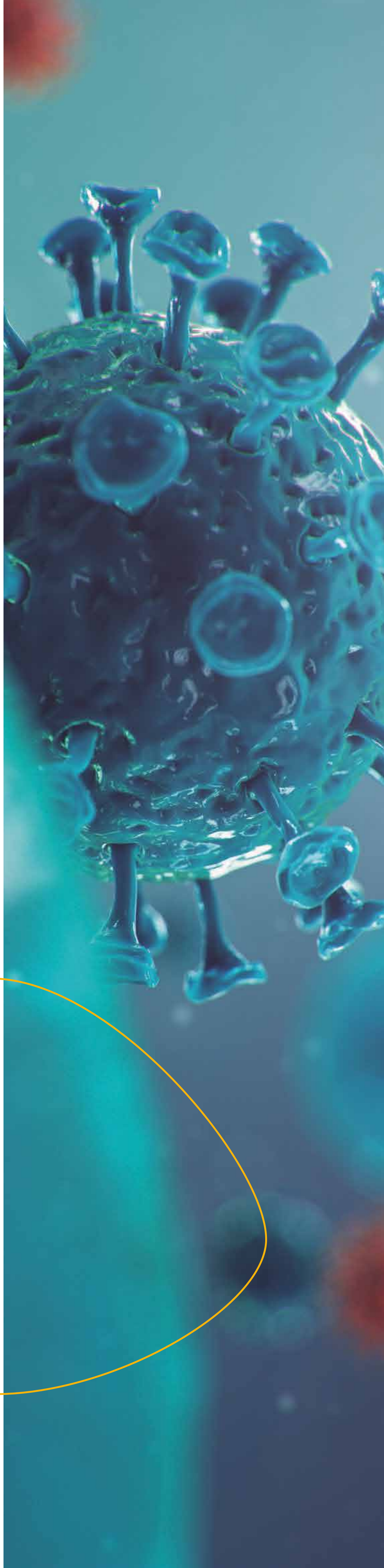
A three-year collaboration between the Bill & Melinda Gates Foundation and Korea Telecom (KT) aims to deliver an AI-powered global epidemic response ecosystem platform. Functionality includes improved early diagnostic capabilities and prediction of viral infection spread based on mobile data and human mobility patterns – ultimately determining the direction of the spread and forecasts of future regional outbreaks.[53]

Advancing research

While no vaccine has yet been identified, companies like Insilico Medicine (USA) and BenevolentAI (UK), as well as public-private partnerships such as the Innovative Medicines Initiative (IMI), are using machine learning to identify thousands of molecules that might bind to the virus and inhibit its function.

- Insilico Medicine is using 28 different machine learning models to design new small molecules that might inhibit COVID-19's functioning.[54]
- BenevolentAI is using NLP to analyze a large repository of medical information and scientific literature to identify approved drugs that might block the viral replication process. So far, the AI system has identified six compounds that effectively block a cellular pathway thought to be critical to COVID-19 replication.

AI is already a vital instrument for every country battling this deadly pandemic. As the virus moves to particularly vulnerable LMICs, the race for AI innovation could tilt the balance between life and death for hundreds of thousands of people.



1 AI-enabled population health

AI-enabled predictive analytics monitor and assess the health of a human population to select and target public health interventions.[55]

AIME
Artificial Intelligence for Medical Epidemiology

What is AI-enabled population health?

Solutions used to gain insights into population health include identifying epidemics, monitoring the spread and burden of disease, disease or population management, risk management and risk stratification, and predictive analytics to project future spread of diseases or major outbreaks. AI-enabled population health solutions usually focus on three main goals: 1) improve population-wide health outcomes, 2) influence broader health determinants by providing key insights or incentivizing behavior, and 3) provide advanced analytics to inform policies, strategies, and interventions that reduce health burdens and inequalities amongst population groups.

Often, the power of AI-enabled population health derives from its ability to build on a variety of very large health, social determinant, IoT, environmental, and ecological datasets. By combining diverse data about relevant data points and benefiting from relatively low regulatory restrictions, AI-enabled population health is able to use relatively accessible or collectible (and cheap) data to create large population-wide impacts. Processing big data on diverse determinants of health has another major innovation upside. Health researchers have long posited that only a small fraction of overall health can be attributed to healthcare – with the advance of AI, data scientists and AI researchers are using real-world data (RWD) on social, behavioral, environmental, and genetic determinants to change how health systems and policymakers approach health policy-making and priorities.

Innovations you should know

Magic Box (UNICEF)
Using big data and machine learning to fight epidemics

Magic Box, built by UNICEF's Office of Innovation, is an AI platform that aggregates real-time data from both public sources and private sector partners to auto-generate actionable insights. Using advanced machine learning, Magic Box provides decision-makers and frontline health workers with disease spread predictions, key response measures, and population level insights. Thanks to its success, Magic Box has benefited from further partnerships with Amadeus, Google, IBM, Vodafone, and Telefónica.

AIME (AIME – Artificial Intelligence for Medical Epidemiology)
One of the world's first integrated country-wide AI platform to predict dengue outbreaks

AIME, which has its origins as a pilot project during the Zika epidemic in Brazil, is an AI solution using big data to predict mosquito-borne disease outbreaks 30 days in advance, with an accuracy of over 80%. In addition, AIME includes a smart management tool that automatically advises government actors on the interventions most likely to be effective at controlling an outbreak in a particular area. The platform also auto-generates a prioritization action index when multiple outbreaks occur simultaneously, ensuring the right supplies of insecticide, larvicide, and human resources can be deployed where they matter most.

With the emergence of the COVID-19 pandemic, AIME has repurposed its machine learning analytical platform to estimate the Inherent Risk of Contagion (IRC) which is used to guide active case detection and contact tracing for COVID-19. The platform is currently being used in Brazil, the Philippines, and Malaysia.

Real-world AI-solutions for population health

The COVID-19 spotlight highlights examples of AI-enabled population health in the real-world, ranging from AI-powered infrared body temperature thermometers in public places, to modeling transmission and predicting disease spread, and geolocating COVID-19 hotspots.

Long before COVID-19, AI had been used to mine mobile and public data to model the spread of cholera in Haiti in 2010, and dengue fever in Pakistan in 2013.[56] These capabilities now help predict and manage other infectious diseases, such as Zika, malaria, yellow fever, and seasonal influenza. In 2013, Singapore introduced its AI predictive platform for dengue control, producing disease control benefits immediately upon inception.[57] Malaysia followed in 2016 by deploying an integrated AI platform to predict dengue outbreaks and provide tailored, context-specific mediation strategies (spotlight AIME on page 43). Epidemic preparedness and management tools are crucial for preventive efforts and allow health systems to deploy their limited human resources in the most effective manner, e.g., by providing health workers with critical intelligence on hotspots, best practices and real-time guidelines, and communication strategies for affected areas. Effective communication such as targeted public service campaigns help fight the spread of misinformation and disinformation. Taken together, these capabilities reduce the stress on health systems and their limited human resources while lowering rates of infectious disease spread.

AI solutions have proven effective in reducing NCDs, providing platforms for risk stratification, risk subgrouping, early detection, long-term disease management, and providing crucial decision-support to clinicians. Solutions such as Casalud's NCD management tool by the Carlos Slim Foundation have also made NCD early detection and management mobile, taking testing kits to both high density areas (e.g., Mexico City's subway) and remote locations. AI-enabled NCD platforms are providing health systems with vital data and new insights on effective counter measures, including much-needed data on vulnerable and low-income populations. These insights enable governments to better understand the multifactorial determinants of health, setting the foundation for targeted policies and precision public health.

Minimizing progression of chronic diseases, and real-time elderly care monitoring, are some other examples for AI in the field of NCDs. A recent clinical decision support system called CHICA (Child Health Improvement through Computer Automation) has been able to predict new risk factors for childhood obesity (with 85% accuracy and 89% sensitivity).[58] Analyzing specific epidemiological risk factors is crucial to building capabilities for targeted health policy, helping to address the rising burden of disease.

AI is also used in health systems to better allocate limited public resources and increase return on investment, e.g., by targeting public service information campaigns to the most affected areas. AI-enabled information management capabilities provide important support for tackling misinformation and disinformation in health and allow fewer health workers to have greater impact, which is especially relevant when there is a shortage of health workers.

For emergency and pandemic preparedness, AI's big data analytics makes it possible to process a previously unthinkable amount of data to optimize response, prevention, and recovery.

This is done by taking into account factors such as hospital staffing and ICU beds, environmental and socio-economic factors, landscape features, and precision public health models.

Yet, there are challenges with AI-enabled population health solutions, too. The US NAM points out that in the era of exponential data growth in the healthcare ecosystem, AI algorithms must be trained on population-representative data to achieve performance levels necessary for scalable success.[59] A lack of efficient data integration and merging creates data silos. Frameworks and standards that help aggregate and achieve sufficient data interoperability for AI exist (e.g., Fast Healthcare Interoperability Resources (FHIR)), yet they require wider adoption to create an ecosystem in which AI in health solutions can be systematically developed, deployed, and continuously improved.

AI solutions focused on mosquito-borne diseases are also creating real-world impact. Microsoft's Premonition is an AI system using machine learning, robotics, and genomics to monitor the environment and detect disease threats early. A breadbox-sized robotics device is designed to "adaptively lure, identify, and selectively capture targeted mosquito species in the environment, continuously monitoring the environment for important types of insects [...] that transmit pathogens".[60] Premonition's robotic device runs live analyses on all the species and viruses in the environment, spotting new transmission patterns as early as possible.

Why is this important? About 60-75% of emerging infectious disease are caused by pathogens that jump from animals to people, with viruses like Zika, dengue, and West Nile moving between humans, animals, and mosquitoes in complex cycles.[61] Solutions like Premonition are thus the basis for early warning systems. Early warning, in turn, is the key to preventive measures and allows health systems to prioritize and target limited prevention funding and human resources.

Another example is the Singaporean government's AI Dengue Prediction Program. Accurate predictions 12 weeks ahead of outbreaks allow the government to deploy vector-control operations and other counter measures, e.g., "preparing hospital beds and diagnostic kits, deploying a staff of about 800 for on-the-ground mosquito control and community outreach, and launching a multi-platform campaign to encourage residents to eliminate any stagnant water and apply mosquito repellent," as declared by Lee-Ching Ng, Director of the Environmental Health Institute, under Singapore's National Environment Agency.[62] The platform has been successful since its inception in 2013, accurately predicting outbreaks and enabling the government to initiate counter measures. AI is also at the forefront of the government's targeted dengue campaigns, called "Do the Mozzie Wipeout Campaigns", which automatically plan community activities to check for and eliminate stagnant water in homes. The spotlights on Magic Box and AIME show two such solutions in more detail.

Policymakers and other relevant stakeholders must lead the way. They should establish policy, regulatory, and legislative mechanisms for fair, representative, and inclusive data collection and aggregation, as well as "transparency around how patient health data may be best utilized to balance financial incentives and the public good".[63] Given the multifactorial nature of health and the urgency to address health needs with a systemic approach, AI solutions in health are beginning to consider a wider range of health determinants, and include data on climate, air quality, income, living conditions, neighborhood characteristics, proximity to recreational areas, and many others. The hope is that new insights will lead to solutions that better address the multifactorial determinants of health and can be translated into more effective and targeted public health actions.

Using big data and machine learning to fight epidemics

Magic Box by UNICEF's Office of Innovation

Major disease outbreaks – from the Spanish flu in 1918 to the COVID-19 crisis – have shown in alarming fashion that health systems can quickly become overburdened by rapidly unfolding health epidemics. Besides the current COVID-19 pandemic, many other emergencies have plagued the world for a long time. Zika, dengue, yellow fever, and Ebola have all been declared as significant public health threats in over 100 countries by the WHO.[64] The yearly death toll of malaria alone hovers around 430 000 deaths while the worldwide incidence of dengue has risen 30-fold over the past 30 years. More than half of the world's population lives in areas where mosquitos transmitting Zika, chikungunya, dengue, and yellow fever are present.[65] Dengue fever alone has an economic impact of USD 9–40 billion annually and an average annual cost of more than USD 3 billion.[66] To curb the social and economic burden of these infections, targeted population health measures are vital to prevent and respond to outbreaks. Predicting them and having actionable information in the form of AI-driven models is now possible, and can allow health systems to allocate or re-organize their resources in a timely fashion, alert health workers, launch public health campaigns, and respond better and faster to emergencies.[67] Digital and AI technologies offer a pathway to bringing such actionable insights to decision-makers.

Magic Box, built by UNICEF's Office of Innovation, is a big data program developed in response to the 2014 Ebola crisis in West Africa. It uses real-time data to inform decision-making in emergency situations such as epidemics. Magic Box's AI uses real-time aggregated data from both public sources and private sector partners to generate actionable insights and a better understanding of complex and changing situations. Magic Box builds on machine learning, network analysis and complex systems research to provide decision-makers and relevant frontline health workers with disease spread predictions, key counter measures, and population level insights. It considers complex and complementary features like precipitation and weather data, high-resolution population estimates, air travel data, aggregated and anonymized mobility data from mobile phone records, geotagged social media traces, temperature data, and case data from WHO reports to build better models and understanding of epidemics and other humanitarian and development contexts affecting children. Thanks to its success, Magic Box has benefited from further partnerships with Amadeus, Google, IBM, Vodafone and Telefónica, further increasing its capabilities and allowing its application to other mosquito-borne diseases like Zika, dengue, and yellow fever, new Ebola outbreaks and the current COVID-19 crisis.

The AI technology in Magic Box is yielding impressive results, too. In a recent study, it correctly recalled 100% of the yellow fever cases reported in the Americas between 2000 and 2018 with 95% precision. All false positives, or areas incorrectly predicted as candidates for an outbreak, were areas that bordered actual outbreaks – making them likely candidates for new yellow fever cases.[68] During the early stages of the current COVID-19 crisis, Magic Box was able to produce risk maps that correctly predicted which African countries were more likely to see imported cases. Currently, Magic Box data analysis is allowing for better monitoring and understanding of the effects of physical distancing policies implemented globally to slow down COVID-19, with the aim to better inform on inequalities, applicability and socioeconomic impacts – especially in low-income and vulnerable communities.

One of the world's first integrated country-wide AI platforms to predict dengue outbreaks

AIME (Artificial Intelligence for Medical Epidemiology) by AIME

The WHO estimates that 390 million dengue virus infections occur every year, of which 96 million manifest clinically. This represents a 30-fold increase over the past 30 years, and results in 20 000–25 000 deaths each year – the majority of which are children.[69] Despite an infection risk in more than 129 countries, a dramatic 70% of the actual dengue burden occurs in Asia.[70] The Magic Box spotlight above revealed the tremendous economic impact of dengue, up to USD 40 billion annually, a larger economic footprint than diseases like cholera or Chagas.[71] Extensive community prevention efforts have been central to prevent outbreaks, but are often costly and cumbersome to scale.

Originally a pilot project that aimed to predict Zika outbreaks during the Brazil 2016 Olympics, AIME quickly matured into an AI platform that now assists public health professionals in Malaysia, Brazil, and the Philippines to tackle multiple mosquito-borne diseases including dengue, Zika, and chikungunya. The solution goes far beyond prediction, however. AIME starts simple: in the case of dengue, for instance, an outbreak occurs when two conditions are met: in a span of 14 days, two or more dengue cases are reported and the distance between these is ≤ 400m.[72] To go beyond a simple alert, AIME continuously pulls multidimensional data from over 90 public databases and adjusts for 276 variables that influence the spread of mosquito-borne diseases. Data include an auto-import of e-Dengue notifications from health centers, weather variability measures, population density, land use indicators, remote sensing of local terrain and roofing types of houses, social media sources, vector data, and water accumulation hotspots.[73] Running vector analytics and machine learning, AIME uses all this data to predict outbreaks 30 days in advance with an accuracy of over 80%, while also offering an outbreak management tool that features maps, models, and tables with necessary actions. The platform automatically advises government actors (e.g., Ministry of Health) on the interventions likely to be most effective for that specific outbreak, proposing actions with detailed maps for fogging, spraying, water removal, and other counter measures. If multiple outbreaks occur simultaneously, AIME auto-generates a prioritization index across the affected regions, so that correct supplies of insecticide, larvicide, and adequate human resources can be deployed to where it matters most.

The main outcome of AIME is the prevention of and early response to mosquito-borne disease outbreaks. Yet, the solution also shows real cost-savings for governments and health organizations via its prioritization index, with actionable recommendations, improved funding, and its resource allocation tool (from procurement of insecticides to work scheduling for health workers, and hospital bed logistics).[74] While difficult to quantify, one study for Malaysia's Penang district showed real cost reductions of USD > 500 000 for the single district.[75] Finally, countries have traditionally spent significant time and money on mass dengue prevention campaigns, often without knowing exactly where the disease was most likely to affect a population. AIME-generated maps provide health workers with real-time, interactive information to target prevention measures and ultimately save lives.

2 AI-enabled preclinical research & clinical trials

AI technologies, especially neural networks and deep learning, assist drug discovery and design, use omics technologies for personalized therapy and deploy AI tools for clinical trial design and execution.

What are AI-enabled preclinical research & clinical trials?

AI's impact on preclinical research is driven by at least two motivations: its ability to process and make sense of unimaginable amounts of complex and often unstructured data from a variety of sources (e.g., patient-level data, chemical and biological libraries, molecular image data, biomedical data, and scientific literature repositories), and its ability to cut both costs and time to market for drug candidates.

Clinical trials have traditionally been organized in a linear and sequential way through examining efficacy and safety of new medicines in fixed phases of randomized controlled trials (RCTs) to test drugs on large populations. However, AI solutions are uprooting this design. Using RWD and AI is speeding up our understanding of diseases, which helps identify suitable patients and leads to new clinical study design processes. These include automatic feasibility testing, smart RWD-enabled patient recruitment, cohort representativeness, real-time monitoring of drug performance (e.g., pharmacovigilance, efficacy), disease progression, and quality of life.

Innovations you should know

Innovative Medicines Initiative (IMI)
Advanced AI for basic research, drug discovery and development

The IMI's MELLODDY and Harmony programs leverage AI advances to bring effective drugs from bench-to-bedside. Harmony harnesses and mines big data to accelerate the development of improved therapeutic options for patients. MELLODDY, on the other hand, aims to leverage the world's largest collection of small molecules with known biochemical or cellular activity to enable more accurate predictive models and increase efficiencies in drug discovery. Taken together, the pharmaceutical industry is embracing virtualization through machine learning to help medical teams better define clinical endpoints and advance drug discovery and development by identifying the most promising candidate molecules.

Benevolent AI

BenevolentAI (BenevolentAI)
Deep learning for new drugs

BenevolentAI uses an array of AI technologies in precision medicine to better understand the underlying mechanisms of diseases and develop personalized treatments. AI creates a new level of understanding for disease mechanisms at the earliest stages while also identifying the patient subgroups most likely to respond positively to treatment.

BenevolentAI is now taking AI into the fight against COVID-19 by tuning its machine learning to consider known chemical properties and biological processes of the virus to identify potential drugs.

Real-world solutions of AI-enabled preclinical research and clinical trials

Due to the tremendous complexities of drug development and clinical trials, there are fewer examples of AI-enabled solutions in this area compared to other use cases.

The COVID-19 spotlight has shown how leading companies and startups are using deep learning to identify and design molecules that may bind to the SARS-COV-2 virus to inhibit its function, or to identify existing approved drugs that may block viral replication, by building on data from the scientific literature extracted with NLP.

Notably, given the global risk of COVID-19 and recognizing the importance of data for AI models, publishers, life sciences companies, and other data owners have opened parts of their huge non-patient data libraries to streamline vital AI-based R&D efforts. Open science has been central to responding to the pandemic and has laid the foundation for many groundbreaking AI developments in the COVID-19 drug development and repurposing response.

Beyond COVID-19, AI has proven its ability to beat animal toxicity testing for drug safety. With over 100 000 chemicals in consumer products, researchers traditionally test chemicals' toxicity in animals. At the extreme, "a pesticide undergoes about 30 animal tests, costing around USD 20 million, and consuming more than 10 000 mice, rats, rabbits, and dogs over five years".[76] Using AI, a solution built by Johns Hopkins University mined existing data on chemical toxicity and produced new insights. As similar chemicals have similar properties, the solution builds a map of the chemical universe where similar chemicals are put close to each other and dissimilar ones further apart.[77] Then, Thomas Hartung, Professor at Johns Hopkins University explains, "the model can place new chemicals on the map, assess what is known about their neighbors, and from that information surmise their potentially harmful health and environmental effects".[78] What might casually sound like guesswork, in reality the software predicted the toxicity outcomes correctly 87% of the time – exceeding the 70% probability of animal tests to find a toxic substance again in a repeat animal test.[79] Compared to the USD 20 million costs of developing a pesticide, having a supercomputer create the map at a cost of USD 5 000 seems like a rather good deal – thanks to the power of AI.

AI is also used to repurpose drugs, a much cheaper process than starting drug development from scratch. The COVID-19 spotlight and the spotlights on BenevolentAI and IMI provide various examples of leading companies using AI to this end.

Atomwise, the San Francisco based deep learning biotech company, has used a similar approach to identify potential compounds for treating Ebola and multiple sclerosis (MS). The solution is based on convolutional neural networks – the same AI technology that identifies faces in a crowd and enables self-driving cars – that uses statistics to extract insights from millions of experimental affinity measurements and thousands of protein structures to predict the binding of small molecules to proteins.[80] This makes it possible for chemists to pursue quick and accurate discovery, and lead optimization and toxicity predictions with unparalleled power and speed.

AI-based predictive solutions are also used to identify molecules that can cross the blood-brain barrier, with untold potential for neurological diseases. In fact, a lack of drug delivery mechanisms through the blood-brain barrier is a major obstacle in medicine and has an estimated market worth of over USD 4.5 billion.

Finally, companies like Deep Genomics are using AI to predict the consequences of genetic mutations, having already amassed a database suggesting the potential clinical importance of more than 300 million genetic variations.

Advanced AI for basic research, drug discovery and development

Harmony & MELLODDY, by Innovative Medicines Initiative (IMI)

Blood cancers, such as leukemia, lymphoma, and myeloma, are a devastating group of cancers. Also known as hematologic cancers, they begin in the bone marrow, which is where blood is produced, and occur when “abnormal blood cells start growing out of control, interrupting the function of normal blood cells, which fight off infection and produce new blood cells”.[81] They are particularly prevalent in children, comprising roughly 30% of all cancers in children and 30% of all cancer related deaths in children. Globally, leukemia alone has reports of around 437 000 cases with 310 000 deaths in 2019.[82] Therapeutic options depend heavily on cancer type, age, stage of disease progression, cancer spread, and other person-specific factors. Beyond radiation and chemotherapy, there is a fundamental need to better understand the individual patient for deep molecular characterization to enable personalized stem cell transplantation.

The IMI2 Joint Undertakings MELLODDY and Harmony leverage AI and big data advances (respectively) to bring effective drugs from bench-to-bedside.

MELLODDY (Machine Learning Ledger Orchestration for Drug Discovery) is a groundbreaking collaboration that has the potential to accelerate drug discovery and improve patient outcomes. This 17 partner consortium brings together data owners, technology experts, and academia to develop a platform using federated learning to train machine learning models across multi-partner datasets while ensuring privacy-preservation of both the data and the models. Indeed, the decentralization of each pharma partner’s highly proprietary databases of annotated chemical libraries will allow them, for the first time, to collaborate in their core competitive space. As the project progresses, the MELLODDY platform will learn from an unprecedented volume of more than one billion drug development data points and hundreds of terabytes of image data, including annotations on biological effects of more than ten million small molecules. By design, the platform aims to boost the predictive performance and applicability domain of the models so to better predict the chances of success that a compound has in the later stages of drug discovery and development. The technology used in MELLODDY will hopefully inspire the same or similar technologies to be used in drug development, clinical practice and other sectors where the potential for

ML-driven innovation has been constrained by fragmented data ownership, and complex and heterogenous data types.

For its part, Harmony seeks to address the lack of available, machine-readable data on relevant outcomes – a key obstacle for clinicians and researchers alike. Harmony harnesses and mines big data to accelerate the development of improved therapies for patients and more effective treatment strategies. The solutions capabilities start with the systematic gathering into one single database of clinical, genetic, and molecular information on patients and diseases (currently stored in separate databases based on individual clinical trials and country registries). Building on this centralized database and with its deep data mining capabilities, Harmony identifies novel drug targets while predicting disease course and drug responses for distinct patient subgroups – the hallmark of precision medicine. As such, Harmony aims to use big data analytics, predicting prognosis, and personalized treatments to improve the overall outcomes that address blood cancers, like the optimization of leukemia management.

Harmony and MELLODDY each contribute to the core mission of IMI2 which is "bringing the right treatment to the right patient at the right time without adverse effects and outcomes". Indeed, both consortia are designed to advance drug discovery and development by identifying the most promising molecule candidates for different diseases and improve overall outcomes. By virtualizing parts of the drug discovery process, MELLODDY's hypothesis is that the privacy-preserving federated machine learning platform will help pharma to explore fewer drug candidates that are of a higher overall quality. Harmony, then again, ultimately helps medical teams define clinical endpoints and transform data into evidence-based outcomes that improve patient care and quality of life.

Deep learning for new drugs

BenevolentAI

Bringing critical medicines to market is costly, time-consuming, and increasingly unsuccessful. The costs for developing a new prescription drug with regulatory approval is estimated at USD 2.6 billion – a 145% increase over the 10 years it actually took to develop the drug.[83] The estimated price tag of post-approval R&D adds another USD 312 million, taking the full product lifecycle cost to close to USD 3 billion.[84] Meanwhile, average forecast peak sales for assets in the drug pipeline dropped by 50% from USD 800 million in 2010 to USD 400 million in 2018. As a result, expected return on investment from drug development has declined steadily from 10% in 2010 to roughly 2% in 2018.[85] Despite the high cost, the success rate of a drug gaining market approval and entering clinical development is just 12% – down from previous estimates of 20%.[86] Of all failures, nearly half of the drug candidates fail during costly Phase III trials or are rejected by regulatory agencies.[87] No other industry operates under such high failure rates for the most central process of the entire business, resulting in large unmet medical needs.[88]

BenevolentAI aims to reduce the cost and failure rate of discovering new medicines by re-engineering drug discovery and identifying why patients are more likely to respond to treatment, thereby accelerating new drug programs and increasing the probability of success. The company fuses the power of AI and machine learning with human ingenuity to enhance scientific capabilities to identify potential disease targets that may have otherwise been overlooked, generate drug-like molecules in fewer cycles, and bring these into precision medicine to better understand the underlying mechanisms of a disease and potentially develop new (personalized) treatments.[89] The AI looks at molecules that have failed in clinical trials and predicts how these might instead be more efficient in targeting other diseases, generating new and unbiased hypotheses based on over a billion relationships between genes, targets, diseases, proteins, and drugs. "When the periodic table of the elements was generated, there were gaps in that table where you know elements had to exist, but they hadn't been discovered," says Jackie Hunter, Executive Board Director at BenevolentAI. "We use our knowledge graph like that: what relationships should be present but are not yet known?"[90] Beyond drug discovery, the solution notably also helps principal investigators define the right patient populations to drive greater clinical success for drugs that enter clinical trials.

The COVID-19 spotlight also showed how the company was able to adopt its AI tools and biomedical Knowledge Graph in the fight against the virus. It fine-tuned its machine learning to consider known chemical properties and biological processes of the virus to identify potential drugs, e.g., drugs that potentially inhibit the ability of the novel coronavirus to infect lung cells. The company identified baricitinib, an already approved rheumatoid arthritis drug owned by Eli Lilly, as a potential treatment. In April 2020, just over two months after publication of their initial research it was announced that baricitinib would enter clinical trials in COVID-19 patients. Ivan Griffin, co-founder of BenevolentAI, emphasized that this research was conducted in a time frame that would have been impossible to replicate without the curated and wide variety of datasets and artificial intelligence of the company.[91]

BenevolentAI's impact begins by conferring a new level of understanding of disease mechanisms at the earliest stage while identifying the patient subgroups who are most likely to respond to a treatment – an important building block for value-based healthcare and greater clinical success at lower costs. It has goal-oriented partnerships with AstraZeneca for chronic kidney disease and idiopathic pulmonary fibrosis, with Novartis on a precision medicine project for its oncology assets currently in clinical development, and with the University of California San Diego to develop non-invasive therapeutic treatments for cerebral cavernous malformations (CCM). BenevolentAI also has active in-house R&D drugs in disease areas such as neurology, immunology, oncology and inflammation. Notably, BenevolentAI applied its AI to better understand ALS, producing a long list of hypotheses for treatments, which was later triaged and then tested by world authorities on ALS research at the Sheffield Institute for Translational Neuroscience (SITraN).

3 AI-enabled clinical care pathways

AI-enabled clinical care pathways are where AI-based solutions fit into existing and new clinical workflows, such as diagnostic or prognosis purposes, clinical decision-support, analysis and automatic transcription of clinical conversations and interactions, auto-referrals, and precision medicine.

Niramai

What are AI-enabled clinical care pathways?

Mounting evidence from cognitive sciences shows that health workers are under tremendous time pressure, lack the right information to ensure best standards of care, and often feel overburdened by administrative duties. Time pressure in particular has been shown to influence decision-making processes and adherence to guidelines in clinical practice, incite clinicians to ask fewer questions, conduct less-thorough clinical examinations, and provide less lifestyle advice.[92] That is bad news for both patients and health professionals.

AI-enabled clinical decision support, triage and referrals, and diagnostic solutions can help reduce both time pressure and doctor-to-population inequalities, while also bringing much-needed specialist expertise to remote locations. AI systems can even assist surgical procedures with decision-support and real-time blood loss monitoring and supply, AI systems are at the forefront of medicine supporting doctors.

In addition, with the rise of imaging in medicine, AI clinical care pathway solutions help doctors manage the ever-increasing quantity of imaging data that they must interpret and act on.[93] In imaging, AI has frequently been proven to outperform clinicians both in diagnostic accuracy and efficiency. In addition, AI-driven solutions can help highlight high-risk patients, alerting physicians about results that require urgent action.

AI-driven clinical care solutions have been especially successful in radiological and histopathological image analysis, largely thanks to remarkable progress in computer vision. Rather than replacing humans, such solutions currently assist healthcare practitioners by providing analytical, diagnostic, and decision support.

Innovations you should know

Apollo Hospitals and Microsoft
AI-powered solution for cardiovascular diseases

Apollo Hospitals partnered with Microsoft's AI Network for Healthcare to develop an India-specific heart risk score to better predict cardiac diseases among the general population. By using Microsoft's cloud and AI tools alongside Apollo's database and field expertise, a specialized team of data scientists and clinicians were able to build a machine learning model to better predict heart risk for the Indian population. In seven years, they have collected clinical and lab data from over 400 000 patients to find novel risk factors for patients who had heart attacks without the regular indicators. The AI solution can now identify new risk factors, and has also proposed new weighting with existing risk factors, doubling the accuracy of the risk score.

Apollo Hospitals is looking to redefine how preventive health check-ups are conducted across its hospitals. The models help gauge a patient's risk for heart disease and provide rich insights to doctors on treatment plans, assist in early diagnosis, and empower doctors with predictive solutions. Thanks to the partnership, Microsoft and Apollo are now co-creating an AI-powered Cardio platform for patients to find their heart risk score without a detailed health check-up, which will then be integrated into electronic medical records (EMR) for patients.

Niramai (Niramai Health Analytix)
AI-enabled thermal sensing for breast cancer

Niramai, an Indian start-up for **n**on-**i**nvasive **r**isk **a**ssessment with **m**achine-learning and **a**rtificial **i**ntelligence, has built a cloud AI solution that uses images from a FLIR thermal sensing camera to detect early-stage breast cancer in a non-contact, non-invasive assessment, replacing the need for mammography and radiation or touch-based diagnostic methods.

For patients, the procedure is simple and comfortable: walk into a small booth with a thermal sensor that measures the temperature variations on the chest – and let the AI software do the rest. Niramai's AI makes use of deep learning's strong performance in image analysis and classification, detecting even the smallest blood vessel structures that help in determining deep-seated tumors often missed by thermography unaided by AI. As a solution ecosystem, Niramai increases early detection using advanced machine learning, leading to earlier treatments and potentially lowering mortality.

Real-world solutions of AI-enabled clinical care pathways

Viz.ai detects signs of stroke in brain scans using machine vision and alerts specialists via their phones – a means of doctor notification for which Viz.ai received approval from the US Food and Drug Administration (FDA).[94] In ophthalmology, optical coherence tomography (OCT) is a safe and straightforward way of imaging the retina, and AI has been a pioneering technology in identifying retinal diseases. Moorfields Eye Hospital in London, UK, and DeepMind (Google) developed an AI tool that is able to identify more than 50 eye diseases in scans, easily matching the performance of leading experts while also making the correct referral decision with 94% accuracy. As the capabilities of mobile devices rapidly increase and costs decrease, a growing number of AI solutions will take advantage of improved hardware and software to build mobile imaging solutions. These advances bring mobile imaging solutions to non-specialist health centers in both HICs and LMICs and can significantly address shortages of skilled workers.

Using patient data, including demographics, family history, and pathology reports from breast biopsies, MIT and Harvard Medical School collaborated to develop an AI-enabled decision-support solution that provides a score indicating whether breast surgery is a good option for high-risk lesions identified in breast biopsies – a model with 97% accuracy in identifying malignant breast cancers while reducing the number of benign surgeries by more than 30%. Another AI tool, built by DigitoHealth, combines glucose, cholesterol, triglyceride and blood pressure information with other health data, smart sensor and optics data to support early detection and monitoring of cardiovascular disease and diabetes. The tool issues alerts to patients and doctors when it detects clinical changes and enables users to share health data in real time with family members and health providers.

Both in HIC and LMICs, AI-based and data-driven strategies to avoid unnecessary surgeries help reduce suffering and costs of surgical procedures for patients, health organizations, payers, and governments. In LMICs, constraints on surgery are particularly high and such strategies can free up highly skilled surgeons who are in short supply, enabling them to prioritize surgeries and patients, while simultaneously lowering the costs and burden of preoperative, intraoperative, and postoperative care.

AI-assisted robotic surgery is another pathway that has shown positive real-world outcomes. An AI-assisted robotics solution can analyze data from pre-operation medical records to physically guide the surgeon's instrument in real time during a procedure, resulting in a five-fold reduction in surgical complications.[95] Leading to fewer errors and complications, AI-assisted surgery also reduces patients' length of stay in the hospital by 21%, creating a massive USD 40 billion in annual savings.[96]

Butterfly IQ is an AI-enabled ultrasound device that connects to a doctor's smartphone. While ultrasound technology has not changed significantly for over half a century, Butterfly IQ has developed an ultrasound machine that is using a semiconductor chip in a single device usable on the whole body and connected to a smartphone, creating a clear ultrasound image without using quartz crystals. The device's AI platform interprets ultrasound images for 13 FDA-approved tests and guides physicians in taking diagnostically relevant images via sound simulations.[97] Given that two-thirds of the global population still lack access to radiological services, mainly due to limited availability of equipment and/or trained health workers, Butterfly IQ's solution brings diagnostic and decision support capabilities to regions that might not have access otherwise.

Intel and GE Healthcare have teamed up to deliver an AI deep learning tool at the point of care that runs across multiple medical imaging formats to help prioritize and streamline x-ray image analysis in real time and on the edge (requiring no internet). The critical care team is immediately notified to review critical findings for pneumothorax – a collapsed lung – and enable rapid life-saving care.[98] The tool's offline decision support capabilities make medical expertise available to health centers that are remote or do not benefit from reliable internet connection.

AI is also able to detect lung nodules – small growths on the lung that, while mostly benign, can turn malignant (cancerous) and spread extremely quickly. NYU Langone Health's AI system quickly and accurately flags specific anomalies in images for radiologist review.[99] AI skin cancer and eye disease detection celebrate similar successes when deep neural networks classify skin lesions with performance on par with experts, meaning these AI solutions would certainly outperform less specialized health professionals like general practitioners (GPs) or many health workers in remote areas.[100]

Finally, AI has also been used to predict the readmission probability of congestive heart failure patients with 82% accuracy, enabling hospitals to initiate counter measures and improve outcomes.[101]

COVID-19 has shown that even when AI solutions work, incorporating them into health systems and clinical workflows is difficult, both in HICs and LMICs. In addition, regulatory hurdles and clinicians' insufficient digital know-how on deploying AI solutions in clinical settings can severely hinder adoption. Yet, despite these obstacles, several AI solutions are already creating impact in health and care across the world.

Clinical workflows

Rigid or complex clinical workflows, regulatory obstacles, and health workers lacking digital training make integrating AI into clinical workflows often difficult.

These examples reflect how integrating AI-driven solutions in health truly enables positive health outcomes. AI is supporting health workers in their demanding jobs, improving decision making and guiding them in their daily practices, as well as helping them detect and treat diseases earlier and with greater accuracy. AI in this field also enables doctors to spend more quality time with their patients, ask more questions, conduct more thorough clinical examinations, and, ultimately, deliver better quality care.

Policymakers should create strong policies and regulations that facilitate the integration of AI solutions in health, while regulators need to provide robust guidelines and collaborate with industry partners and health organizations, who should proactively get involved with AI innovators and developers.

AI-powered solution for cardiovascular diseases (CVDs)

Apollo Hospitals and Microsoft's AI Network for Healthcare

Noncommunicable diseases (NCDs) such as heart disease, diabetes, cancer, and respiratory diseases cause more than 70% of global deaths – killing about around 41 million people each year. The largest burden of these diseases lies in LMICs, with people presenting these health problems at earlier ages and facing worse outcomes. Of all premature deaths from NCDs (i.e., between 30–69 years of age), 85% occur in LMICs.[102] In addition to their human and social impact, the disability and mortality caused by NCDs has an economic impact due to loss of productivity and severe constraints on health system budgets. For diabetes care, the cost in Latin America and the Caribbean alone is estimated at about USD 115 billion a year – an eight-fold increase over 20 years.[103]

In India, nearly three million heart attacks occur every year and over 30 million people are living with coronary diseases. Cardiovascular diseases are the biggest cause of mortality in India with nearly 25% of these within the age group of 25–69 years.[104] The Chief of Cardiology at one of India's largest private healthcare companies, Apollo Hospitals, Dr. J. Shiv Kumar, has stated that cardiovascular diseases are almost an epidemic in India.[105] Many NCDs are chronic, lasting over the life course, making early diagnosis, treatment, care, and prevention the key strategy to save lives, cut costs, and lessen the negative economic impact.

Apollo Hospitals partnered with Microsoft's AI Network for Healthcare to develop an India-specific heart risk score to better predict cardiac diseases for the general population. By using Microsoft's cloud and AI tools alongside Apollo's database and expertise in the field, the team of data scientists and clinicians built a machine learning model to better predict heart risk among the Indian population. The team worked with Azure Machine Learning services for learning experimentation and rapid prototyping, scaling up on virtual machines, and managing model performance. This AI solution can now identify new risk factors and has also proposed new weighting with existing risk factors, doubling the overall accuracy of the risk score. Based on the new heart risk score for India, Apollo Hospitals is looking at redefining how preventive health check-ups are conducted across its hospitals. The models help gauge a patient's risk for heart disease and provide rich insights to doctors on treatment plans, assist early diagnosis, and empower doctors with predictive solutions. The team is now working on an AI-powered Cardio API platform for patients to find their heart risk score without a detailed health check-up, and the team is working on integrating their model into Electronic Medical Records (EMR) for patients. As such, Apollo has actively and holistically integrated various AI workflows into its clinical setting.

Apollo has integrated its AI-powered CVD solution with preventative health check-ups across its hospital network and has also formed a National Clinical Coordination Committee that includes the All India Institute of Medical Sciences (AIIMS), New Delhi and King George's Medical University (KGMU), Lucknow for an ongoing study on prospective validation in the Indian population. Apollo is also working with Maastricht University in the Netherlands for clinical validation/enhancement of the model outside of the Indian population. To date, over 200 000 people have been screened using the AI-powered API across Apollo Hospitals and in many cases, physicians have been able to predict the risk score of patients seven years in advance of a cardiovascular disease event.

AI-enabled thermal sensing for breast cancer

Niramai, by Niramai Health Analytix

Breast cancer is the leading cancer in women, impacting over two million women worldwide each year and representing the greatest number of cancer-related deaths in women.[106] In LMICs, women can often face critical barriers to breast cancer prevention and care, from hurdles in accessing early detection to receiving timely care. This reality is mirrored in the five-year survival rates, which range between 40% and 60% in LMICs versus 84% in North America.[107] India records the highest number of breast cancer deaths per year, estimated at 80 000. More than 50% of Indian breast cancer patients are diagnosed in stages three or four, resulting in an overall survival rate of about 50%.[108] Lack of awareness, delays in screening and diagnosis, privacy concerns, and cultural obstacles all play a part in these poor outcomes, yet early detection and risk prediction is vital to improve outcomes and survival.

Niramai, an Indian start-up and acronym for non-invasive risk assessment with machine-learning and Artificial Intelligence, has built a cloud AI solution that uses images from an FDA cleared FLIR thermal sensing camera to detect early-stage breast cancer in a non-contact, non-invasive assessment – replacing the need for mammography and radiation or touch-based diagnostic methods. The significance of the words non-contact and non-invasive is easily overlooked, but technologies that fail to consider cultural sensitivities will lack the opportunity to scale across wide segments of society. Dr. Geetha Manjunath, founder and CEO of Niramai, points out that the no touch, no see, non-invasive solution addresses "the socio-cultural issues in cancer screening [in India], particularly for rural women given the cultural discomfort of disrobing in front of a stranger for routine screening".[109] For women, the entire procedure is simple and comfortable: walk into a small booth with a thermal sensor that measures the temperature variations on the chest – and let the AI software do the rest. Niramai has even brought its solutions directly to shopping malls and other unconventional distribution channels to reach a broader base of end-users and address cultural sensitivities.

The technology of the US-patented analytics platform, called Thermalytix, uses machine learning to automatically perform image interpretation and identify malignant lesions, the results of which are then reviewed and approved by an expert healthcare professional. The breast health report gives feature scores, location of abnormality, and thermal images with colored temperature gradations for easy interpretation. Niramai uses AI's strong performance in image analysis and classification, detecting even the smallest changes in blood vessel structures that help identify deep-seated tumors. The platform also features a web-interface for healthcare professionals to upload patient demographic information (social determinants) and for a certified technician to upload the thermal images. Niramai's AI tool has tested more than 32 000 women and completed several successful clinical trials that show a 27% higher accuracy than normal mammography and a 70% higher positive predictive value than visual interpretations of thermography – while reducing the test procedure time to under 15 minutes.[110] A recent study establishes an overall sensitivity of the solution of 93% with a negative predictive value of 97% (i.e., the probability that following a negative test the person will not have the specific disease). The solution can alert physicians of very early breast cancer patients, suggesting the need for further testing.[111] Niramai's strength is based on four key areas: (1) It is non-invasive and doesn't utilize carcinogenic radiation; (2) enables access for underserved populations thanks to its portability; (3) enables safe, non-painful, non-touch screening for women of all ages (including those below 45 who mostly forego mammography); and (4) increases early detection using advanced machine learning, allowing for earlier initiation of treatment and better outcomes.

4 AI-enabled patient-facing solutions

AI-enabled patient-facing solutions use AI to interact directly with patients and other users, including the delivery of non-clinical therapies, chatbots, self-referral, personalized advice on health and behavioral changes, personalized outreach, medical record collection, self-care, and information provision.[112]

What are AI-enabled patient-facing solutions?

Patient-level RWD is often central to patient-facing AI solutions, and patient-facing solutions in turn generate tremendous amounts of RWD. Insights generated from these solutions help enable a better understanding of patients and their various health determinants, e.g., to help AI identify the type and severity of a patient's condition and directly provide health recommendations. Recommendations include guidance on self-care, lifestyle, and behavioral change, or advice on how and where to seek professional care. The aim is to motivate patients to take more responsibility in managing their own health, though it is not intended to replace health professionals in the provision of diagnosis and care.

Especially in places with low doctor-to-patient ratios, or a lack of specialists, these AI tools can bring "tremendous value to patients by enabling them to access medical information, behavioral and lifestyle recommendations, care routing advice, and even potential diagnoses without having to go to a health facility, which can be time-consuming and expensive in LMIC health systems".[113] Importantly, these solutions can also ensure that only individuals who truly need to use formal healthcare services do so, freeing up health workers' time for other patients. Of course, consumers of patient-facing tools must also be empowered and have an appropriate level of digital literacy to effectively use the AI-enabled patient-facing tool.

Innovations you should know

Ping An Good Doctor (Ping An)
The unprecedented scale of an AI-enabled health ecosystem

Ping An has created an AI-powered healthcare ecosystem platform, Ping An Good Doctor. It aims to provide every family with a doctor, an e-health profile including an electronic health record (EHR), and a healthcare management plan. Based on its service model of "Internet + AI + 1 409 in-house expert physicians," Ping An has created cloud-based internet hospitals, internet pharmacies, and internet health centers. With 315 million users and 66.9 million monthly active users performing 729 000 daily consultations, and partnerships that include thousands of hospitals and pharmacies, Ping An's innovative AI health ecosystem is undeniably helping to address Asia's burgeoning healthcare needs, empower pharmacies in developing new retail business models, and positively impact patient lives. Especially for patients in remote communities, Ping An is providing instant and comprehensive care where access to qualified doctors may not have existed before.

Ada Health (Ada Health)
AI-enabled symptom checker

Ada is a technology company founded by doctors, scientists, and industry pioneers to create new possibilities for personal health. It provides an AI-powered mobile symptom assessment solution that helps increase access to medical information for clinicians and patients, and provides recommendations on next steps. A person enters their symptoms via a chatbot, answering several adaptive questions, until Ada has reached an assessment of the potential health issue using probabilistic reasoning, based on global medical knowledge. For every assessment, Ada considers all available and uploaded patient-level data, including past medical history, symptoms, risk factors, EHRs, and social determinants of health. The solution now counts 10 million users with 18 million assessments, and in Sub-Saharan Africa more than 800 000 people have downloaded the app (which is the first symptom assessment solution translated into Swahili). Solutions like Ada have the potential to address existing health inequalities and provide medical expertise to clinicians, health workers, and patients alike – all with the aim of improving the quality, access, and cost of healthcare delivery.

Babyl Rwanda (Babylon Health)
Your AI doctor at home

Babyl Rwanda is Babylon Health's AI-powered triage and symptom checker platform in Rwanda, and has recently partnered with the Government of Rwanda to give every person over 12 years of age access to digital health consultations. The AI platform enables patients to receive a digital consultation with a remote health worker via a mobile phone. The health worker's expertise is augmented by Babylon Health's AI system. In time, Babylon Health will also release its standalone AI mobile phone app in Rwanda, calling in remote health professionals only when escalated by the AI or for formal diagnosis. The AI platform produced a world's first when it passed the medical examination set for UK doctors, proving its ability to provide health advice on par with practicing clinicians. Babyl is fundamentally changing how patients connect with physicians and receive a diagnosis and advice, providing access to healthcare for millions in a country with a low doctor-population ratio but a high level of broadband connection and mobile phone penetration. Babyl currently performs over 13 000 weekly consultations in Rwanda, and that number is growing fast, illustrating its ability to easily integrate with the cultural needs of its users.

Real-world solutions of AI-enabled patient-facing solutions

The Indian startup Wysa created a chatbot that helps with the behavioral health aspects of diabetes, smoking, and depression. Based on interactive questions, Wysa guides its users through cognitive reframing, breathing exercises, and other coping strategies depending on the person's current feelings. In India alone, the app counts 1.8 million users and a spike was observed during COVID-19. After it passed the UK's clinical safety standard, the NHS was an early adopter of Wysa and recommended it to troubled children in Greater London. The chatbot can escalate conversations to qualified therapists, who then provide live sessions or text messaging for further support. In this way, Wysa and other AI-enabled mental health tools can lessen human resource constraints regarding specialized mental health workers while also helping address stigma challenges around mental health.

In China, children at more than 2 000 pre-schools now enjoy a quick daily AI-based health check before attending class. Walklake has built a robot with a yellow square body and cartoon-like face that takes three seconds to scan a child's hands, eyes, and throat to detect signs of illness. The robot automatically marks symptoms on a side view display and defines a tentative diagnosis. Walklake is trained to detect more than 20 diseases such as conjunctivitis (pink eye), basic respiratory viruses, hand and mouth disease, influenza, and pharyngitis. The Chinese government has praised such AI-enabled tools for their role in large scale screening and preventing health issues from spreading in schools, while also tackling a shortage of qualified health workers in China more broadly.

In Nigeria, a startup called Ubenwa uses AI to diagnose birth asphyxia in newborns by recording the infant's cry on a smartphone in real time. The AI-powered tool then analyzes the amplitude and frequency patterns of the cry and provides an instant diagnosis. Initial assessment delivered a sensitivity greater than 86% and specificity at 89%. Traditionally, diagnosing birth asphyxia involved a trained expert analyzing blood gas values, and then potentially providing oxygen support. Access to such equipment and expertise is a major obstacle in Sub-Saharan Africa, especially in remote areas, hence the issue often goes undiagnosed and untreated, with a high risk of harmful consequences for the child's further development.

Working on attention-deficit/hyperactivity disorder (ADHD) and Alzheimer's, Akili Interactive gamified cognitive assessments and integrated adaptive algorithms to detect early symptoms of the diseases. Using gameplay sensors, players navigate an avatar by tilting the mobile device and respond to targets by tapping the screen. The app keeps track of those movements, including eye movements, and is able to detect early symptoms of ADHD or Alzheimer. Akili is partnering with various life sciences and MedTech companies, firmly putting AI-enabled gamification on the map as support to clinical care. Akili also brings innovation into the area of chronic diseases, moving beyond care management and into the realm of easily accessible, low-cost digital therapeutics.

Casalud is a comprehensive healthcare platform designed by the Carlos Slim Foundation and scaled across Mexico.

It is a set of smart tools to manage and prevent NCD issues in Mexico throughout the entire patient and public health journey – including timely disease detection, precision diagnostics and systematic risk assessments, effective long-term management and personalized patient-follow-ups, and medicine supply chain optimization for essential NCD medicine stocks of primary health centers. The solution was featured in the Broadband Commission's report, The Promise of Digital Health: Addressing Noncommunicable Diseases to Accelerate Universal Health Coverage in LMICs. The solution algorithms identify over 80 clearly defined NCD risk profiles based on patient-level data including age, sex, family history with NCDs, lifestyle, height, weight, waist circumference, blood pressure, and capillary blood glucose. On the clinical side, Casalud includes an integrated proprietary decision-support tool that guides health professionals in patient disease management. Casalud is now also piloting a new patient-facing AI app that serves as a long-term virtual coach to guide users and provide personalized interventions.

AI4Leprosy, a solution being built by the Novartis Foundation, Microsoft, the Oswaldo Cruz Foundation (Fiocruz), and the University of Basel, is a smartphone-based imaging solution for early detection of leprosy. It aims to accelerate leprosy diagnosis, in the last mile on the path to leprosy elimination. Users can take pictures of suspected skin lesions, add symptoms, and receive a probability score for leprosy, with those with a positive score directed to the nearest facility to confirm their diagnosis and start treatment if necessary. Deployment of this AI-driven solution is planned in collaboration with local health authorities and other partners.

Finally, while there are few examples of autonomous treatment delivery systems, progress has been made with autonomous insulin pumps for Type 1 diabetes. The pumps feature closed-loop systems that continuously sample patient glucose levels and automatically regulate insulin delivery rates. The AI software analyzes the samples in real-time and predicts when a patient's blood sugar is likely to decline, suspending insulin delivery 30 minutes prior to the predicted hypoglycemic episode. The aim of this innovative solution is to reduce the risk of debilitating hypoglycemia.

AI tools played an important role in China and South Korea's COVID-19 response. AI has provided real-time guidance on social distancing and helped prioritize health messages per user group. It also aggregated supermarket and pharmacy data to provide real-time mapping of stores with available masks, or mapping to guide travellers to avoid COVID-19 hotspots. Several symptom checkers updated their algorithms for COVID-19 indicators, enabling users to get tentative information on whether their symptoms were potentially related to COVID-19.

The big scale of Ping An's AI-enabled health ecosystem

Ping An Good Doctor, by Ping An

China, like many other Asian countries, suffers from a lack of qualified health workers in both urban and rural areas. The doctor-patient ratio in China is 1.8:1 000,[114] with rural areas suffering an even lower ratio of 1.3:1 000, following the country's rapid urbanization. Countries such as South Korea, Mexico, Poland, Japan, and the US all hover around 2.5, while Germany, Switzerland, Sweden, and Norway have ratios of about 4.5:1 000.

China's demand for health services is increasing fast due to a stark rise in NCDs and environment-related illnesses, as well as rapidly increasing longevity, with an estimated 300 million people being over 65 by 2040.[115] To ease the pressure on health services, China's State Council and its National Health Commission have pushed for a greater role and better integration of new technologies, in particular AI, into China's health system. Strong AI governance has led to the fast-tracking of internet hospitals and AI applications for the provision of safe medical services.

Ping An, the world's largest insurance company by market capitalization, has built an innovative health empire over the past five years. Answering the government's call for more AI in health, Ping An has created a one-stop, AI-powered healthcare ecosystem platform, called Ping An Good Doctor that aims to provide every family with a doctor, an e-health profile including EHRs, and a healthcare management plan. Based on its service model of Internet + AI + 1 409 in-house expert physicians, Ping An created cloud-based internet hospitals, internet pharmacies, and internet health centers: essentially a new approach to outpatient service delivery where people seek healthcare at an unstaffed, 24/7 medical consultation facility near their home and meet a digital AI doctor or, if necessary, a real doctor through the internet.[116] Patients answer questions and share potential symptom images, while data on vitals such as body temperature, blood pressure, and blood glucose concentrations (etc.) can be obtained by machine-operated devices onsite and shared with the AI doctor or attending physician. After a preliminary diagnosis, a physician joins if necessary and the system automatically prints a prescription for the patient.

The AI-System is equipped with knowledge of about 3 000 diseases. Continuously trained with data from 670 million consultations, the system covers the entire consultation process, doubles the efficiency of doctor consultations, reduces the possibility of misdiagnoses and missed diagnoses, and improves patient experience with remote medical consultations. During the pandemic, the system accumulated 1.11 billion consultation records.[117] In addition, thanks to its central warehousing model and collaboration with a network of 94 000 pharmacies, Ping An can provide one-hour delivery in vast areas of China. COVID-19 is accelerating this trend, as demand for Ping An's services increased tenfold in January in China, Ping An is also working on an English version of its platform, building on partnerships with major life sciences companies.

Globally, through notable and innovative partnerships, for instance with Grab, South-East Asia's first decacorn (startup with a valuation of over USD 10 billion) and largest multinational ride-hailing and delivery company, Ping An Good Doctor can also bring its services to new markets such as Indonesia, which has a population of 270 million and a doctor-patient ratio of 0.6:1 000. Furthermore, Ping An Good Doctor established another joint venture in 2019 with Softbank Group, launched an online healthcare service platform in Japan and cooperated with local strategic partners such as hospitals, doctors, insurers, pharmacies, logistics and distributors to offer a wide range of service in Japan.

AI-enabled symptom assessment solution

Ada Health

At least half of the world's population lacks access to basic healthcare, while out-of-pocket payments for healthcare push another 100 million people into extreme poverty.[118] Achieving UHC is one of the main targets of the Sustainable Development Goals (SDGs). However, the significant worldwide shortage of health professionals and inequalities in access to quality healthcare make achieving this goal difficult. The WHO estimates that by 2030, the world will need an extra 18 million health workers – with the largest shortages occurring in LMICs.[119] Fortunately, data, digital technology, and now AI can help us re-engineer the way we deliver health and care around the world.

Ada is a CE-marked and ISO-certified mobile symptom assessment solution helping clinicians and patients get more information about potential symptom causes and recommending potential next steps. This AI chatbot connects users to medical expertise on their smartphone. A person describes the symptoms, answering adaptive questions until Ada has developed a set of conclusions about the potential health issue. Hila Azadzoy, Managing Director of Ada's Global Health Initiative, explained, "Ada will ask a series of personalized questions, much like a doctor would, and based on the answers, provides an assessment of the probability of the possible causes of those symptoms, along with suggested next steps – this could be to go and see a pharmacist, or to make a doctor's appointment, for example".[120] The solution uses probabilistic reasoning, based on a representation of global medical knowledge to infer disease probability estimates. For every assessment, Ada considers all available and uploaded patient-level data, including past medical history, symptoms, risk factor, EHRs, and social determinants of health. Through multiple closed feedback loops, Ada continues to become more intelligent.[121] A recent Ada innovation is its adaption of the AI solution to the Swahili language. To localize the solution, Ada Health worked closely with regional stakeholders, in this case a Tanzanian university, to adapt the tool culturally and linguistically. To ensure that the app would correctly factor in the conditions and symptoms that are more common in Tanzania and East Africa, the team explained, 160 disease models were optimized, including maternal and child health issues, cardiac conditions, mental health-related problems, and infectious diseases like malaria, HIV, diphtheria, and pertussis.[122] Moreover, Swahili differs from English in how it describes symptoms and symptom locations. For instance, the palm of the hand clearly refers to the anterior part of the hand in English, yet such translations do not always work in other languages and, whereas previously this was an obstacle for an AI system that relies on precise descriptions of symptoms, Ada and its partners found a workaround by adding more detailed explanations when no direct translation existed.

The solution now has 10 million users with 18 million assessments, and in Sub-Sahara Africa about 800 000 people have downloaded the app – a number that is steadily growing. In East Africa, Ada has the potential to improve healthcare guidance for more than 100 million people. Globally, solutions like Ada have the potential to significantly address health inequalities and bring healthcare expertise to clinicians, health workers, and patients alike – all with the aim of improving the quality, access, and cost of healthcare delivery.

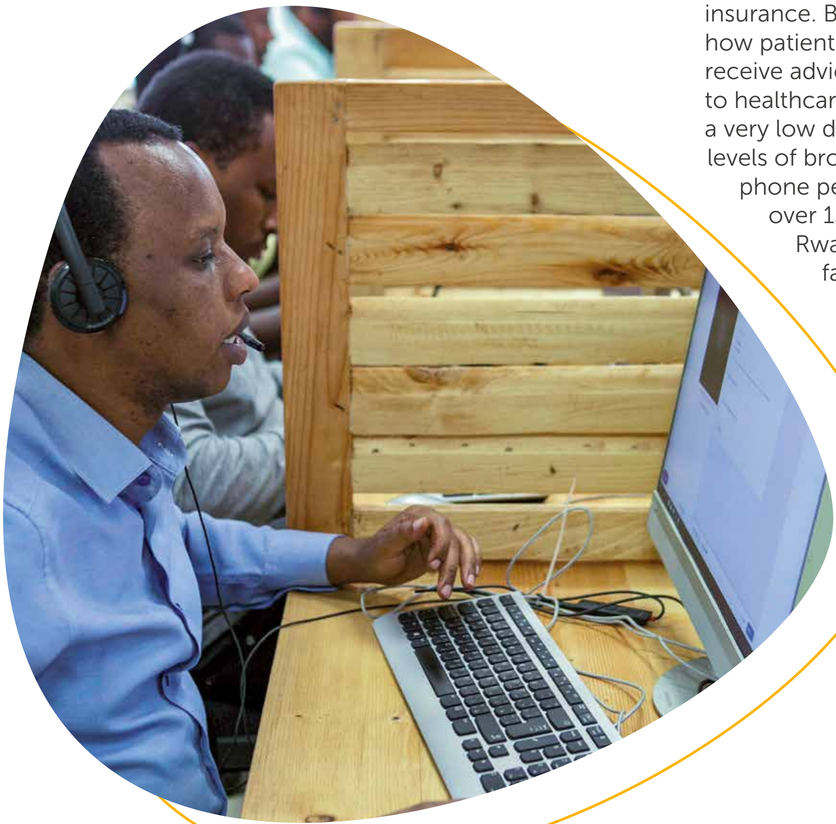
Your AI doctor at home

Babyl (Rwanda), by Babylon Health

For nearly 12 million Rwandans, there are only 1 300 doctors, a people-doctor ratio of 0.1:1 000, and about half of them are GPs.[123] In rural areas, one doctor may serve as many as 60 000 people. While the Government of Rwanda has set a target of one physician per 1 000 people, the severe shortages of trained health professionals puts tremendous pressure on the health system. This reality stands in stark contrast to Rwanda's rightful reputation as one of Africa's major tech hubs. And in fact, Rwanda is turning to AI to help address its health situation.

Babyl, and its parent company Babylon Health, have signed a 10-year partnership with the Government of Rwanda to give every person over 12 years access to digital health consultations. More than 30% of Rwanda's adult population has signed up, and the new partnership will also see the introduction of Babylon's AI-powered triage and symptom checker platform. The AI platform enables patients to have digital consultations with a remote health worker on their mobile phone, which is augmented by Babylon's AI system. Eventually Babyl will roll out its services as an AI-powered standalone app that only loops in certified health workers when relevant, such as for formal diagnosis, difficult cases, or prescriptions. The AI system matches user responses with potential conditions: through machine learning, the platform reasons with millions of combinations of symptoms, diseases, EHR information, and risk factors to identify conditions matching the information entered by the patient. In instances where in-person care is required, patients are automatically referred to a health facility within Babyl's ecosystem.

The AI platform produced a world's first when it passed the medical examination set for UK doctors, proving its ability to provide health advice on par with practicing clinicians. In fact, while the average pass grade over the past five years was 72%, Babylon's AI scored 81% in its first try and is expected to continuously learn and accumulate knowledge and case evidence. In Rwanda, Babyl's partnership features another major advantage: every appointment is automatically paid through the government's Mutuelle de Santé community-based health insurance. Babyl is fundamentally changing how patients connect with physicians and receive advice and diagnoses, providing access to healthcare for millions in a country with a very low doctor-population ratio but high levels of broadband connection and mobile phone penetration. Babyl currently performs over 13 000 weekly consultations in Rwanda, and that number is growing fast, illustrating its ability to easily integrate with the cultural needs of its users.



MACRO-EYES

5 AI-enabled optimization of health operations

AI-powered optimization of health operations refers to the use of AI to optimize back-end processes in health systems, such as procurement, logistics, drug manufacturing, staff scheduling, emergency service dispatch management, automated completion and analysis of medical notes, NLP-enabled transcription, and patient experience analyses, among others.[124]

What is AI-enabled optimization of health operations?

This use case is all about strategic deployment of physical and human resources to deliver health and care. With rising NCD rates globally and double disease burdens in many LMICs, tackling priority national health needs is a growing challenge. Across industries, AI has proven time and again its capacity to optimize processes, supply chains, administration, and logistics. Healthcare is no different. The potential value created by AI in healthcare administration workflow optimization and fraud detection alone totals well over USD 35 billion globally.[125]

Equally important, all the previous examples and use cases depend on quality data, from monitoring and predicting disease transmission, prediction and early identification of risk factors, to appropriate health planning and resource allocation.[126] Yet, data has to be interoperable to unlock these capabilities. When interoperability is guaranteed and AI is unleashed, it opens the door to true evidence-based and real-time public health policy and health system planning and management.

Innovations you should know

CHAIN (macro-eyes Health)
AI-powered supply chains that reduce vaccine stockouts and wastages

Based on advanced machine learning, macro-eyes has built a predictive supply chain for vaccines that provides granular overviews of future vaccine consumptions and recommends appropriate supply levels. The solution, mainly deployed in Tanzania and Zambia, builds on comprehensive datasets of electronic immunization registries from national governments. The AI platform anticipates shifts in demand and consumption at the health facility level for weeks and months ahead, decreasing vaccine stockouts and wastage by auto-recommending supply levels and thereby increasing opportunities for immunization. In Tanzania, macro-eyes has demonstrated that its AI platform can forecast vaccine consumption with 70% greater accuracy than the best performing models, leading to a more precise and equitable supply chain that saves lives in areas most affected by shortages.

Corti

Corti
AI detects cardiac arrest in 48 seconds through phone calls

Corti has found a way to use AI to help identify out of hospital cardiac arrests (OHCA) during emergency calls, enabling the fastest possible response by the emergency team while also providing targeted instructions for lifesaving first aid measures to the emergency caller. The solution works by using AI, specifically real-time natural language processing (NLP), to listen to emergency calls and look out for several verbal and non-verbal patterns of communication. The AI was trained with historical datasets of emergency calls to establish a predictive value for cardiac arrest that is automatically relayed to the first responders' team. As a result, Corti acts as a personal assistant to emergency phone call responders, prompting them to ask the most relevant questions, and to the emergency team by providing insights and a prediction on the probability a caller is suffering from cardiac arrest. To further help emergency call centers improve, Corti analyzes data from each call to provide feedback to call dispatchers and managers. Corti is able to identify cardiac arrest more accurately and faster than humans. Speed is vital for OHCA, as every minute without treatment reduces survival chances by 10%.

Real-world solutions of AI-enabled optimization of health operations

In the early 2000s, Hong Kong's Health Authority began using basic AI for staff rostering. The simple AI tool developed in collaboration with City University of Hong Kong produces weekly and monthly staff rosters that satisfy a set of constraints and criteria, such as staff availability, staff preferences, working hours, ward operational requirements, and hospital regulations. Deployed across more than 40 public hospitals, the AI tool now automatically creates weekly rosters for over 40 000 staff and has significantly increased productivity, improved morale and quality of care, and provides management with insights into working patterns and resource utilization.[127]

Robust healthcare delivery also depends on good logistics. Famously, large retailers like Amazon and Walmart use AI-based analytics to anticipate demand for products. Knowing what quantities of which drugs need to be where and when is of the essence, because the lack of medicine increases the risk of circulation of counterfeit drugs. This knowledge ensures not only that patients can access the medicines they need but also that expiration dates of drugs are known. The spotlight on predictive supply chains illustrates how procurement, logistics, and distribution can be linked to significantly reduced stockouts and wastage.

Similarly, NLP-enabled tools can actively assist health practitioners with administrative tasks, which constitute a major part of their day-to-day work. Freeing up time allows health professionals to redirect their energy and expertise to patients, team workshops, Peer-2-Peer (P2P) learning, tumor boards or other exchange platforms.

AI-enabled intake and triage solutions operated by systems that predict which patients are likely to miss appointments or arrive late have enabled clinics to optimize their patient scheduling parallel to their staff scheduling. These technologies are having a significant impact on health service delivery and waste reduction in health systems. They also avoid inappropriate referrals or appointments, as well as no-show patients (see spotlights).

Other AI-enabled optimization of health operations solutions include intelligent machine and device maintenance, drug manufacturing processes, emergency dispatch management, patient experience analysis, prediction of admission and readmission rates. Besides optimization of health operations, AI has also significantly sped up and re-engineered drug manufacturing and supply chain management in the healthcare industry.

In drug manufacturing, medicines and reference archival material are mostly stored in freezers. Thus, freezer failures can lead to the loss of archival reference material worth millions of US dollars. AI has enabled improved management of these materials through predictive device maintenance alert systems. Novartis, for example, uses over 300 freezers in its Kundle site in Austria. Using rule-based models, Novartis integrated smart alerts that enabled technicians to take quick action based on predicted failure risks. This not only avoids damage to costly reference products, but also minimizes the costs associated with product quality investigations and broken freezers (USD 1–3 million each). For patients and supply chains, such capabilities and many others of AI in drug manufacturing mean less drug delivery disruptions.

A closer look at counterfeit drugs

Globally, counterfeit or substandard drugs are both a severe health issue and a multibillion industry. According to the UN, 1 in 10 drugs sold in LMICs are fake, creating a USD 30 billion industry. As some markets have been flooded with cheap fake drugs, pharmacists are often drawn by lower prices, purchasing and selling substandard or fake drugs without knowing their origins or contents.

The WHO estimates that Africa alone accounts for 42% of all globally detected cases of substandard and fake medical products, producing significant death tolls. The 2019 US National Academies of Sciences, Engineering, and Medicine (NASEM) report on quality of care in LMICs revealed that the large quantity of substandard and falsified drugs results in ineffective treatment, contributing to the loss of nearly 8 million disability-adjusted life years (DALYs), and likely exacerbates the problem of AMR. Counterfeit antimalarials alone, for instance, are estimated to cause 150 000 deaths annually in sub-Saharan Africa.[128]

RxAll, a Nigerian deep-tech startup, has developed a handheld nanoscanner that authenticates drugs and helps pharmacists and patients avoid counterfeits. The nanoscanner uses AI to verify the legitimacy of medicines at more than 97% accuracy within a simple 20-second test that analyzes the infrared wavelength emitted by a drug and cross-checks it against the profile of the legitimate version (each drug has its own unique spectral fingerprint reflecting the type and quantities of its compounds).

In addition to the AI-enabled nanoscanner, which is ISO, CE and FC certified, RxAll also curates a large database and platform that includes the spectral profiles of hundreds of drugs as well as a heatmap visualization app that helps pharmaceutical companies and governments identify where specific brand counterfeits are regularly showing up.

AI-powered supply chains that reduce vaccine stockouts and wastage

CHAIN, by macro-eyes Health

Immunization currently prevents 2–3 million deaths every year.[129] According to the WHO, for the very young to the old, vaccines prevent debilitating illness, disability, and death from vaccine-preventable diseases such as diphtheria, hepatitis A and B, measles, mumps, pneumococcal disease, polio, rotavirus diarrhea, tetanus and yellow fever.[130] Yet every year, one in three countries experience at least one stockout of at least one vaccine for at least one month, a problem that is most prevalent in Sub-Saharan Africa where nearly 40% of countries experience national-level stockouts.[131] When such a stockout happens, there is a 90% chance that subnational stockouts occur at district levels and, even more concerning, interrupt immunization services.[132] Vaccine wastage – the sum of vaccines discarded, lost, damaged, or destroyed – is likely to occur when predictions and forecasts are inaccurate. Vaccines account for a significant portion of immunization program costs; minimizing waste without jeopardizing vaccination coverage is key.

macro-eyes, an AI company with roots at MIT, supported by the Bill & Melinda Gates Foundation, Draper Richards Kaplan Foundation, and UNICEF, has built a predictive supply chain for health powered by machine learning: CHAIN (Connected Health Artificial Intelligence Network) provides granular overviews of future consumption and recommends appropriate supply levels. The solution, with components currently in implementation in Tanzania and Mozambique, builds on comprehensive datasets of electronic immunization registries and machine learns from satellite imagery, publicly available data, and direct communication from frontline health workers.

CHAIN anticipates shifts in demand and consumption for the months ahead, while decreasing stockouts and waste by auto-recommending facility-specific supplies.[133] What sets apart the macro-eyes machine learning system is the human-in-the-loop approach, emphasizing health workers as the experts – and on a technical level, decreasing the labelled data points necessary for prediction, by relying on strategic human-level domain expertise, generating to-date inaccessible insight on the context for care.

Drew Arenth, Chief Business Officer at macro-eyes, notes that storytelling is a crucial form of input for AI: AI is often imagined as work in some kind of sterile lab: scientists fiddling with vast fields of numbers, ordinary life nowhere to be seen. The image couldn't be further from the truth. Refining our machine learning models, we discovered that the stories behind the data, the context of how and why data was collected, had significant impact on accuracy. Partners such as PATH and Ministries of Health, as well as local health workers and administrators, not only shared data, they explained the process of data collection – enabling macro-eyes machine learning scientists to encode the how and the why of the data into the model.[134]

The result is a predictive supply chain in the early stages of being deployed in LMICs. In Tanzania, macro-eyes has demonstrated that AI can accurately forecast vaccine consumption – down to the level of individual health facilities – with 70% greater accuracy than the best performing models on the market. A more precise supply chain is a more equitable one, saving more lives with the same resources.

Today, for every 100 vials used, the supply chain in Tanzania delivers between 43 too many and 43 too few vials. When too few vials are delivered, lives are lost. When too many vials are delivered, there's wastage. The macro-eyes machine learning system is able to cut errors from 43 to between 1 and 2 vials (for every 100): 96.4% reduction in misallocation.[135]

Many countries have not gone through the difficult process of implementing national databases and digital health records. macro-eyes realized that CHAIN must be able to create impact where it is needed most; extensive digital infrastructure cannot be a prerequisite. To ensure for scale, macro-eyes does not rely on patient-level data, using only data in the public domain. This radically simplified system demonstrated a reduction in delivery errors of 94.4%. The macro-eyes supply chain product makes it possible to anticipate where care will be needed, preserving resources and saving lives.

AI is detecting cardiac arrest in 48 seconds – via phone

Corti

Each year, over 600 000 out-of-hospital cardiac arrests (OHCA) occur in Europe and the US. The first five minutes after a person has a cardiac arrest are the most critical, and for every passing minute, the chance of survival decreases by around 10%.[136]

In Western countries, sudden cardiac death accounts for 15% of all fatalities and has a tremendous economic impact. The annual, indirect, economic burden in the US alone stands at USD 450 billion. This means that every percent increase in OHCA survival can result in as much as USD 4.5 billion in annual savings.[137]

The Danish company Corti has developed a state-of-the-art solution to this problem. Corti has built a solution that uses AI in the form of real-time natural language processing. Corti is built to listen to medical emergency calls and patient interviews and help the call-taker identify signs of a critical illness like cardiac arrest. By comparing thousands of historical medical interviews and the accompanying data, Corti can find patterns in verbal and non-verbal cues in the communication during live emergency calls, which can lead to a faster diagnosis – e.g., a caller's tone, or descriptions of how patients might be breathing. As the emergency call proceeds, Corti is capable of recognizing cardiac arrests in real-time in an evidence-based process, presenting the most critical insights to call-takers in a user-friendly way. In doing so, it enables the fastest possible response by the emergency team.

In 2019, clinical trials were initiated to validate Corti's offering, as early publications from Copenhagen Emergency Departments showed that Corti is able to identify cardiac arrest more quickly – 44 seconds to be precise – and more accurately than humans. In the extensive study to date, on 108 607 Danish emergency calls, Corti reduced the amount of undetected cardiac arrests by 43%, and it was significantly quicker, too, recognizing the most relevant signs 25% faster than the human call-taker could alone. Corti therefore acts as a personal assistant for the call responders, prompting them to ask the right questions and providing the right first aid steps to callers.

If the clinical trials show similar results, rolling out the technology could have an immense impact on patients across the world, saving thousands of lives each year, while also ushering in a new paradigm in emergency medicine, since humans and robots might increasingly be working together to save lives.

Similar to a co-pilot on a plane, Corti works as a personal assistant to the emergency call taker, offering advice in crucial moments, suggesting and predicting the best next steps, and taking notes to free up time for the human call-taker to be more attentive. After each call, Corti shares feedbacks with its human counterpart and helps find ways to improve.

Currently, Corti is deployed in Copenhagen, Seattle, Sweden, and in various locations in France. This year, Corti is scheduled to go live in more locations in the US, Denmark, and Australia.

The six areas for AI maturity in health

Developing, deploying, and continuously maintaining or improving AI solutions in a complex health system is no easy feat. From public to private sector stakeholders alike, gaining a good overview of the challenges and enablers for AI in health is critical. This overview provides us with the tools to draft policies and regulations, foster collaborations, and launch needs-driven initiatives to create an AI-enabling ecosystem with positive health impact.

Important actors and institutions have already defined AI-relevant principles and guidance, including the Digital Development Principles, the OECD Principles on AI, the G7 Statement on Artificial intelligence and society, and Designing for Children's Rights Guide, among others.[138] These principles and guidance have articulated important objectives for AI that also inform this report's discussion. They touch on a broad range of factors, including user-centric design, co-creation with all stakeholders, integrating within existing ecosystems, sustainability, open standards, privacy and security, global stewardship, trustworthiness, and human rights. This report sees these as meaningful guidance and builds on them to advance our shared global efforts of human-centric AI in health.

We have systematized the challenges and enablers for AI in health into **six areas for AI maturity in health**.[139] These thematic clusters form the enabling ecosystem for AI in health.

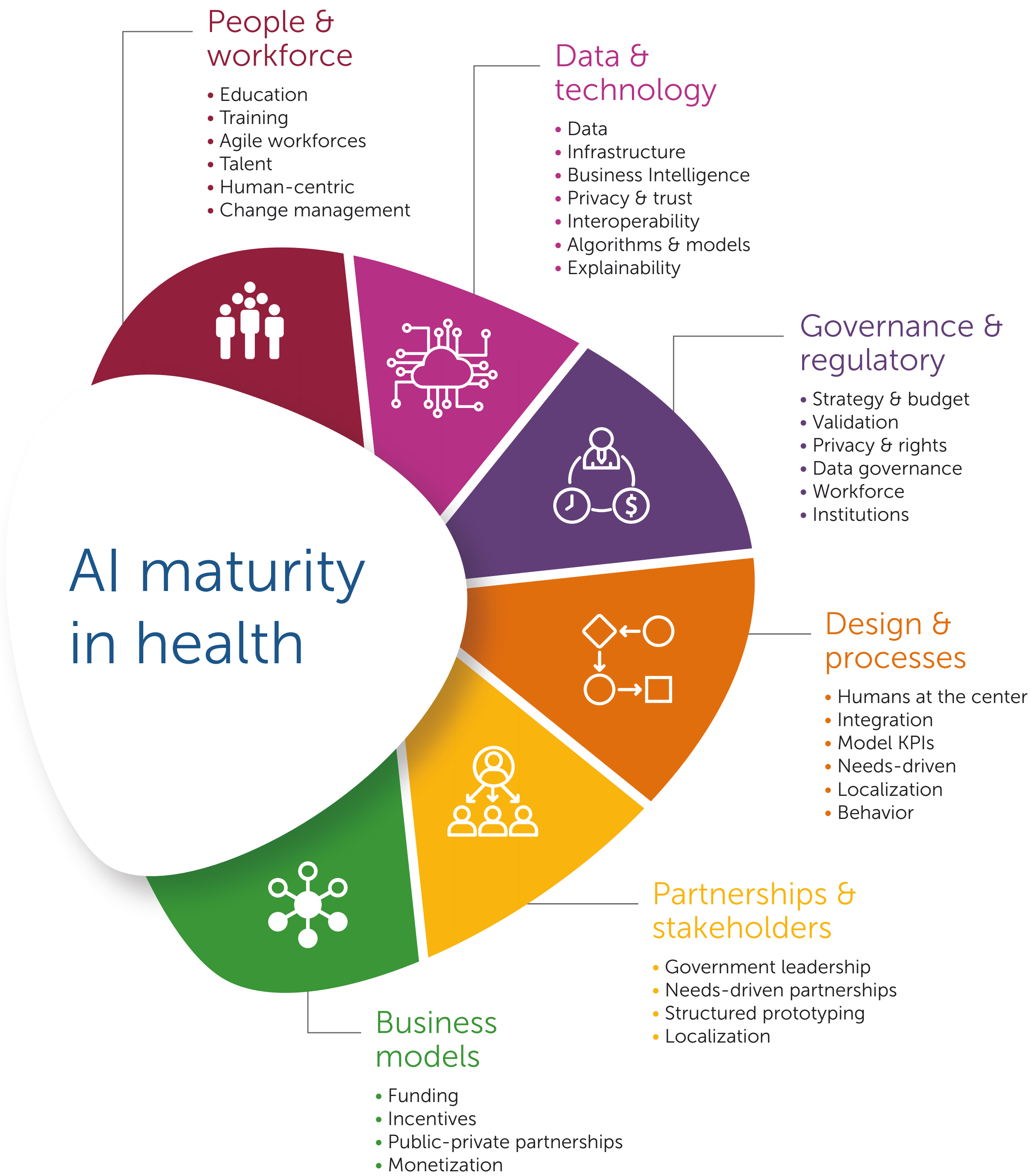


Figure 10: The six areas for AI maturity in health

People & workforce

This area focuses on education, training, on-the-job learning, and human factors. It revolves around the importance of strengthening capabilities and educational offerings at different levels. It includes professional training, social learning, and on-the-job training. Fundamentally, people & workforce is about human-centric design and behavior – dimensions that are often ignored in a tech-driven education.

Key topics include:

- National curricula for AI and data science in health
- Educational offerings at secondary school, universities, and professional institutions
- Professional and on-the-job training
- Talent acquisition and retention
- Workforce capabilities and skills
- Agile tools and methodologies
- Change management
- Human-centric design for people-driven technology

Data & technology

This area focuses on technology, interoperability, algorithms, and models. It includes data ingestion, storage, consumption, data ownership sharing, and data validation. It also includes algorithm and model accuracy, training, and explainability, as well as standards and interoperability.

Key topics include:

- Enterprise architecture and infrastructure
- Data strategy, availability, sharing, ownership, stewardship
- Data consumption maturity (BI)
- Data security and privacy
- Data integrity, validation, representativeness
- Interoperability
- Fixed and adaptive algorithms (and how this affects models)
- Explainability
- Model accuracy, fairness, and transparency
- Model benchmarking and auditing

Governance & regulatory

This area focuses on formal governance structures and regulations. It encompasses the development of relevant national strategies, clear costing for implementation, clinical and scientific validation, privacy and security regulations, innovation vision, and key regulatory policies.

Key topics include:

- Government and industry leadership
- Strategy and budgeting for AI in health
- Data governance and stewardship
- Rights, privacy, and social contracts
- Clinical and scientific validation

Design & processes

This area focuses on the integration of AI solutions in health systems and clinical workflows, model usage and performance metrics, localization of solutions, and human-in-the-loop design.

Key topics include:

- Human-in-the-loop processes and human-centric design
- Clinical and health-related workflows
- Model usage and performance metrics
- Localization of solutions

Partnerships & stakeholders

This area focuses on effective partnerships, multisectoral public-private initiatives, goal-oriented and concerted prototyping, as well as appropriate stakeholder engagement that ranges from high level political support and industry support to relations with local partners and patients.

Key topics include:

- Needs-driven partnerships that encompass:
  - Multisectoral public-private partnerships
  - Government partners
  - Industry partners
  - Local partners
  - Academia
  - NGOs and IOs
  - Patients
- Structured prototyping that counters fragmentation following uncoordinated pilot initiatives

Business models

This area focuses on funding sources, incentive structures, financial sustainability, pricing models, and different forms of innovative monetization.

Key topics include:

- Funding sources and pricing models
- Incentives (tax immunity, grants)
- Innovation (innovation parks, grand challenges, public-private initiatives, open innovation)
- Sustainable business models
- Monetization models
- Social value generation and innovative financing mechanisms

Key challenges & enablers within individual AI maturity areas

People & workforce

Insufficient opportunities for AI and digital health education and training remains a key challenge for countries and health systems. To build a highly skilled workforce, an education and learning ecosystem focused on AI in health is essential. Countries should identify the health priorities for which AI could be a tool and draft national curricula to reflect these.[140] Training opportunities have to be offered both in-service and pre-service. Given that both health and technology workers need core skills and capabilities related to AI in healthcare, governments and other stakeholders should create the conditions for a strong education and training ecosystem that increases the capabilities of health professionals in Data Science and AI (DSAI). In addition, cross-sectoral workers such as engineers, informaticians, and others should also be empowered to benefit from DSAI education and training opportunities. Without such a supportive ecosystem, the national workforce will remain limited in its ability to realize the potential of digital technology and AI to better address important health issues – let alone the ability to innovate how health and care can be delivered. Tools that countries can use to assess digital skills are emerging and will better enable countries to address gaps. Notably, the ITU's Digital Skills Assessment Guidebook provides countries with a comprehensive, practical step-by-step tool for national digital skills assessments. It enables countries to determine the existing supply of a digitally skilled cohort at a national level, to assess demand from industry and other sectors, to identify skills gaps, and to develop policies to address future digital skills requirements.[141] Such tools are essential for countries to train their workforce and should form part of any AI in health strategy.

The below enablers have been identified as most critical for increasing national and local capabilities for DSAI, foremost in health but also in other fields.

People & workforce

Education	Training	Agile workforces	Talent	Human-centric	Change management
Challenges					
Computer science and AI in health are not prioritized	Lack of certified training on digital and AI in health	Non-agile workforce	Highly skilled talent is in short supply	Lack of human-centric design skills	People's resistance to tech-driven change
Enablers					
Integrate DSAI into national curricula; use expert groups to help shape curricula	Work with established players to scale certified training programs on AI in health	Establish agile trainings and prioritize agile in professional curricula; incentivize the workforce for agile upskilling	Break down private/public sector silos to foster an enabling environment and attract talent; fund national research grants	Introduce human-centric design as a foundational pillar of AI in all curricula	Proven change management processes to address workers' concern and help them in integrating AI in their workflows

Three key challenges and enablers

1. Education

The challenge

Not prioritizing DSAI in health nationally at all school levels, but in particular at higher education levels, results in an insufficiently skilled workforce and lagging innovation at public research institutions.

Furthermore, missing opportunities for digital and AI training in advanced health worker education and on-the-job training causes major bottlenecks in the upskilling of a country's workforce. This is particularly important for the fast-evolving fields of digital and AI in health.

Inadequate retraining opportunities for non-technical roles that nonetheless seek to leverage AI represent a major obstacle to successfully integrating AI into health organizations, especially since AI application implementation usually hinges on a broad set of actors with different levels of digital literacy.

Insufficient opportunities and incentives for agile skill and human-centric design development are major stumbling blocks for unleashing a country's AI innovation potential. AI systems are almost always developed and improved in short cycles (often called sprints). Both technical know-how and a general mindset shift are required.

Related to human-centric design, a lack in overall digital literacy in a country's population is a major obstacle to successful AI adoption in national health systems.

The enablers

Countries should explicitly prioritize AI and data science for health in their national curricula. Core skills most relevant for addressing public health priorities should be explicitly outlined. Curricula can build on international scientific consensus while balancing national health priority topics.

Prioritization also entails providing prestigious scholarships and financial incentives, international exchange opportunities, and national research grants.

Open science drives broad and open innovation at public institutions and helps to translate research into teaching and vice versa. Open science also fosters a flourishing and collaborative public-private research innovation landscape.

Continued on-the-job trainings are enablers for upskilling a country's workforce and ensuring workers are satisfied by opportunities for self-improvement, particularly if these are framed within certified training programs.

On-the-job learning may include experience gained in experimental learning (e.g., rotation programs, working groups, work shadowing, workshops) and social learning (e.g., coaching and mentoring, knowledge exchange and knowledge transfer sessions, brown bag lunches), as well as e-learning, video learning, and intranet resources.

Agile tools and methodologies empower workers to build software and AI solutions through collaboration and cross-functional teams based on adaptive planning, evolutionary development, early delivery, and continual improvement. It enables rapid and flexible responses to change.

Introducing agile and human-centric design into national curricula, formally making DSAI a national education priority, and incentivizing various training opportunities on and off the job should be a government and workforce focus. Opportunities to develop and strengthen DSAI capabilities should not, however, be restricted to health workers.

Other professions, such as engineers, informaticians, and statisticians should also benefit from opportunities to learn DSAI skills.

Education and public learning opportunities to enhance the overall digital literacy of a country's population, including among youth and vulnerable groups, also require prioritization, as these opportunities enable people to manage their own health and reach informed decisions ranging from consent to active participation in health management.

2. Talent

The challenge

Acquiring and maintaining talent in the fields of data science, digital health, and AI is a fundamental challenge as demand for highly skilled workers far outstrips supply. LMICs' inability to attract and retain talent is detrimental to innovation and a maturing AI economy. These trends can further exacerbate the existing inequitable distribution of AI and data science skills in favor of HICs.

The enablers

Top talent can be incubators for new ideas and approaches. They bring fundamental and advanced capabilities while attracting more talent. To recruit and maintain talent, policymakers and other stakeholders should create a rewarding environment by prioritizing pull factors such as innovation hubs, research clusters of excellence, strong public-private collaborations, and grand prizes and challenges. The integration of innovation into public health services has also been shown to attract talent. In addition, legislators should create a strong legislative framework underpinning workers' rights and working conditions.

The new workforce of the 21st century is characterized by multidisciplinary talent with education and experience spanning across business, technology, and health. Stakeholders should actively foster intersectoral collaborations to attract and cultivate such talent.

3. Technology integration

The challenge

Resistance to technology-driven change, especially for AI blackbox technologies, is a well-recognized obstacle to trust and therefore the implementation of AI solutions in healthcare. Working with employees and users to mediate resistance can be a prolonged and sensitive challenge without adequate strategies.

The enablers

A robust change management plan is essential to integrating AI in health and care systems. This can include strategies for strong communication, access to training, considerations for cross-generational learning, continuous review and implementation processes, incentives for behavioral change, regular workshops, active removal of barriers, or dedicated resources for both short- and long-term gains.[142]

Data & technology

Without strong data availability, quality, sharing foundations, robust ICT infrastructure and good connectivity, AI's potential for health system transformation is hamstrung. The below challenges and enablers do not cover ICT infrastructure and connectivity in detail as these are addressed in other Broadband Commission reports. However, investments in these foundations remain critical and urgent, particularly for LMICs and LDCs.

As a source, data is all around us: IoT and sensors have mushroomed and provide the essential fuel for new AI breakthroughs in health. Large volumes of high-quality, validated data are essential to train models in specific tasks such as recognizing patterns in data, performing classifications, or providing recommendations.

Yet, the abundance of data also brings a number of challenges: how to process big data? How to store it? How to make sense of it and produce insights?

Big data processing tools and clean architecture are part of the answer. Algorithms, which are sets of coded instructions to reach an outcome, decision, or recommendation, require a number of fair and transparent design principles to address these questions. Interoperability ensures a shared set of rules, guidelines, and definitions for systems and datasets to communicate and interact.

Governments and other stakeholders should establish a policy framework that prioritizes establishing strong foundations and providing guidance and regulations around interoperability, standardization, and explainability of data and models.

Data & technology

Data	Infra-structure	Business Intelligence	Privacy & trust	Inter-operability	Algorithms & models	Explain-ability
Challenges						
Lack of data availability, sharing, ownership, validation, represen-tativeness	High data volumes, velocity, and variety put a strain on infrastructure	Inability to operationalize AI-powered BI for decision-making processes	Inadequate security & privacy layers for highly sensitive data	Lack of standards for technical, structural, and semantic interoperability	Real-time adaptive algorithms lack RWE/RWD and regulatory clarity	Verification and adoption lags due to model non-explainability
Enablers						
Foster open data, data collaboratives, and data solidarity; support strong governance and data stewardship	Prioritize needed infrastructure–e.g., real-time vs. batch processing, connectivity, cloud vs. warehouse	Use data consumption metrics to provide actionable intelligence in reports, graphs, maps, and dashboards	Robust privacy-preserving and security layers create trust and goodwill while protecting a health organization's key asset: sensitive data	Collaborate with key actors to define standards and put in place laws and institutions to enforce them	Regulators offer AI fast-track or novel pathways for approvals; fund creation for RWD/RWE in research centers of excellence	Legislate minimum explainability requirements and interpretability for physicians and patients

Three key challenges and enablers

1. Data

The challenge

Inaccessible datasets mean AI cannot add value by applying data mining. Most learning models require large volumes of data for training and validation, and a lack of adequate quality data, robust sharing practices, and clear data ownership (e.g., ability to determine use and access of data for research, commercial, and other purposes, including secondary uses) is a key barrier to value creation and to positively impacting health outcomes. Inadequate data quality can lead to AI systems that recommend poor decisions or have other adverse consequences.

Data security and privacy are paramount. Given the sensitive nature of health data, privacy and security are vital to public trust. Data breaches may result in legal proceedings or regulatory investigations. However, establishing appropriate security and privacy layers is a significant technical, operational, and financial challenge.

Ensuring that AI models are trained on population-representative data to avoid biases in models that could exacerbate health inequities rather than reduce them, are essential for success. Data representativeness goes beyond appropriate statistical sampling and should address the inclusion of all parts of the targeted population, in adequate proportions.

The enablers

Today's health systems are quickly turning into big data factories. A robust enterprise architecture and infrastructure, including adequate computing capacity, hardware, and connectivity, should be a priority in national data strategies.

Making data accessible, publicly or through agreements, is a strong AI enabler. Innovative ways to do so while ensuring privacy include data anonymization, aggregation de-identification, virtual cohorts, differential privacy, pseudonymization, federated learning, sanitization, encryption, and privacy-preserving machine learning.[143] These practices enable better data sharing, data sharing framework agreements, and data collaboratives. As training high-quality AI systems depends heavily on the availability and sharing of quality data, disjointed data practices must be replaced by data sharing framework agreements between capable parties (e.g., health organizations and industry) while maintaining privacy and security standards.

Strong data stewardship practices enable the realization of interoperability and standards, the consistent use of data management, and easy tracking of data between health organizations. Data stewardship also covers the four dimensions below:

1. Data stewardship ensures that data ownership rights are operationalized and taken into consideration for data acquisition, use, and distribution practices. Data ownership lays the groundwork for data sharing models, including data collaboratives, data solidarity or data altruism models, and/or a data marketplace.

2. For AI solutions to work in their target populations, the data they train on must be representative of those populations. Ensuring data representativeness (Figure 11) includes the formalization of requirements, protocols, guidelines, and best practices that set minimum requirements for the desired population characteristics and proportions. Representative data is critical to ensuring data biases do not lead to further health inequalities in vulnerable population segments.

3. Data lineages enable data stewards to trace the origins of data, what happens to it, and where it moves over time. This enables stewards to find errors and root causes in analytics processes and to replay specific data flows for step-by-step debugging or regeneration of lost output.[144]

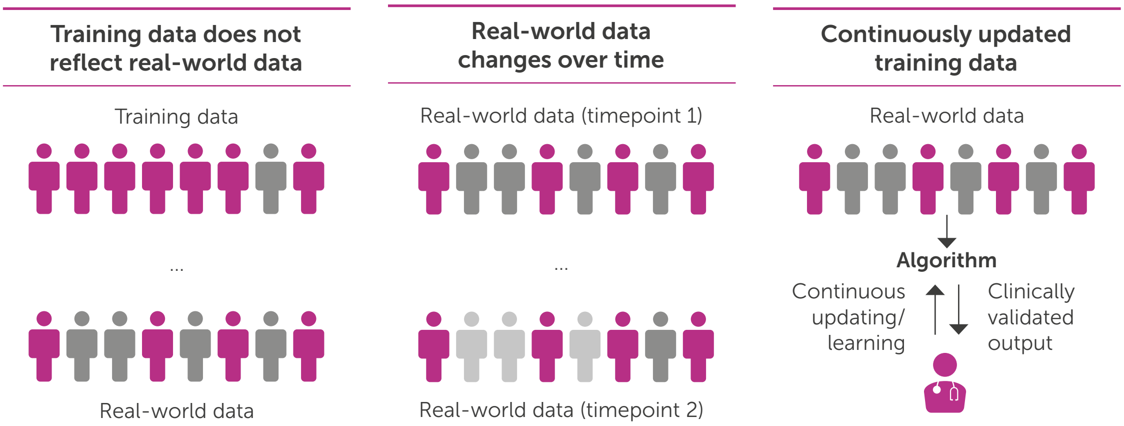
4. Big data's volume, variety, velocity, and veracity (4Vs) require (semi-) automated and rigorous data validation. Data validation ensures data quality: completeness, consistency, integrity, fairness, transparency, and accuracy of data. Accurate and standardized data annotation is crucial and needs to be validated to ensure the overall usability of data. Data must therefore be annotated by a sufficient number of qualified medical experts to avoid garbage-in, garbage-out (e.g., as stipulated by the FDA). Highly validated data is essential in healthcare, where data is highly sensitive and health interventions can directly impact a patient's wellbeing. Data quality and data validation processes are thus critical to mitigate potential risks associated with poor data. This is in line with the World Bank's forthcoming World Development Report 2021 on Data for Development, which provides a clear basis for thinking about data quality and governance along the full value chain (e.g., collection, storage, transformation, analysis, and implementation of data).[145]

For AI, these best practices are particularly important as they safeguard the integrity of training, validation, and test datasets, as well as the representativeness of the intended use population.

Safeguarding overall data integrity is key to data mining efforts and guaranteeing the independence of three specific datasets in AI training.[146]

- **Training data:** the data used to fit an AI model to solve a problem.
- **Validation data:** the data used to provide an unbiased evaluation of an AI model while fine tuning the model's (hyper)parameters to improve performance.
- **Test data:** the data used to provide an unbiased final evaluation of a model.

Potential scenarios involving training data



In the first scenario, the training data does not represent the intended real-world population. In the second, the training data does not initially represent the real-world population, but the real-world data changes over time. In the third scenario, the algorithm is continuously updated (trained) based on real-world data. Note that this is not intended to be an exhaustive list of scenarios. Based on: The Royal Society (2017). Machine learning: the power and promise of computers that learn by example.

Figure 11: Potential scenarios involving training data[147]

Finally, data stewardship practices should also extend to Business Intelligence (BI) tools and data consumption metrics. If the goal is to derive value from data for better patient outcomes and stronger health systems, then health organizations must ensure data is used and used correctly. BI dashboards and visualization tools enable health organizations to quickly understand what data they are using and how, and what data is siloed or sitting idly.

2. Interoperability

The challenge

Lacking interoperability standards is one of the most pressing challenges facing health information systems (HIS) globally. Obstacles include:

- Enforcing interoperability standards across diverse care settings
- Lack of data sharing participation (e.g., payer, clinics)
- High cost of integration and standardization

The enablers

Data interoperability standards reduce medical errors, improve patient privacy and security, increase productivity, reduce costs, and enhance the patient experience, especially when data is shared across different levels of care. Four types of interoperability enable better AI performance and outcomes.[148]

1. **Technical** – Enables the inter-connectivity requirements needed between systems or applications to securely communicate and receive data.

2. **Structural** – Enables the definition of data formats and data organization and exchange, as well as their organization (e.g., uniform PDF or Excel standards, or even defining standard titles and subtitles in documents for machines to recognize).

3. **Semantic** – Enables shared medical terminologies, nomenclatures, and ontologies; ensures that meaning of medical concepts can be shared across systems, i.e., a digital lingua franca for machines and human.

4. **Organizational** – Enables governance, policy, social, legal, and organizational considerations to facilitate the secure, seamless, and timely communication and use of data both within and between organizations, entities, and individuals.

Enablers for interoperability also include open source software that standardizes complex processes as well as a dedicated governmental agency to manage national standards and audits. Additionally, an enabler is the development of a unique person identity management.

3. Explainability and adaptive systems

The challenge

Whatever an AI solution's effectiveness and impact, its adoption is severely restricted if its decision-making processes cannot be explained. Determining a threshold of explainability or interpretability for AI tools, and how this threshold may change based on use case, indication, end user, and other variables, is a challenge.

For the same reason, while adaptive algorithms are working well in many environments with little risk for patient harm, they have been barred from most clinical settings. Adaptive algorithms change their behavior at the time they run, based on information available and reward mechanisms defined in advance. Algorithms that can change their behavior in unpredictable ways are seen by regulators as a significant risk.

The enablers

Explainability concerns the ability to explain both the technical processes of an AI system and the related decisions, both human and machine-driven.[149] There are three aspects to this:

1. Care providers are the users of AI: they should be able to trust and understand it without having to be data science experts.[150] For example, models should provide explanations for why a patient was diagnosed with a disease while another was not. It is crucial for health professionals to understand and verify decisions.

2. Technical explainability is sufficient when doctors need not be involved. Technical explainability refers to an AI system's ability to represent its decision processes transparently in the form of highly complex model pathways or complex mathematical representations. While AI and regulatory experts understand decision processes, no one could reasonably expect the same from all other users and that may limit the solution's clinical application.[151]

3. Self-explaining agents in healthcare are AI systems that can, for example, indicate the specific medical reasons why it administered a drug, for instance in a decision-tree graphic.[152]

For adaptive systems, regulators and other stakeholders will have to explore new ways to ensure learning can take place in real-world settings, not only at specified intervals with the associated re-approval regulatory processes.[153] For explainability, stakeholders should work together and develop new ways for AI systems to explain their decisions.

Governance & regulatory

Generally, governance refers to the way rules and actions are structured, maintained, regulated, and implemented – as well as how accountability is assigned. A governance framework is always part of a socio-economic, political, and cultural fabric and interacts with the world around it as governance intends to serve society. The Singaporean government has enshrined in its AI governance principles that AI solutions must be human-centric, thus providing clear guidance for innovation and policymakers.[154]

It is critical to acknowledge that AI – whether through data bias, exclusion bias, measurement bias, algorithmic and model bias, and indeed human bias – can reproduce existing health inequities along the lines of sex, gender, age, race, sexual orientation, etc. Important work is being done, as referenced below under point 3 (Privacy & rights) and elsewhere in the report, but recent political events and health realities are showing that critical action and nuanced deliberation are still much needed. This report calls for diverse actors to come together and lead both conversations and actions that address biases in all their forms.

Weak governance usually translates into weak national AI strategies, insufficient privacy and ethical considerations, inadequate budgeting, and a lack of regulatory guidance, all of which create uncertainty and can hinder health system strengthening.

Good governance and robust regulations are essential to establish policies, acknowledge rights, and define priority rules and accountability mechanisms on how AI can function in a social system.

Governance & regulatory

Strategy & budget	Validation	Privacy & rights	Data governance	Workforce	Institutions
Challenges					
Lack of explicit national AI health strategies, budgets, and workforce policies	Lack of guidance for regulatory, scientific and clinical validation	Weak privacy governance curbs public trust and accountability	Weak governance hinders data flow, utilization, and quality	Misalignment between workforce requirements and national strategies	Lack of authoritative institutions for AI and digital health
Enablers					
Develop a nationally budgeted AI roadmap with clear focus on workforce, governance, financial, regulatory, interoperability, and privacy standards	Leverage medical and technology academies/ societies and other relevant stakeholders to develop consent-driven scientific and clinical validation	Establish laws and working groups to ensure basic rights (e.g., equality, non-discrimination) and implementation of security and privacy layers	Empower data stewards and define best practices for data governance processes	Establish inter-agency working groups (education, ICT, finance, health) to prioritize upskilling strategies for the national workforce	Establish authoritative institutions aligned with key national AI goals or empower and upskill existing institutions

Three key challenges and enablers

1. Strategy & budgets

The challenge

Writing a national AI strategy for health is not an easy task but is important. It includes choosing priorities among the many important health burdens a country faces, taking stock of capabilities and feasibility, aligning on budgets, and empowering agencies for oversight.

However, health systems that skip this essential step will lack the necessary governance and focus to effectively scale AI in healthcare.

The enablers

A national AI strategy for health is the first step in aligning innovation with public health priorities. To be successful, national AI in health strategies require long term and sustained financing commitments from the country's leaders.

The content of a national AI in health strategy should include:

- The national health problems chosen as priorities for which AI can make a difference,
- the national agency, organization, or task force that is charged with execution,
- a roadmap for strong, consensus-driven regulations (including regulatory sandboxes and guidelines) and privacy standards,
- other good AI governance enablers such as legal structures and principles, compliance protocols and incentives, roles for continuous monitoring and improvement of the strategy and innovations, and standardization, verification, and impact assessment mechanisms.

Strategies can also explicitly call for government-led innovation initiatives and programs. Innovation forums, public-private partnerships, and other high-impact initiatives have incubated innovation ecosystems that can successfully align with governmental priorities.

Singapore, for example, has set up a series of direct investment initiatives and a startup program, combining government investment with private equity. Botswana's Innovation Hub includes a Startup Campus to house companies that benefit from seed funding provided by the country. And with the IMI, the European Union (EU) and European Federation of Pharmaceutical Industries and Associations (EFPIA) have set up a jointly funded public-private partnership. Each of these examples resulted from a strong strategy and clear governance calling for open or collaborative innovation.

Such models are at the heart of AI progress and show that collaboration and knowledge exchange between public institutions and private companies are strong enablers of ecosystems of partners, who use the power of co-creation to build new value chains.

2. Clinical and scientific validation

The challenge

Missing or weak regulations and guidelines on clinical and scientific validation create costs and bottlenecks for advancing innovation.

Solutions that undergo regulatory review without clear guidelines usually take significantly longer to get validated and may not make use of potential fast-track options.

The enablers

Governance on scientific and clinical validation and regulatory guidance enables innovation and targeted R&D. Regulators, medical academies and societies, and authoritative professional bodies should be involved in setting consent-driven clinical and scientific validation criteria for AI solutions, as well as intended use regulations and clinical trial guidance.

Good governance on clinical issues also enables regulators such as FDA, European Medicines Agency (EMA), and others to put in place timely fast-track or subgroup processes for speeding up AI applications review. It enables them to adjust their traditional medical hierarchies of evidence to support better adoption of AI tools. For instance, pilot data is categorized as the lowest level of evidence, followed by observational and risk-adjusted assessment results, with clinical trials at the very top.[155] Yet, today there are discussions on how in silico clinical trials (computationally simulated) could shake up the very notion of evidence generation.

Beyond clinical trials, given the novelty of AI solutions in health and the rise of RWD and Real-World Evidence (RWE), further evidence of a solution's intended use should be produced in post market contexts and fed into regulatory processes. For certain currently existing solutions, such as digital therapeutics, this could become meaningful.

3. Privacy and rights

The challenge

Privacy and rights in the digital age require both technical knowledge and a rights-based vision. From a technical perspective, the challenge is to translate privacy and fundamental rights into technical frameworks, use cases, and capabilities.

The challenges to establishing a strong rights-based vision include fast-evolving technology and often rigid legislative frameworks. Updating not only technology to reflect laws but also laws to address new technological capabilities is an important challenge of today.

The enablers

Fundamental rights, such as the right to non-discrimination and to equality, as well as fundamental privacy regulations (e.g., General Data Protection Regulation (GDPR)), ensure that health systems and patients build trust in AI capabilities. They also ensure that adequate technology layers for security and ethics are built into AI solutions and that accountability mechanisms are put in place.

Ethical and human rights-based governance and legal frameworks enable governments to guide the development and use of AI health tools in a way that reflects societal consensus and public health priorities. Recent studies analyzing the rise in AI-related human rights topics and legal framework documents have shown a growing consensus around eight thematic trends:

1. Privacy
2. Accountability
3. Safety and security
4. Transparency and explainability
5. Fairness and non-discrimination
6. Human control of technology
7. Professional responsibility
8. Promotion of human values and international human rights[156]

Notably, while this report does not focus on a particular age group, children and youth should receive special attention because additional safeguards are needed to prevent misuse or other discriminatory and non-ethical use of their data – a topic on which The Lancet and Financial Times Commission "Governing health futures 2030: growing up in a digital world" is making significant inroads.

Additionally, as shared earlier, AI can reproduce existing health inequities along the lines of sex, gender, age, race, sexual orientation, etc. For example, postal code information has been shown to be an important variable for various health AI tools, yet they can disadvantage those who live in poor or predominantly African-American neighborhoods – as was the case for an AI tool that would allocate important additional health resources to those in need but in reality ended up favoring patients from predominantly white and affluent areas.[157] To mediate such biases, AI design must be guided by the eight principles above and by an explicit recognition that sex, gender, race, etc. can be causes of systematic discrimination in AI tools.

Research has shown that governance leadership must enable strong policy around privacy concepts such as consent, the right to erasure, the control over data use, and data ownership/sharing.[158]

For accountability, continuous evaluation and auditing requirements should be regulated, and there is a clear need for the adoption of new regulations.[159]

From a human rights perspective, rights such as non-discrimination and equality are instrumental, but auxiliary concepts such as data representativeness, fairness, and inclusiveness are also priority agenda items.[160]

Governments, policymakers, and other stakeholders must also advance the global conversation around a social contract for AI. A social contract, the idea that a notional contract would express, in some way, the entitlements and obligations of all participants in a system of healthcare provision – is an enabler for societal, consent-driven AI for health.[161] Implicitly, a social contract that is translated into governance processes would recognize the obligations of data stewardship on professionals and institutions, while also recognizing the obligations of individuals who enjoy the advantages of health systems and biomedicine as a public good.[162] As such, a social contract invokes concepts of data solidarity and data altruism. The Lancet and Financial Times Commission "Governing health futures 2030" is currently making significant progress on the concept of a social contract for health data, reflecting in new and productive ways on ideas of data solidarity and data altruism.

Policymakers and other stakeholders can build on these and other existing efforts and frameworks but should also establish new regulations and governance processes where previous efforts fall short. Their aim should be to push the fractured global conversation on the future of AI towards a consensus-oriented one.

Design & processes

Deep knowledge of healthcare workflows and design principles for AI in health is critical for integrating disruptive technologies into existing health systems and workflows. And without such integration, the positive health impacts of AI driven solutions will be limited or foregone completely.

AI design – like all healthcare technologies – must start by acknowledging that design has to be centered around people and health needs, not around what is technologically possible. Design should always put the best interest of human health at its center, complementing the human-centric design aspects that focus on user experience. Equally important, AI tools must be safe and secure by design and by default in a clinically meaningful way. Taking this as the starting point, human-centric design seeks to make interactive systems usable and useful for users, focusing on their needs and requirements, and applies usability design and techniques for human benefit. This approach has proven to enhance effectiveness and efficiency, user adoption and satisfaction, and accessibility and sustainability of AI solutions. The design of AI tools for health is foremost a collaborative activity. It requires co-creation processes, design workshops, and broad stakeholder engagement. From development to deployment and continuous improvement, co-creation should always involve representatives across the spectrum, from hospitals to patients, governments to civil society representatives, vulnerable groups, to young people and children.

From a health system and organization viewpoint, AI systems need to be designed with a clear understanding of clinical and healthcare-related workflows, administrative processes, and regulatory landscapes.

For AI solutions that may not immediately result in better outcomes, consent-driven acceptability standards and processes for testing are still needed if they enable learning, so they can ultimately lead to better outcomes with more human-centric designs. Policymakers and other stakeholders should prioritize legislation, guidelines, and collaborations that put human-centric AI design first, and which proactively build solutions designed for direct integration into clinical and healthcare workflows. Such solutions deliver value to health workers, patients and other end users, and health systems more generally.

Design & processes

	Humans at the center	Integration	Model KPIs	Needs-driven	Localization	Behavior
Challenges	Designing human-in-the-loop requires expert skills and resources	Integration of AI into health systems and clinical workflows	Keeping count of AI models and processes in health systems and organizations	Aligning design processes with public health priorities and human needs	Designing a solution sensitive to local culture, practices, and environments	Conflict between human behavior/decision-making and the introduction of AI technologies
Enablers	Support research, measures, and processes that advance human-in-the-loop technologies	Build strong relations with health system & clinical stakeholders; collect evidence on a specific solution's impact, efficiencies, and improved outcomes	Define best practices for tools/dashboards that provide model performance and data utilization insights; foster industry standards	Collaborate with health officials and co-create design processes that address an unmet public health priority	Deep socio-economic market research and mapping of cultural specificities for design development; plan local capacity building efforts	Build on change management tools that push participation and empower, address competency concerns, and grab low-hanging fruits

Three key challenges and enablers

1. Humans at the center

The challenge

Human-centric design has gained a great deal of traction, yet it is still not fully incorporated into the development stages of many AI solution providers. As it is critical to always have the end-users in mind, AI systems have to be made user-friendly and useful by taking into account user needs, requirements, and culture, and with an integrated human-in-the-loop step where necessary.

The enablers

Four considerations are critical for placing humans at the center of AI in health:

1. A needs-driven approach, or one that is based on health priorities, is an essential starting point for design. It helps developers build a stronger value proposition.

2. AI must be localized, which requires market research, local stakeholder engagement, and co-design workshops. Localization goes beyond traditional stakeholders, requiring collaboration with all communities affected by health challenges including children, youth, women, people with disabilities, minority groups, rural communities, and others. Ideally, all these groups should be involved in the co-creation of AI tools. Gaining a solid understanding of and from these actors, their daily routines, language nuances, and cultural sensitivities is critical. Localization should also assess the need for local capacity strengthening.

3. Human-centric design should follow five steps: 1. empathize, 2. design, 3. ideate, 4. prototype, 5. test. Its enablers include the identification of different end-users and mapping health system touch points to understand where change would be beneficial.

4. Human-in-the-loop design is important for ensuring AI solutions in health support humans, is accountable, and reflects the equation Humans + AI = Better outcomes. At its core, human-in-the-loop design is about human participation in AI and harnessing the efficiency of intelligence automation while remaining amendable to human feedback.

Besides the gains in transparency, the benefits of AI in health solutions that have a human-centric design include quality and efficacy increases in healthcare, workload for health staff, and health system operations. Ultimately, this can enable improved patient outcomes and stronger health systems.

2. Systems integration

The challenge

Integrating new and often disruptive AI technologies into an existing health system is challenging and requires deep knowledge of health, regulatory, clinical, and payer environments, as well as strong relationships with health system stakeholders.

As regulatory landscapes between countries can be significantly different, solution developers are frequently asked to iterate multiple versions of the solution to match national health priorities and requirements. This creates a business model challenge for scaling AI solutions.

It can also be challenging to integrate the software of AI solutions into existing clinical workflow platforms. Integration becomes a hurdle when, for instance, a solution requires the installation of a standalone system or platform.

The enablers

Preparing a health system to integrate AI solutions into its network of actors, institutions, and systems is a complex task. Enabling local users and stake-holders to successfully navigate this may require training or knowledge exchange platforms. A general overview and understanding of existing clinical workflows is fundamental for integration. As a result, some health organizations have begun to map their clinical workflows on digital platforms, making the identification of potential obstacles to AI integration simpler.

From a developer's perspective, collaborating with regulators, consulting overviews and guidelines, and completing trainings can significantly reduce design errors. AI software that integrates into existing modular clinical platforms are preferable, such as on a physician's tablet or on a desktop near an x-ray machine. If the solution requires health workers to open a separate software or online interface, workflow integration can suffer.

Integrated platforms in health organizations, such as HIS, can usually be accessed by authorized personnel, enabling multi-departmental access and workflow integration. This also enables overall usage and success.

Beyond technical workflows, however, it is important to detail properly how AI solutions integrate across multiple care settings, services, and locations, and how they could alter existing workflows. Policy frameworks that prioritize AI as a core component of healthcare delivery are strong enablers of integrating AI solutions in health, as are government-led collaboration frameworks that simplify AI integration into workflows and processes.

3. Model tracking and KPIs

The challenge

As health systems grow, keeping track of the AI models and processes becomes a challenge, potentially leading to legacy models or incorrect model operations. Introducing processes that track the active models and their performance can be an important challenge for large systems and organizations.

The enablers

Dashboards, platforms, and other business intelligence interfaces enable the accounting, tracking, and visualizing of AI models and processes in a health organization. Interfaces also enable measurement and comparison of model performance across and between health organizations, while avoiding unnecessary legacy models. Such performance metrics keep AI solutions aligned with strategic goals and KPIs of health systems, and they provide the basis for continuous improvement.

Partnerships & stakeholders

Partnerships and stakeholder engagement are a key currency for anyone working in AI for health. Life sciences companies, technology companies, health organizations, and digital tech-oriented government agencies have become increasingly reliant on strong strategic partnerships, and for good reason.

As healthcare's core focus continues to expand from a care delivery system to a model that aggregates dispersed health data about behavior, traits, and environment in addition to medical symptoms and test results, partnerships will provide the fuel for a new AI in health innovation: high-quality data.

National initiatives have emerged, such as former United States President Barack Obama's All of Us program, which aggregates genetic and health data from one million volunteers and primarily relies on its more than 100 partners (ranging from teaching hospitals to Verily Life Sciences, Google's moonshot program in life sciences). Similar initiatives have also been established in Canada, the EU, and China.

For governments, external partnerships create an ecosystem that goes beyond capacity building. Partnerships enable stakeholders, including governments, to draw upon a network of experts from the private and public sectors, academia, civil society, and beyond to leverage cross-sectoral expertise and resources, and to promote knowledge sharing. In the UK, the Alan Turing Institute was set up by the National Research Council and a group of leading universities as the National Institute for Data Science and AI, bringing together disparate cross-sectoral expertise on how to deliver AI solutions for public good. Its public policy program enables government agencies to harness a wealth of external expertise to inform public services and administration.

Partnerships & stakeholders

	Government leadership	Needs-driven partnerships	Structured prototyping	Localization
Challenges				
	Lack of political backing and/or policy continuity	Lack of needs-driven and goal-oriented partnerships	Fragmentation of efforts and resources	Lack of local partners and/or patient involvement
Enablers				
	Align AI capabilities closely with national public health priorities and engage political leadership across relevant ministries	Define a needs-driven partnership roadmap with recommendations on KPIs and operationalization processes. Public-private partnerships play a key role	Incentivize an overarching AI piloting & scaling ecosystem/marketplace with diverse players and representatives	Define local partners as part of the business and public health strategy and put in place incentive mechanisms

Three key challenges and enablers

1. Political support and policy continuity

The challenge

Without political support and some degree of policy continuity, scaling AI in health is impossible. The importance of political support at the highest level (e.g., office of the head of state, ministries of health, finance, ICT, education) cannot be overstated.

In addition, ensuring policy continuity is vital for the long-term sustainability of scaling AI in health nationally.

The enablers

While there is no magic bullet to gaining political support for AI in health, key enablers include broad partnering between government agencies and companies, INGOs, and foundations that have established good stakeholder relationships. In addition, collaborating with Centers of Excellence (CoEs) and teaching hospitals can also be an enabler for gaining top level government support.

For policy continuity, an important enabler is continued cross-party consensus that builds around questions of public health priorities and the role of AI in achieving these. Establishing working groups and legislative frameworks spearheaded or co-led by various party leaders or members is perhaps the single most effective enabler for policy continuity.

2. Needs-driven partnerships

The challenge

While their advantages are clear, partnerships also require time and resources. Without a needs-driven partnership strategy, operationalizing an agile working environment driven by Key Performance Indicators (KPI) is nearly impossible. Inefficient partnerships can be a major resource drainer and derail otherwise fruitful projects.

The enablers

Partnerships can scale and create an impact greater than the sum of what their members bring to the table, not least by combining expertise, ideas, assets, and other resources. However, to unlock the potential of successful partnerships, they must be needs-driven and create value for all involved.

Governments can act as fundamental enablers by breaking sector siloes and bringing stakeholders together around prioritized topics. Events such as conferences, innovation sessions, hackathons, roundtables, and working groups all have proven track records of impact. The private sector should prioritize collaborations and joint funding arrangements to support a multi-source funding landscape led by innovative business models and profit-sharing agreements.

Governments and other stakeholders should prioritize multi-sectoral public-private partnerships as key incubators for AI in healthcare. Public-private partnerships have the advantage of bringing diverse collaborators under a shared framework and streamlining targeted-oriented innovation (e.g., the spotlight on IMI). They generally also provide better infrastructure and higher return on investments. Additionally, public-private partnerships are catalyzers for local innovators and for joint ventures with large multinational firms.

Partnership strategies must always be rooted in a clearly identified health gap, a common goal for those involved, clear communication, and consent driven KPIs. Partnership governance must include predefined processes for monitoring and evaluation, continuous improvement, and operationalization.

3. Structured pilotism

The challenge

Fragmentation of efforts and resources is an important challenge for AI innovation, especially in LMIC settings. Part of the difficulty is maintaining the innovation benefits of free blue-sky pilotism while also ensuring a structured ecosystem for coordinated, targeted impact. Fragmentation leads to missed impact opportunities, low scalability, few measurable outcomes, and the duplication of efforts.

The enablers

Government leadership for innovation hubs, CoEs, international conferences, and public-private partnerships are key enablers for an organized piloting ecosystem and marketplace.

Incentivizing goal-oriented innovation through grants, grand challenges, research centers, tax incentives, digital platforms to connect stakeholders and innovators as well as donors, is crucial to enabling effective resource allocation, and innovation while steering clear of fragmentation.

Business models

The economic and financial viability of organizations in health and care ecosystems is crucial to their day-to-day business operations, overall impact, and long-term sustainability. Establishing diversified funding portfolios, taking advantage of incentive structures, monetizing privacy-conforming data, research and commercialization strategies, vested IP rights, and product scaling remain key challenges for organizations and overall health systems, while they can also be crucial enablers.

Governments and business leaders should also collaborate to ensure emerging business models are equitable and AI tools in health systems do not only serve those who can afford them. Sustainable business models include innovative pricing and payment models that facilitate access for all. Similarly, public and private sector partners should also push for greater opportunities to engage social enterprises in creating solutions for LMICs.

Business models

Funding	Incentives	Public-private partnerships	Monetization
Challenges			
Sustainable funding solutions	AI innovation funding	High cost and bureaucracy of ad-hoc public-private collaborations	Monetization of diverse tech assets
Enablers			
Aligning capabilities with public health priorities and fostering needs-driven partnerships unlocks long-term funding instruments	Creating incentive structures (e.g., tax benefits/immunity, grants, innovation parks) creates targeted business collaborations	Creating PPPs & joint-initiatives to provide formal collaboration structures that enable co-shaping of best practices, create P2P learning, help monetize AI innovation, and facilitate in-kind skill exchange	Capitalizing on data and insight assets and scale core capabilities and products for (out-) licensing

Three key challenges and enablers

1. Funding

The challenge

Access to sustainable funding with a long-term focus on creating impact and scale is one of the most important challenges for innovators. In AI for health, a long-term financial vision is critical.

The enablers

The strategic alignment of AI with public health priorities, its novelty, and its potential for health impact are the strongest enablers for long-term funding. In parallel, fostering needs-driven partnerships that result in measurable outcomes can unlock future long-term funding. Overall, a diverse funding portfolio is preferable to increase the business model's sustainability.

2. Incentives

The challenge

Several governments do not yet have enough incentive structures for systematic innovation within AI in health.

The enablers

When governments formalize incentives, such as robust tax benefits, tax immunity, innovation parks, grand challenges, and government grants, the AI innovation ecosystem can significantly benefit and better serve public interests. Industry stakeholders can contribute by organizing innovation and incubation prizes, in-kind workshops, and other contributions.
To cultivate targeted innovation, direct government financing mechanisms are strong enablers. Beyond governments, IOs also have a crucial role to play. The World Bank, for example, is developing AI in health centers of excellence to encourage and support sustainable and needs-driven AI development. Such initiatives help consolidate scarce AI talent in high-profile and agile networks that can move quickly from design to implementation and spearhead the introduction of new capabilities in national health systems. They also allow innovators to make a more sustainable business case for their solution.

3. Monetization

The challenge

The sustainable monetization of core assets is a challenge for many organizations. Capitalizing on data and insights requires in-depth knowledge of modern commercialization models and robust privacy expertise.

The enablers

The ability to monetize data and insights, as well as scaling core capabilities and products for commercialization (e.g., (out-) licensing) is one of the most important and self-sustaining enablers.

For data monetization, legislators and data owners should design and demand business models that break down data silos and connect healthcare stakeholders, reduce inefficiencies, and accelerate the translation from research into practice (from bench-to-bedside) and the transformation from innovation to scale. Privacy-preserving, secure data monetization models that work in the patients' interest are in high demand but require more innovation and research to mature.

CoE development can help establish legislation that enables research commercialization. Examples are laws that co-vest intellectual property with the institutions and collaborators that fund or support research. PPPs can also help mature and monetize products through collaborations, concession arrangements, and in-kind exchanges in capabilities or services.

5

Roadmap for AI maturity in health

What is the AI maturity roadmap and what's to gain?

What is a maturity roadmap?

A maturity roadmap is a practical guide towards a clearly defined goal, in this case the realization of an environment that enables AI solutions in health to unleash their full transformative potential.

The roadmap is built on the evidence-based analysis underlying this report: a landscaping exercise that looked at over 100 real-world examples of AI in health and performed a deep dive on 40 selected examples to derive key challenges, enablers, and best practices. The roadmap represents a journey map that describes the progressive path to AI maturity, empowers health systems and policymakers to evaluate their positioning in the AI maturity journey, and assesses critical big bets and promising investments needed to advance the enabling environment at various maturity levels. It also helps to set priorities that are broken down into bite-sized milestones spanning from quick wins to long-term strategic plays.

What are maturity levels?

Maturity levels are not fixed categories. They describe benchmarks and milestones on a global level without claiming to paint the full picture or to fit all contexts. While most of the below guidance is addressed to national governments, it can also be interpreted for district health systems and health organizations.

Who is this roadmap for?

As a tool to create an enabling environment for AI in health, the maturity roadmap aims to become a reference to players across different fields and sectors in the health space. Creating an enabling environment requires the participation of diverse stakeholders: policymakers, regulators, funders, AI innovators and implementers, the private sector, NGOs/INGOs, academia, digital health and AI advocacy platforms.

What's there to gain?

The maturity roadmap aims to map out clear benchmarks for advancing from one maturity level to the next. Maturity roadmaps allow stakeholders to:

- Better understand the critical enablers for AI in health
- Learn from insights on best practices and lessons learned
- Define opportunities to leapfrog and cultivate equitable AI in health progress and fairer benefit distribution
- Prioritize areas for strategic investments and collaboration
- Better understand where they are placed in the AI maturity journey
- Understand how to track their AI maturity progress by selecting the relevant benchmarks, priorities, and milestones

Why a roadmap is timely and needed

AI's transformative impact and potential for healthcare is well-established. Yet, not everyone is benefiting equally from these advances. LMICs have the most to gain, yet they also have the most to lose.

AI solutions are often developed in high income countries and applied in LMICs without co-creation. The consequences include strong or hidden biases in AI models, algorithms, data, and commercialization models. There is a widening gap between AI's six areas for maturity in LMICs and HICs, yet there are also opportunities to leapfrog. The roadmap provides a concise guide that helps countries prioritize investments.

Does the roadmap relate to other frameworks?

The maturity roadmap builds on and benefits from the robust foundations of existing initiatives and maturity frameworks, notably the Global Digital Health Index (GDHI), the Health Information Systems Interoperability Maturity Toolkit, and the Health Information System Stages of Continuous Improvement Toolkit. Broadly speaking, these frameworks focus on national-level governmental efforts to create an enabling environment for digital health and identify six maturity areas. Building on existing efforts avoids fragmentation and acknowledges that any AI roadmap needs to advance and enlarge these existing frameworks to address the novel dimensions of AI in health. The goal is a usable roadmap for policy-makers to act on.

Introducing the roadmap for AI maturity in health

The roadmap describes the stepwise progression for LMICs towards AI maturity and the enabling environment that fosters it.

Taking the six areas for AI maturity in health as its canvas to highlight benchmarks, milestones, and enablers, the roadmap maps the progressive path towards maturity for:

1. People & workforce
2. Data & technology
3. Governance & regulatory
4. Design & processes
5. Partnerships & stakeholders
6. Business models

These six areas for AI maturity are interdependent, no single one can be prioritized. Rather, investments into maturity should advance progression on all fronts. Given that countries and health systems begin or continue their AI journey from different starting points, the goal is to advance AI maturity by identifying specific gaps and existing capabilities. It is crucial that while differences between countries exist, particularly for LDCs, the call to invest in AI in health is a call for global action and solidarity by all countries. We describe three distinct maturity levels:

1. Exploring

Efforts to leverage AI in healthcare are largely ad-hoc with no relevant AI strategy to refer to. Policymakers, governments, and other stakeholders have begun to explore selected AI capabilities but have not yet started to draft policies or guidelines that systematically support an enabling environment.

2. Emerging/activating

Efforts to leverage AI in healthcare are systematically explored and refer to a national AI strategy with clearly defined priorities. Policymakers, governments, and other stakeholders have drafted policies to support the targeted incorporation of AI into healthcare to achieve public health goals. While an enabling environment is being created, coordination between individual efforts is not streamlined and a real ecosystem for AI in health innovation does not exist yet.

3. Integrated ecosystem

Efforts to leverage AI in healthcare are embedded in strategic national plans and fully aligned with public health priorities. Policymakers, governments, and other stakeholders have implemented and are continuously updating the policies to support systematic incorporation of AI into healthcare as a key enabler to achieve public health goals. The government has created platforms and digital resources that bring together people, expertise, funding opportunities, and other relevant resources. An ecosystem for AI in health is fully established and cross-sectoral collaborations are the norm.

The roadmap for AI maturity in health

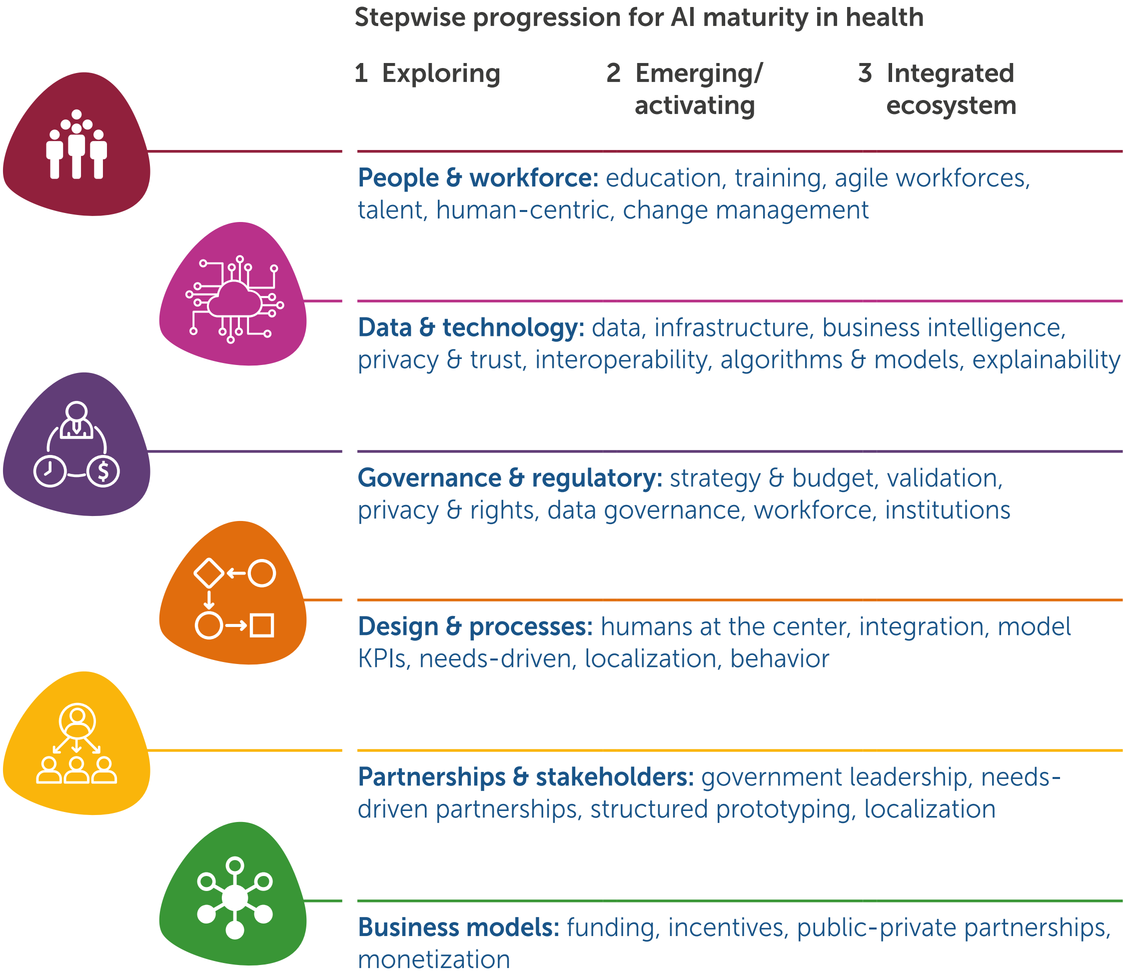


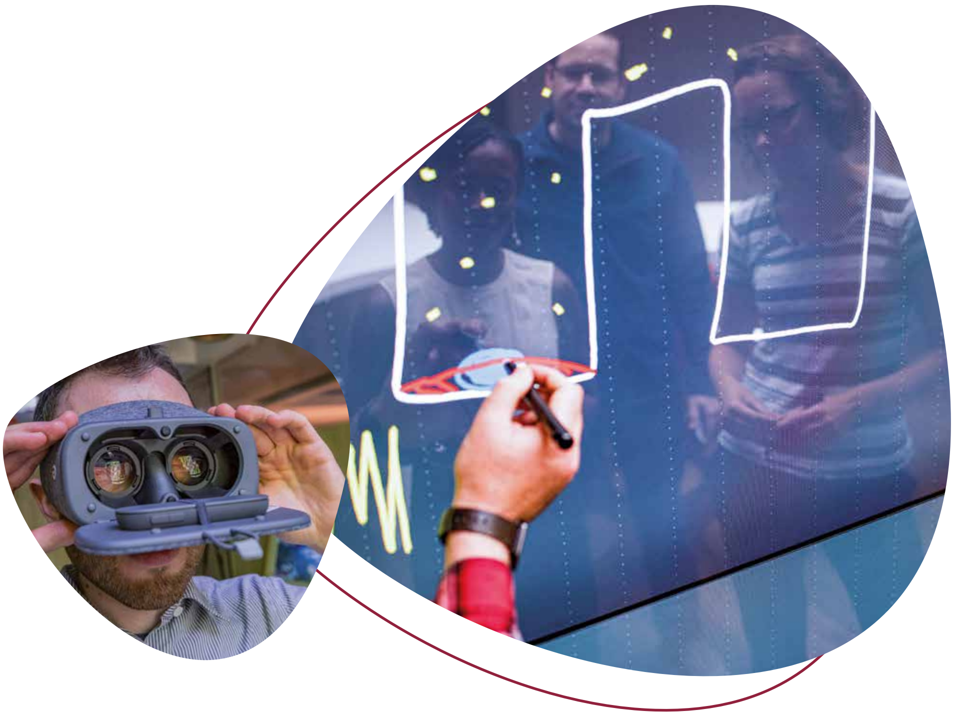
Figure 12: Six areas for AI maturity in health

1. People & workforce

A country's workforce and educational system are the foundations for AI in health. Maturity indicators include national curricula and educational institutions, professional training and on-the-job training opportunities, national talent acquisition and retention strategies, the distribution of highly skilled labor, change management processes for digital technology implementation, and agile and general workforce capabilities.

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
National curricula and education institutions		
• National curricula for health in tertiary education do not include Data Sciences and AI (DSAI) • Government actions are focused on drafting policies for DSAI to become part of formal health education	• Selected health-driven DSAI courses are compulsory for higher education programs in health • Public health priorities and the role of DSAI are taught at the basic level in secondary education • Government is prioritizing university research on DSAI in health through funding and incentives (tax benefits, Centers of Excellence, etc.)	• Secondary school curricula introduce basic DSAI concepts • DSAI skills are mandatory for medical and health-related degrees • Higher education institutions not only prioritize teaching and research in DSAI for health, they also incubate national cross-sectoral collaborations
Professional and on-the-job training		
• Professional DSAI trainings in health are not compulsory for specialized health workers and course offerings are restricted to basic courses • Development of technology skills is rarely part of continuous learning opportunities for health staff • No continuous education curricula for in-service training of health staff have been drafted • Social learning is supported by key actors but lacks systematic support	• Training programs on DSAI in health are closely aligned with public health priorities • Health systems are actively prioritizing the extension of trainings from specialized medical workers to general health workers • Continuous and social learning on AI in health is an integrated part of on-the-job training goals	• Certified trainings in DSAI in health are mandatory on a national level for all relevant health professionals and are fully aligned with public health priorities • National actors work towards international recognition of training certifications and public-private sector trainings are initiated for upskilling and knowledge exchange • Continuous learning on AI in health is compulsory for most medical and health workers • Creation of government-led professional networks
Talent acquisition		
• There is no national strategy to attract and retain DSAI talents, yet the government is defining its first strategies to attract talent, e.g., through innovation parks, research hubs, strong workers' rights and benefits, and streamlined processes for integrating innovation into public sectors	• Attracting and retaining AI and talent with both expertise in health and DSAI is anchored in policy initiatives and supported through financial or tax incentives • This may extend to the establishment of well-funded research centers, innovation hot spots or rotation programs	• Existing efforts to retain key talent are supplemented by the establishment of prestigious grants, grand challenges, and adjunct research positions for thought-leaders from both private and public sectors
Distribution of skills		
• Inequitable distributions of skills are not addressed nationally, which leads to issues such as persistent imbalances in skills or lack of advanced capabilities	• Active measures, such as scholarships, rotation programs, or exchange programs are introduced to foster equality in skills training	• Fostering technical skills within the national population, in line with international developments, is a top national priority • Countries are promoting the role of the citizen data scientist through information and awareness campaigns

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Change management		
• Behavioral challenges are not systematically addressed, yet change management is recognized as an enabler to advance on the road to AI maturity	• National guidance for change management is provided with roadmaps and processes for effectively addressing technology implementation, including behavioral issues or job transitioning • Relevant national working groups for effective technology change management are empowered	• Change management best practices are co-created with diverse stakeholders, and their roadmaps and guidelines are being implemented with top level sponsorship • A strong portfolio of specific trainings in change management is established
Agile workforces and people		
–	• Workforce upskilling in agile methodologies and human-centric design (HCD) are supported by the health system	• Health systems have fully incorporated agile methodologies and HCD, as transversal methods to reduce workforce and expertise silos and empower structured pilotism
General workforce		
• A working group focused on establishing robust and empowering workforce policies for AI in health has been set up or is in the making • Collaborations between ministries (e.g., education, ICT and health) are ad hoc • Opportunities to increase the digital literacy of the general population exist but are not widely used	• Policies supporting a highly skilled workforce are operationalized on a national level and institutions to oversee implementation are established • Collaborations between ministries (e.g., education, ICT and health) are driven by a national strategy • There is a national drive to increase the digital literacy of the general population through a diverse set of channels, and these are tailored to various age groups and vulnerable populations	• An ecosystem of national policies supporting a highly skilled workforce (in terms of workers' rights, social benefits, and educational policies) is established • The impact of these policies is regularly reviewed and processes for continuous improvement are defined • Collaborations between ministries (e.g., education, ICT and health) are fully integrated into the digital health and DSAI ecosystem • Increasing the digital literacy of the general population is one of the foremost priorities of national governments and measurable targets have been identified and linked to specific education campaigns



2. Data & technology

Data, models, algorithms, interoperability, and technology are all part of an AI system that enable it to positively impact health and care. Constituent parts need to meet certain requirements. Large volumes of quality (ideally annotated) data that are representative of the target population are key to adequately train AI models. Technologies and datasets need to be interoperable and benefit from validated data annotation processes to be useful in healthcare, and algorithms need to be fair and transparent to gain real traction. Solutions should also address a human need, strengthen health systems, and improve outcomes. Maturity indicators for data and technology include data foundations, security and privacy, standards and interoperability, AI explicability, data consumption, and business intelligence.

Policymakers and governments need to create policy frameworks, regulations, and initiatives that set guidelines, minimum standards and best practices for health-related data and technologies. Governments should also develop guidelines and policies to foster the transfer and tailoring of successful solutions and best practices from other countries to the national context. It is the role of governments to create and nurture an AI for health ecosystems that fosters integration of solutions in the local health and care systems as well as their continuous improvement during deployment.

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Data foundations		
• Publicly accessible databases (crucial for AI learning systems) are not nationally supported • Data sharing occurs on a case-by-case basis (requiring individual agreements for each transfer) • Data ownership is governed by basic rights without technical guidelines and limited options for owners to indicate preferences regarding data use and distribution • An active national effort exists to consolidate health data, provide guidance on data security, data sharing protocols, and data solidarity. There is also a national effort to establish legislation on AI in health • The government has established ad hoc efforts or a working group to set up best practices for data validation and data quality	• Basic health records are stored in a secure national database while non-sensitive data from other national repositories is publicly available • Sharing agreements between health organizations are established and government actors are/have drafted a nation-wide framework for health data sharing, data collaboratives, data solidarity and altruism, and/or a data marketplace • A dedicated governmental working group to drive data foundations has been set up • The government proactively shapes norms and policies for data validation and is setting quality requirements for health data. Regulators publish guidelines on data validation for AI systems but do not have a dedicated agency or sub-agency group • Regulations on data ownership and sharing, with technical guidance on safeguarding control over data use and distribution, have been implemented	• Health records governance occurs on a national level and storage is centralized, in accordance with national/international data privacy and protection regulations (e.g., GDPR). Non-sensitive data is publicly available • Data ownership and sharing is regulated nationally, and sharing agreements, data collaboratives, data solidarity/altruism or a data marketplace that leverage data for public good, are institutionalized and streamlined to enable innovation • Data lineage standards are defined and enforced for direct patient data and for data origins and movements • Data integrity (also for training, validation, and test datasets) is guaranteed through strong data governance and stewardship [163] • The government has issued strong guidelines for data validation best practices, is actively engaged in PPPs that aim to produce high-quality data, and is defining processes for incorporating best practices into health organizations • Regulators have established a dedicated agency or sub-agency group for AI and data validation

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Security & privacy		
• Governments and health systems are starting to shape guidelines on best practices for security and privacy compliance, auditing processes, and the harmonization between data sensitivity and appropriate security layers	• The national government has defined binding privacy and security requirements and corresponding auditing processes	• Security and privacy legislation are enforced through dedicated institutions and regular audits are integrated into the data governance ecosystem
Standards & interoperability		
• At a basic level, governments and health systems are implementing technical interoperability measures, i.e., establishing the interconnectivity requirements needed for systems or applications to communicate data; implementing minimum semantic standards (such as nomenclatures) to ensure meaning is conveyed consistently	• Robust standards for interoperability are defined and enforced nationally, with a focus on structural interoperability, i.e., defining the format, syntax, and organization of data exchange [164] • Specific health IT standards (e.g., FHIR or openEHR) are established	• Robust standards for interoperability are defined and enforced nationally, with a focus on semantic and organizational interoperability, i.e., providing common underlying models and standardized definitions from publicly available value sets and coding vocabularies, and providing shared understanding and meaning to the user[165] • Governance considerations for secure, seamless, and timely data use are integrated into interoperability governance processes • Best practices conform to and co-shape international standards
Explainability		
• AI explainability requirements have not been established, but national efforts exist to provide technical explainability guidelines (e.g., guidance on making AI systems understandable and traceable to humans). While there is no consensus around algorithm and model transparency and bias, the government is establishing a working group to propose recommendations	• AI explainability requirements are formalized for applications requiring regulatory approvals and strong guidelines are in place for others • Beyond technical explainability, this includes interpretability requirements enabling physicians to transparently explain to patients proposed decisions for informed patient consent	• AI explainability is closely regulated and government support extends beyond explainability and interpretability to foster transparent, re-enactive, comprehensible, retraceable, and reproducible models or self-explaining agents
Data consumption and business intelligence		
–	• Basic data consumption and business intelligence metrics are integrated into essential operating processes, e.g., dashboards and interfaces to steer decision-making on how a health organization is deriving value from data, what data is used, how it is accessed, which decisions are data-driven, etc.	• Advanced data consumption and business intelligence metrics, including advanced real-time analytics on outcomes and value generation as well as live feeds on workflow integration, create an ecosystem of data-driven decision-making across the health system and health organization’s business processes

3. Governance & regulatory

The remit of governance and regulatory is wide-ranging. To succeed in healthcare practice, the lifecycle of AI use must be overseen through effective governance and regulations. AI-enabled healthcare requires a health data ecosystem that links health actors within a country's health system and beyond. Good governance practices are critical to ensure the ethical management of health data, AI systems in health workflows, and care delivery through AI tools.

Beyond data, the deployment of AI-enabled solutions in healthcare requires future-oriented governance on maturity indicators such as national AI strategies and budgets, strong political will and industry leadership, clinical and scientific validation guidelines and protocols, governance and stewardship, rights-based approaches to privacy and security, and open innovation with strong Intellectual Property (IP). The central challenge for governance is to harness AI technologies and data for the collective benefit of society (and its health systems) while also ensuring that AI systems and personal health data are managed responsibly and ethically. For policymakers and governments, the fundamental goal is to create a multi-level governance structure that strengthens public trust, privacy and security, and innovations in healthcare.

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Strategy & budgets		
• While no digital health strategy has been established, the government is actively participating in international initiatives around AI in health • Budgets have not been granted or earmarked for digital health, although individual AI in health solutions may be supported opportunistically • While the importance of AI for addressing public health priorities is recognized, no policy documents or AI in health agenda has been drafted • Open innovation occurs only sporadically and is often considered at odds with IP	• The government has published and is operationalizing its AI strategy or a digital health strategy with specific articles on AI, and has allocated dedicated funding (e.g., a percentage of the overall health budget) for AI pathways that support national health priorities • The government and health system actors are actively co-shaping global initiatives and discourse on AI in health • National public health priorities and the role of AI are described in an official document • The government prioritizes the fostering of a broad landscape of AI innovators to innovate for AI in health, as opposed to incentivizing only established players • Open innovation is supported in large initiatives, such as PPPs, and strengthens existing or new IP models. National strategies broadly highlight their value	• There is a dedicated national AI in health strategy that directly links national AI strategies from different sectors with the aim of cross-sectoral support and a learning ecosystem • The strategy is fully budgeted and integrated into the overall health roadmap for multiple years • Health system actors are participating in global thought leadership and agenda-setting for AI in health. The government and private sector collaborate to create an ecosystem for innovation that includes companies and developers across maturity stages, and helps to focus efforts and resources • Dedicated agencies and good governance stewards oversee implementation, outcome measurement, and continuous support • Open innovation is systematically integrated into national strategies and an essential part of the larger innovation ecosystem that is creating new value chains
Leadership		
• The government supports the implementation of AI for health on an ad hoc basis, and top-level support is often missing	• The government systematically supports the incorporation of AI into healthcare at a leadership level • National agencies for key governance and regulatory AI dimensions are established and supported by political leadership	• Creating an integrated AI for health ecosystem across the full application spectrum is a top priority at the highest levels of government and for industry leaders • A digital/AI unit is formally established within the Ministry of Health/ICT • Support stretches across key ministries and executive offices

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Clinical & scientific validation		
• Regulatory bodies set basic rules for clinical validation, without addressing the specifics of AI technologies. Clinical validation is measured against the yardstick of clearly defined regulations, substantiated by criteria that are generally accepted by the medical community, such as authoritative professional guidelines and evidence-based trials	• Regulatory bodies govern clinical validation and include guidelines for AI in health solutions. Clinical validation standards are defined by regulators in collaboration with the medical and technology communities • Regulatory authorities have established guidelines for AI specific clinical trials, such as smaller subgroup trials • Medical academies and societies, authoritative professional bodies, and other experts are involved in setting strong, consent-driven clinical and scientific criteria • Consent-driven scientific validation governs the review of intended use in trials (e.g., RCTs), peer review, or other relevant scientific experiments such AI model testing on historical data (etc.)	• Regulators have defined clear guidelines for adaptive algorithms and AI-based Software as Medical Devices (SaMDs) • Regulatory and clinical validation standards outline special processes for AI based SaMD submissions • Regulators have put in place timely fast-track or subgroup processes for AI solutions • Scientific validation depends on a cross-sector scientific community (e.g., DSAI in health)
AI governance and stewardship		
• AI whitepapers, including those on data, models, and ethical considerations, inform governance best practices and guidelines • Health data management accountability is formalized but not centralized. Rules, standards, and guidelines are not defined nationally	• Data, algorithm, model, digital technology, ethical, and workforce policies inform the governance, acquisition, ingestion, transformation and use of data in health, according to public health priorities • National data stewardship efforts create a public sector platform for creating and managing health data, documenting relevant rules and standards, and managing data quality	• Data, algorithm, model, digital technology, ethical and workforce policies, are sufficiently robust to achieve the strategic national transformation for a data-driven health future • National data stewardship efforts define guidelines for data controls, rules and uses that are underpinned by policy and champion all data as an asset for public health.[166] There are concerted national efforts to comply with and co-shape international standards and policy frameworks • Data stewardship is formalized and ensures that data policies and standards are turned into practice, including regular audits
Rights, privacy, and social contract		
• Basic security policies and regulatory guidelines for technical data privacy are formalized in legislation • Security layers are implemented ad hoc depending on the requirements • No formal accountability mechanisms have been defined by the national government, but first efforts in this direction are taking place in working groups	• Strong rights, especially fundamental rights such as non-discrimination and equality as a human right, as well as privacy, are integrated into health system operations and governance structures • Security layers correspond to privacy compliance requirements, but do not go beyond these • A social contract is described in a whitepaper or guidance that outlines the entitlements and obligations of all participants in the health system	• Robust data privacy and data security policies are established regarding the proper handling of health data – consent mechanisms, whether and how data is shared, for what purpose, and how data is collected and stored, as are regulatory restrictions such as GDPR, HIPAA, GLBA, or CCPA • In addition to fundamental rights, more advanced rights such as the ability to govern secondary use of data and ethical considerations, are defined and within the control of data owners • Security layers are automatically aligned with privacy compliance requirements and protect data integrity, sharing, and owners • Accountability mechanisms have been formally integrated into good governance structures • The social contract whitepaper or guidance details professional and institutional obligations of data stewardship as well as the obligations of individuals who enjoy the advantages of health systems and biomedicine as a public good

4. Design & processes

The design of AI-based health and care solutions and the processes that underpin their development, deployment, and continuous improvement are key maturity indicators from a design and process perspective. Human-centered design ensures that AI solutions are centered around the people and health systems they serve. Human-centered design is one of the foundational pillars that enables the successful integration of AI tools into healthcare processes and, particularly, clinical workflows. To achieve human-centered design and health system integration, clear processes that prioritize public health needs and patient outcomes should be implemented and monitored. Put simply, AI tools that are difficult or cannot be integrated into existing health systems have a limited or nonexistent chance of adoption.

Important maturity indicators are: how well AI is or can be integrated into health systems and clinical settings, whether human health needs are put at the center, and whether adequate processes to measure and improve AI performance are implemented. To achieve this, decision makers should prioritize legislation and guidelines, and also partnerships and collaborations that put humans at the center and deliver value to health workers, end users, and health systems at large.

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Health system and workflow integration		
• Valuable AI technologies are not systematically integrated into the existing health system, but require individual adoption processes and protocols for the organizations implementing them • Government agencies and health system managers start to work together to give guidance on AI health system integration • Clinical workflows are not sufficiently adaptable to new technologies and require substantial alterations or regulatory adjustments for each AI solution	• While solutions are developed with an agile approach, their integration is often challenged by existing bottlenecks within the health, regulatory, clinical and payer environments • National guidelines on integrating AI-driven health solutions have been co-created by relevant government agencies and health players • The integration of AI solutions into clinical workflows is enabled through stepwise protocols and targeted guidelines and rules on clinical processes, equipment requirements, and information generation/consumption. Clinical workflows have been updated or are easily updatable due to the advances of digital and AI technologies • Given variations between diverse health systems, solutions are designed with modularity in mind, facilitating the customization for country-specific requirements • The benefits and health outcomes of AI solutions are measured on a frequent basis, but no clear decision-making process has been defined • Gap analysis for technical requirements, user requirement specifications, and target solution profiling has been conducted, and collaborations between health organizations and innovators are taking place	• AI solutions are an essential and integrated component of the health system, with outcome reviews built into regular cost-benefit analyses. Integration into the health system is streamlined and follows clearly outlined processes, and can be completed with relative ease thanks to robust guidelines, agile health organizations, and predefined workflows • In addition to robust guidelines, a working group for the continuous improvement of AI health system integration has been set up and provides frequent updated guidance • A modular design to enable customization for country-specific requirements and specific health organization demands is part of best practice guidelines. • Clinical workflows and AI solutions are fully integrated processes and an important pillar of the health system ecosystem. All relevant medical equipment is a connected device. Guidelines are regularly updated and adapted to new technological specifications • The benefits and health outcomes of AI solutions are continuously measured and directly influence decision-making processes and BI

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Humans at the center		
• The localization of AI-based health solutions is not a supported national priority and only supported ad hoc • Local capacity building for health workers is limited to individual efforts that focus on the implementation of a specific AI solution and is available only to a small group of the workforce • No formal human-in-the-loop design guidelines exist, only draft documents and initial working groups are in the making, as the importance of this design feature is widely recognized by health organizations and policymakers	• Health solution localization for AI technologies is recognized as vital to addressing public health priorities in a human-centered manner, collaborating with local partners including key groups that are often excluded, e.g., children, youth, women, people with disabilities, minority groups, rural communities • Basic e-resources, such as websites and registries, exist that connect solution developers with local hospitals, local government institutions, citizen scientists, or other local stakeholders • Local capacity building for health workers is focused on specific solutions and scaled through virtual platforms (e.g., e-courses) • Clear AI design principles, guidelines, and processes for human-in-the-loop design have been developed by public-private initiatives and are government endorsed. They range from general governance and ethical considerations, to technical protocols for looping in human decisions and review cycles	• National guidelines for localizing AI in health solutions are co-created by a PPP and published as an official guidance, all key local groups outlined are integrated into the design and deployment of AI solutions • Tailoring products to the local context is systematically supported through public-private initiatives that connect solution developers with stakeholders such as local communities, creating a platform to foster the co-creation of human-centered design. The partnership also helps improve market awareness and identify health needs while guiding product localization by hosting stakeholder workshops, design sessions, knowledge exchanges, and agile co-creation sprints • Local capacity building for health workers is supported through an ecosystem of virtual resources and includes formal certification programs for specific AI in health solutions • In addition to the public-private endorsed guidelines on human-in-the-loop design, the principle that AI is meant to support humans and not replace them, is integrated into design guidelines and national recommendations
Model KPIs		
• Health systems have not defined processes for keeping track of the number and performance of integrated AI models, and substantial legacy models exist. Health organizations lack dedicated data stewards but have begun to define these roles and are establishing relevant processes	• Health systems are keeping track of the number of integrated AI models and are regularly eliminating or updating legacy models. Roles such as data stewards have been recruited and formally defined as part of the data strategy of health organizations	• Health systems track all active and non-active AI models integrated into health organizations and continuously measure model performance for optimal organizational results. In addition, standard KPIs for using AI in health are benchmarked and assessed • Successful models are shared as an open-source public good internationally

5. Partnerships & stakeholders

This area of AI maturity relates to strategic, purpose-oriented partnerships that leverage collaborations and agreements to aggregate and use diverse health data for better delivery of health and care. Strong partnerships and stakeholder engagements fuel AI innovation and positive health impact. They usually foster a diverse landscape of small, medium, and large innovators, rather than one dominated by a handful of multinational companies. A landscape with companies of different maturity levels and approaches to addressing public health problems is the true litmus test of a country's AI innovation ecosystem.

Maturity indicators for this area of AI maturity include high-level political support and the ability to leverage needs-oriented partnerships, limit fragmentation by supporting strategic pilots, and successfully engage stakeholders. An enabling environment for partnerships decreases the burden on governments by drawing upon a wide network of experts from the private and public sectors, academia, and civil society. The role for governments is to clearly define the priority health needs and to create policies and legislation for innovation around these priorities. When governments drive and leverage such PPPs, they can harness private sector capabilities for the public good.

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Political support		
• Political support from individual ministries for AI in health focuses on a few individual solutions • There is no extended track-record for AI in health policy continuity, yet there is initial government action focused on drafting relevant legislation supporting AI for health	• Broad political support for AI in health exists across various ministries; senior government officials actively participate in co-shaping AI health frameworks in international initiatives • There is clear policy continuity for the most central aspects of AI in health, such as those directly aligned with public health priorities	• Heads of state and all relevant ministries directly support an integrated AI in health ecosystem that systematically addresses public health priorities • AI in health enjoys support across all major political parties and actors, and policy continuity is guaranteed
Needs-oriented partnership strategy		
• Health system-related partnerships for AI are set up on an individual basis and without cross-coordination to maximize outcomes and integrate capabilities • While PPPs are being discussed, no such initiatives are operational yet • Existing partnerships do not include predefined KPIs to monitor and improve processes tied to important milestones	• Health system-related partnerships are streamlined and driven by clearly defined health needs, KPIs, and continuous improvement processes • PPPs on AI in health have been set up and are well funded. They include multinational participants as well as academic contributors	• In addition to being needs-driven, partnership strategies include a focus on the cross-coordination between partners in different sectors to cultivate cross-sectoral learnings • Public-private partnerships span multiple sectors and form part of a collaboration ecosystem that aims at driving value creation for public good – for health and beyond
Structured pilotism to counter fragmentation		
• Pilotism is supported by a broad remit of actors ranging from IOs, INGOs, and governments; however, there is little or no coordination between disparate pilot projects	• The value of innovative pilotism is widely recognized by public-private actors and is brought under an organizational umbrella to maximize value generation while minimizing duplication and a lack of coordination	• The umbrella structure for coordinated piloting is integrated into the larger ecosystem of scaled and operational AI in health solutions as well as into cross-sectoral working groups. Funding opportunities can be managed through a centralized platform designed for funders and donors

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Broad stakeholder engagement		
• Limited stakeholder awareness, not driven by strategic value assessments	• Advanced awareness; stakeholder engagement encompasses a broad remit of relevant actors at national level	• High levels of stakeholder awareness and engagement encompass actors on both national and international levels, ranging from patient organizations to IOs and INGOs to civil society and local players

6. Business models

The economic and financial viability of the health ecosystem is an essential pathway on the road to AI maturity, as it directly determines if innovators exist and can cope with shifting demand, regulatory environments, and national health priorities. Without sustainable business models, there are no innovators. A mature landscape includes policies that foster diversified funding portfolios, incentive structures for innovators, pathways to monetize assets including data, insights and products, and commercialization strategies with vested IP rights. Maturity also refers to a market's ability to break down technology and health silos and systematically connect health stakeholders.

Maturity indicators here include diversity and sustainability of funding, incentive structures for innovators and multinationals, monetization of assets, and overall sustainability of business models.

Level 1: Exploring	Level 2: Emerging/activating	Level 3: Integrated ecosystem
Funding		
• Majority of the funding stems from grant funding/ad hoc investments	• Funding opportunities exist from large donors and financial support is aligned to priority national public health needs	• A network of national and international funders exists and supports companies at different maturity stages
Incentives		
• Limited incentives, such as tax benefits, are in place • Usage remains low due to the technical nature of applying for incentives	• Health system players are making use of incentive structures, e.g., tax benefits, tax immunity, or government grants, and are incorporating these into business models	• Health system players are making use of incentive structures, beyond tax benefits to also include innovation parks, grand challenges, and other initiatives, while systematically incorporating them into business models
Monetization		
• No real monetization strategies exist and there is heavy reliance on external funding sources	• Health system players are piloting new strategies to monetize data. This includes data that can be made usable (consumable) for different purposes, and selling the insights coming from the data analysis	• Health system players are systematically monetizing solutions and data, while scaling core capabilities and products for (out-) licensing or financial collaborations, with governments, INGOs, IOs, or private sector players (e.g., life sciences companies)
Business models		
• Sustainable business models have been introduced with limited scope and no national guidance exists • National funding for AI in health is not led by dedicated budgets but builds on existing budgets	• Health system players are testing and piloting sustainable business models, while still largely relying on external funding • AI in health has a nationally dedicated budget and forecasts for long-term sustainability	• Health system players are scaling product and business models to target large NGO, commercial, or government adoption of AI solutions

6 Actionable recommen-dations & call to action

Actionable recommendations and call to action

Thanks to major scientific, medical, and technological advances, patients have never had better chances of receiving quality of life improving or potentially lifesaving care. AI is establishing itself as a paradigm shift, profoundly transforming the ways in which preventive, curative, rehabilitative, and palliative care are delivered. Yet, to unlock the full potential of AI in reimagining health systems and improving and extending lives, an enabling ecosystem for AI in health is required.

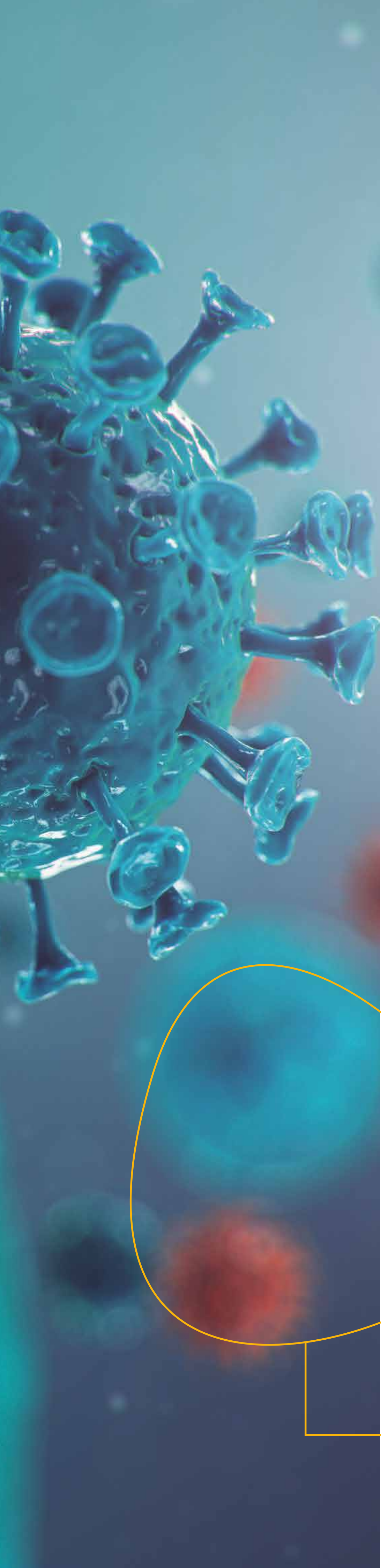
Previous work by the Broadband Commission, including its 2017 and 2018 digital health reports, showed that broadband internet connectivity is foundational to many digital tools; it is a critical enabler for AI innovation and tools too. Strong equitable public policies and investments to widen access to affordable broadband and internet connectivity are key in the world today, as has been irrevocably highlighted by the COVID-19 crisis.

The report calls for global action to create meaningful legislation and robust policy frameworks that build and incentivize an AI-enabling environment, especially in LMICs. Six areas have been identified as critical for countries to progress on the way to AI maturity. Progress on that road empowers health systems to best use AI capabilities to their priority health needs. Particularly in LMICs, AI has the potential to help overcome growing health challenges, including rising healthcare costs, demographic and epidemiological shifts, unmet health needs related to the dual burden from infectious and noncommunicable diseases, and a significant shortage of skilled health professionals.

Policymakers, governments, industry leaders, innovators, and investors play a crucial role in helping the world progress toward mature integration of AI in health systems. This actionable recommendations and call to action section describes the most important steps for advancing countries on their path to AI maturity. It also identifies critical big bets and promising investments. Each country is beginning or continuing its AI in health journey from a different point, with some of the infrastructure, policies, and other enablers already partly in place. This report provides detailed recommendations, yet without a generally correct order to follow. It is essential to advance on all fronts, to identify the specific gaps to address and capabilities to leverage. As such, the maturity roadmap is a referential, not step-by-step guide.

Actions and recommendations have been identified for the following groups:

- Ministries of health, finance, education, and technology
- INGOs, civil society, and implementers
- Private companies, broadband connectivity providers, and startups
- Advocacy groups
- Health organizations (e.g., teaching hospitals, health centers, pharmacies)



AI and COVID-19

While COVID-19 has brought the physical world to a near standstill, the digital world is booming. The global response to the viral pandemic has put the spotlight squarely on digital tech and AI's transformative power in health and care delivery. The world's response has shown that concerted global, national, and regional efforts across sectors can enable and fast-track AI tools to help reduce the human resource and pandemic response constraints experienced by overcrowded and overburdened health systems. Thanks to new collaborations, the introduction of emergency authorizations by governments, public-private sector funding, and a sense of global urgency, AI innovation has produced tangible successes, including:

- Speeding up testing
- Early detection and diagnosis
- Contact tracking and tracing
- Modeling disease spread
- Modeling countermeasure effectiveness (e.g., social distancing policies)
- Enabling new prevention strategies
- Providing information and education to both the public and health workers
- Triage capabilities for health centers and telehealth
- Health, quarantine, and post-care management
- In-hospital management
- Research & development

AI in health tools have demonstrated they have moved beyond the hype, showing real-world impact and positive health outcomes in record-time while enabling unprecedented scale.

1. People & workforce

Actionable recommendations

1. Strengthen national DSAI capabilities and integrate AI solutions in health
   - Make DSAI a national priority throughout all levels of pre-service educational programs and curricula, in health and beyond.
   - Introduce certified in-service training tailored to the needs of health professionals, health managers, and policymakers. Such training opportunities should also aim to prevent fears of job loss. Introduce scholarship opportunities for data-driven health and care, targeting both health and engineering scholars, and potentially organized in dedicated CoEs or research institutes.
   - Develop a strategy to develop, attract, and retain talent in DSAI and monitor the national availability of DSAI skills regularly, potentially through an annual statistical index.
   - Implement measures to increase the digital literacy of the general population to support AI usage, particularly for youth and vulnerable groups.
2. Integrate AI solutions into health workflows through appropriate change management
   - Draft guidance for effective roll out of AI-driven solutions and their integration in the health system workflows and processes through effective change management.
3. Human-centric design for AI in health
   - Integrate agile methodologies and human-centric design as transversal methods into health system workflows and educational offerings.

Call to action for stakeholder groups

Ministries of finance, education, health, and technology

- Set priorities by focusing on the health system needs and weaknesses that can be addressed or improved with the help of AI. This priority list should be publicly available and revised annually.
- Co-develop policies and regulations for AI in health, potentially with health system managers, hospitals, health professionals, engineers, civil society, and thought leaders.
  - Establish public engagement, support, and trust by creating dialogue mechanisms on the value of data for healthcare and the initiatives leveraging AI.
  - Create cross-organizational working groups dedicated to drafting the policies and regulations.
  - Organize strong pre- and in-service DSAI training and define a strategy to develop, attract, and retain talent.
  - Provide political support and funding for adequate talent and capacity distribution throughout the country.

INGOs, civil society, and implementers

- Participate with the government and private sector in agenda-setting, capacity building, and planning for strengthening DSAI talent and skills.
- Support DSAI content development in national curricula and training programs by seconding expertise or offering scholarships of interest.
- Support health systems to integrate validated AI solutions and to strengthen DSAI service capabilities.
- Engage in PPPs for further research, validation or translating new solutions or evidence into practice.

Private companies and startups

- Complement public sector gaps, e.g., by providing subject matter experts to PPPs or by providing support for professional trainings.
- Share industry best practices for technology adoption, data governance, and change management.

Advocacy groups

- Promote basic human rights related to AI, such as the right to non-discrimination, equality, diversity, fairness, and more technical rights, such as data ownership for secondary uses of data.
- Drive public education campaigns to illustrate the benefits and risks of AI in health (e.g., highlighting appropriate security and privacy measures to promote AI as a force for positive change, such as better health outcomes or more efficient health systems.
- Convene international working groups to share best practices and foster international collaboration.

Health organizations

- Define health organization needs and measures of success where AI can have the greatest impact based on current and future health needs.
- Implement change management best practices for technology adoption and operationalizing of modified processes while also addressing health worker concerns through education and participation. Teaching hospitals should play an active role in providing continued education on data and AI-driven health and care.
- Hire or train stewards on agile and human-centered design and empower them to optimize health operational workflows. Facilitate their participation in PPPs and public initiatives.

2. Data & technology

Actionable recommendations

1. Define national goals for AI innovation to center around priority health burdens and health system gaps. Execute the strategy – including a clear health data strategy, and deploy the resources to achieve these goals.
    - Resources should include physical components for AI (e.g., computer, networking hardware and facilities, connectivity), data science tools, platforms and network components, high data throughput, and ways to allow real-time access.
    - The data strategy has to foresee the necessary processes for digitization and data integrity, training and validation sets, and test datasets. It should also promote open data standards, public datasets, and security layers for data sharing and storage (onsite or cloud). Data sharing, data collaboratives, and data sharing framework agreements should be prioritized for public health needs while strictly safeguarding privacy (whether it concerns ad hoc sharing, framework agreements, or data collaboratives, data solidarity/altruism, or data marketplace ecosystems).
    - The data strategy should also promote good data governance, systematic data validation and advanced analytics across diverse health system applications.

2. Co-create and implement authoritative standards for interoperability (technical, structural, semantic, organizational) and draft consent-driven guidelines for their appropriate implementation in healthcare.
3. Draft legislation on security and privacy standards and implement best practices across the healthcare value chain.

Call to action for stakeholder groups

Ministries of finance, education, health, and technology

- Invest in appropriate infrastructure, such as robust connectivity and storage capabilities (onsite or cloud) for health data and their security layers.
- Make non-sensitive data publicly available and sensitive data privacy-compliant and securely accessible for accredited actors (e.g., for public health priorities and basic research), while promoting framework sharing agreements for streamlined innovation.
- Draft legislation for interoperability standards and regulate explainability requirements while engaging broadly with the public to promote policies on ethical AI (e.g., patient organizations).

INGOs, civil society, and implementers

- Promote, fund, and engage in AI initiatives that implement open data standards, or participate in data collaboratives.
- Foster public forum discussions on data strategies and stewardship, interoperability, privacy and ethics, and the importance of explainability in health.
- Promote exchanges via international technology working groups and government-led efforts.

Private companies and startups

- Lead efforts on AI for Good solutions.
- Produce mature data consumption metrics and RWE, including federated learning opportunities and open-selected data repositories for public health benefits to illustrate AI's positive impact on health outcomes and health system improvements.
- Implement industry leading best practices for standards, interoperability, and explainability in alignment with public guidelines.

Advocacy groups

- Promote open data standards and practices and put explainability and interoperability at the center of good data and technology governance.
- Advocate for strong privacy, security, and data protection.
- Patient organizations to actively participate in policy discussions.

Health organizations

- Collaborate with stakeholders on robust security and privacy policy and implement strong security and privacy layers to cultivate public trust.
- Define clear processes for patient identification, facilitate simple patient engagement and patient access to health information, and improve patient understanding of the benefits and risks of data and AI in health.
- Build a comprehensive database and insights dashboard of patients with integrated clinical, social determinants and claims data.

3. Governance & regulatory

Actionable recommendations

1. Define a national implementation roadmap for progressing on the maturity curve for AI in health. This should include all relevant stakeholders, outline governance – including roles and responsibilities – and foster both government and private sector actions.
2. Develop clear policies, guidelines, and whitepapers to empower strong data and AI stewardship, establish accountability mechanisms, and champion data as a public health asset.
   - These should include policies for continuous monitoring and auditing of AI in health solutions, as well as policies for IP and open innovation for AI in health.
   - Define clinical validation standards and policies for efficacy and safety of AI in health (for the intended use). Drive scientific validation through medical and technology academies, societies, and authoritative professional bodies.
3. Integrate fundamental rights (e.g., rights to non-discrimination and equality), regulatory restrictions (e.g., GDPR, HIPAA), and privacy into legislative frameworks and health system governance.
   - Formalize processes and channels to show how data is used and accessed, building a strong privacy and security governance apparatus.
   - Introduce ethics and rights-based legislative frameworks, including for vulnerable groups.

Call to action for stakeholder groups

Ministries of finance, education, health, and technology

- Drive the government's AI in health strategy and roadmap and involve stakeholders and experts in the process.
- Have regulatory bodies establish clear regulation for market access and clinical validation of AI-based solutions, provide detailed guidelines for AI-based submissions and fast-track procedures, and collaborate broadly with external stakeholders for knowledge exchange.
- Enact strong privacy and security protections and detail the implications of AI on fundamental rights.
- Foster policy frameworks for open or co-innovation in AI for health, and international cooperation models for policies on AI, health, and education.

INGOs, civil society, and implementers

- Support the government in creating national AI in health strategies through international collaborations, PPPs, working groups, and other initiatives.
- Work with the government to foster strong human rights and security for AI in health.
- Organize or participate in forums to co-define AI for data governance and shape initiatives.

Private companies and startups

- Healthcare and technology industry partners can work with governments to address gaps with expertise or knowledge transfer to support AI as a public good.
- Work closely with regulators to streamline review processes and market submissions.

- Implement clear workflows and processes to guarantee respect for human rights and compliance with regulatory restrictions and enactment of best practices.

Advocacy groups

- Promote strong leadership for AI in health to achieve public health goals and UHC.
- Establish watch dog bodies for governance and regulatory compliance in AI in health.
- Push for the adoption and continuous enforcement of fundamental rights for the real-world application of AI in health as well as for basic research.

Health organizations

- Provide experts who can aid in the drafting and continuous improvement of the national AI in health strategy and implementation roadmap.
- Medical and technology societies and academies cultivate consensus and validity around scientific and clinical validation of AI solutions.
- Make rights and privacy the basis of health organizations' data and analytics strategy to cultivate trust.

4. Design & processes

Actionable recommendations

1. Health system and workflow integration
   - Assess needs and opportunities for implementing AI solutions that can strengthen health systems, such as operational process optimization, more accurate and faster diagnosis, or other solutions that can improve quality of care or reduce workload for health professionals.
   - Establish human-in-the-loop and localization as standard practice for AI in health solution development, deployment, and continuous improvement.
   - Define KPIs for monitoring and assessing the scalability of AI solutions across different levels and use cases of health and care, and for tracking active and non-active AI models throughout the health system, while also quantifying their impact on health outcomes, efficiencies, and other metrics.

Call to action for stakeholder groups

Ministries of finance, education, health, and technology

- Draft and continuously update authoritative guidelines on integrating AI into health system processes; collaborate with health system leaders to define best practices, protocols, and workflows.
- Support public initiatives that focus on human-centric design in data and AI-driven healthcare.
- Establish a position for human-centric design within the ministries of health and ICT.
- Define KPIs for monitoring the scalability of AI solutions and for tracking active and inactive models.

INGOs, civil society, and implementers

- Provide health system, governance, or policy expertise to national and local health system leaders and managers.
- Co-develop human-centric AI principles.
- Patient groups to seek participation in design of AI for health.

Private companies and startups

- Work closely with health organizations to ensure AI is designed for adequate health system integration.
- Provide integrated solutions for model and performance tracking compatible with HIS.
- Foster human-centric innovation, e.g., through an innovation platform, innovation campus, or innovation week.

Advocacy groups

- Establish strong relationships with local stakeholders and incorporate them into innovators' business development and solution design.
- Showcase the evidence of AI's positive impact on health and collaborate with stakeholders to help health systems integrate AI.

Health organizations

- Actively collaborate with innovators, developers, patient groups, and industry leaders to help develop AI solutions, thus streamlining clinical/healthcare adoption; assist government agencies in drafting authoritative guidelines for AI health system integration.
- Organize or participate in initiatives on human-centered design and highlight its importance for patient usage, adherence, and outcomes.
- Build and invest in capabilities and competencies to track AI models within a health organization and to measure health outcomes or other KPIs that feed into a continuous review and improvement cycle.

5. Partnerships & stakeholders

Actionable recommendations

1. Ministries and industry leaders prioritize and support AI as a tool to improve health and care delivery and strengthen health systems.
2. PPPs focus on the public purpose of improving health, and coordinate efforts to avoid fragmentation while minimizing the complexity and bureaucracy of partnership operations.
3. Establish an organizational innovation umbrella to counter fragmentation, such as an innovation park or framework that is aligned to public health priorities and donor interests. A forum for stakeholder discussions and coordination is also established.

Call to action for stakeholder groups

Ministries of finance, education, health, and technology

- Ministries at the highest level formally support prioritizing AI technologies to improve healthcare and health systems, and provide relevant human, financial, expert, and other resources.
- Offer a centralized, reviewed, and government endorsed framework and/or platform for more effective partnerships.
- Support the establishment of a government-supported innovation park.

INGOs, civil society, and implementers

- Showcase the transformational real-world impact of AI on health systems and outcomes (lobbying) to foster strong political and leadership support.

- Develop detailed reports or guidelines on effective partnership strategies in the age of AI and an agile workplace.
- INGOs, patient organizations, and civil society participate in initiatives for overall health benefit through expert commissions or citizens' science.

Private companies and startups

- Industry leaders and innovators promote the role of AI in healthcare and engage in public events such as innovation and technology conferences or discussions.
- Provide a focused overview of the strategic aims and general role of partnerships in achieving better health outcomes; participate in innovation events and conferences as well as PPPs.
- Support pilot initiatives and provide (in-kind) assistance to scale them.

Advocacy groups

- Promote the positive societal and health benefits of innovation parks, grand challenges, and research clusters.
- Act as a catalyst for integrating AI solutions in health by pooling different stakeholders and interest groups.

Health organizations

- Establish a formal role for partner engagement with direct reporting to executive leadership of major health organizations.
- Collaborate directly with government agencies to highlight the largest health system pain points and AI's potential to address these, as well as experiences and lessons learned.
- Enroll only in pilots that pass a basic test for scalability and stress.

Multiparty data collaboratives

Multiparty collaboratives are a critical enabler for the health industry to convene various stakeholders and expand data partnerships with other industries. These collaboratives establish a shared purpose of building the next set of intelligence to help reduce disease burden, bring operational efficiencies within local markets, and enable new cross-border opportunities.

To facilitate these collaboratives, cloud platforms enable low-friction data sharing within trust boundaries defined by the partners. This fosters the powerful network effect realized by combining efforts across industries with unique capabilities. This could support marketplaces and collaborative workspaces that combine assets from various stakeholders. It will also drive unique developments in multiparty AI that will pave way to new dimensions in model validation and efficacy, while establishing feedback loops from the first mile. Microsoft's collaborative efforts across cardiology, eyecare, and pathology with leading healthcare providers in India and the US in 2018-2019 (see Apollo spotlight on page 54) as well as Microsoft's Open Data Campaign in 2020 are concrete steps in this direction.

With an exponential growth in the amount of data being generated across the world, there is an increasing recognition that this data should play a critical role in solving some of the most difficult public health problems. Data collaboratives make use of PPPs, innovation capabilities, disparate data, and our increased ability to analyze datasets to generate public value and solve some of society's greatest health challenges.

6. Business models

Actionable recommendations

1. Funding
   - Create, simplify, and promote incentive structures for AI solutions that address public health priorities or strengthen the health system, such as tax benefits, tax immunity, government grants, in-kind benefits, and other benefits.
     - Incentivize sustainable business models so the scaling of AI in health products and services can be supported through national and private sector investments.
     - Implement agile budgeting for government work related to AI in health.
   - Cultivate an active and broad network of donors and funders that is easily accessible to innovators and startups.
     - Explore the use of innovative financing mechanisms for initiatives with social impact such as AI in health. This can bring new sources of capital to AI and increase incentives for health outcome and impact monitoring of AI in health solutions.
     - Public research institutions and universities should collaborate to commercialize research and vested IP rights.
   - Develop and support sustainable monetization strategies that are aligned with public health priorities and also privacy-compliant (e.g., consumable data, results and insight monetization, scaling capabilities and products for (out-) licensing, etc.)

Call to action for stakeholder groups

Ministries of finance, education, health, and technology

- Establish strong relationships and incentivize donor investments in the national AI in health innovation sector.
- Co-fund the establishment of a national AI for health R&D program or PPP.
- Introduce or support innovative financing for AI in health, e.g., social impact bonds.

INGOs, civil society, and implementers

- Fund or connect with donors for AI in health projects that meet criteria such as health system impact, patient outcome, open innovation and data, etc.
- Publish thought leadership and/or guidelines on fair and privacy-compliant data and insight monetization practices.

Private companies and startups

- Startups, industry, and donors collaborate on novel and sustainable business models addressing public health and global health challenges.
- Drive efforts to scale social impact business models that leverage AI for public health.
- Industry leaders offer grand challenges, prizes, in-kind payments (e.g., expertise) to up-and-coming innovators.

Advocacy groups

- Promote fair and privacy-compliant data and insight monetization practices.
- Address public health priorities and implement best practices for promoting patients' rights.

Health organizations

- Health organizations grant access benefits (e.g., data, patient access, research, etc.) to AI in health developers that are likely to have a large, positive impact on the organization and health system.
- Health organizations participate in health organization networks and promote evidence-based adoption of solutions with proven positive impacts.

7

Conclusion

Conclusion

AI is revolutionizing healthcare with new, game-changing capabilities and reshaping societies and global economies along the way. This report has demonstrated that AI has moved beyond the hype – it is here to stay.

AI is addressing growing global and national health challenges. It has become a multi-billion dollar industry, projected to reach USD 31 billion by 2025. More importantly, AI solutions in health are creating real-world impact, improving patient outcomes, strengthening health systems, and accelerating UHC across the world.

However, AI's positive impact on health is not automatically spread equally across countries and regions.

Health challenges in LMICs

The longstanding and systemic health challenges in LMICs include:

- A shortage of health workers
- Emerging threats
- A dual burden of disease
- Underserved populations
- Rapid urbanization
- Misinformation & disinformation

AI is already a major force helping to address these challenges and has the potential to fundamentally uproot how health systems tackle these problems and provide quality care to patients.

The report holds that while LMICs may have the most to gain from AI's radical potential to transform health systems, they may also have the most to lose. The report also holds that LMICs, with lower regulatory constraints and legacy infrastructure, may be well-positioned to make fast gains in AI in health.

The report identified five use cases for how AI is applied in health:

1. AI-enabled population health
2. AI-enabled preclinical research & clinical trials
3. AI-enabled clinical care pathways
4. AI-enabled patient-facing solutions
5. AI-enabled optimization of health operations

Real impact

Examples of AI in health solutions deployed in real-world settings and having positive patient impact go far beyond what this report can showcase, yet the examples illustrate some of the capabilities AI can bring to health today.

We have only scratched the surface

To systematically bring AI capabilities to the next level, countries should be proactive and foster a robust enabling environment for needs-driven AI.

We urge global action and solidarity from all countries to invest in AI in health – the value of which COVID-19 has critically demonstrated.

To help governments and other stakeholders create the necessary enabling environment and to build and continuously improve a healthcare innovation ecosystem, the report identified six areas that countries should prioritize to advance on their journey to AI maturity:

1. People & workforce
2. Data & technology
3. Governance & regulatory
4. Design & processes
5. Partnerships & stakeholders
6. Business models

Zooming out: reflections and conclusion

A new paradigm
AI is fundamentally changing the healthcare landscape: it is rendering health and care delivery more accessible for patients, both in terms of the participatory and interactive nature that AI enables, which empowers patients to take charge of their own health management, and in terms of its geographic reach – especially for people living in remote areas far removed from health centers. Health systems are constrained by both the rate at which they can train, organize, and deploy human labor and by human limits themselves. However, AI can help overcome such scale limitations to help reimagine how health and care are delivered to patients and how patients engage in their own health management.[167] Moreover, if used correctly and with the right governance, AI can help address health inequalities.

Continuous, connected data and the AI solutions that build on them enable governments to make better and more informed decisions for the benefit of health systems and countries.

Beyond the recommendation for governments and stakeholders to build up and invest in the six areas for AI maturity in health, sustainable AI health solutions need to be prioritized. Governments and policymakers alike have a major role to play in this.

How to get started?

Collaborations and best practices
Launching AI innovations in health may seem daunting at first, and finding ways to strategically invest in all six areas for AI maturity in health may seem overburdening. Yet, many countries, health systems, and private sector players are already tackling the challenge, providing experiences from which others can learn. This report serves as a guide for policymakers and governments to draw on to achieve larger-scale and more mature innovation and health ecosystems. Leveraging AI also means collaborating: the onus for creating an enabling environment goes far beyond governments and includes private companies and startups, INGOs, civil society, implementers, advocacy groups, health organizations, and large initiatives such as PPPs.

Taking rights and privacy seriously
The importance of ethics, rights, accountability, privacy, and security warrant highlighting. It is critical for all stakeholders to be proactive and co-shape ethical and human rights-based governance. Legal frameworks should be established that enable governments to guide the development and use of AI health tools in a way that reflects societal consensus and public health priorities.[168] To this end, AI in health must be guided by a needs-driven vision and built around human-centered designs.

Financial sustainability
Achieving business and financial sustainability to scale AI in health nationally and beyond remains a tough nut to crack – especially in LMICs.

Protecting citizens against financial hardship linked to out-of-pocket payments for healthcare should be a top priority for governments. This can be done through financing support and by promoting innovative financing models for AI in health solutions. Putting in place a national reimbursement system for AI in health would ensure financial accessibility in the long run.

For sustainable business models, stakeholders should support platforms that connect innovators to donors and provide diverse funding opportunities. Strategies for asset monetization, e.g., of data, insights, and products, should also be fostered while governments create incentive structures (e.g., tax breaks, innovation parks) to support innovation aligned with health needs.

This report has identified and highlighted best practices and the conditions needed to build a sustainable AI in health ecosystem that addresses critical health needs. It has put forth recommendations for stakeholder groups around the six areas for AI maturity in health that empower countries and other stakeholders on their path to maximizing the positive impact of AI in health and care.

What comes next?

More research is needed
AI in health is a constantly evolving field of innovation, where actors from all sectors are building or supporting the next generation of AI-enabled health tools. In this context, it is critical to monitor new developments, keep track of and actively push change, assess and reassess investments, update use cases, and actively follow transformative innovations. The speed of transformation also means governments and other stakeholders are never really done – additional work and continuous updating are the only constant. Specifically, we identified a handful of areas where governments, industry, AI practitioners, health organizations, and civil society have a crucial role to play.

Ethics and law
New government regulation and legal frameworks are needed in the age of AI. Research into AI and human rights, privacy, accountability, transparency, and fairness should be combined with technical research on AI design and AI usage in real-world settings.

Explainability standards
AI systems should be designed and implemented in a way that is understandable to decision-makers – from policymakers to doctors to patients. Research into the principles and requirements that guide this is a critical priority. Recent studies have shown that transparency and explainability principles rank highly as public concerns. Stakeholders need to come up with workable solutions to address this concern and cultivate public trust in AI in health.

Evidence
Evidence generation, validation, and replicability for AI tools in health require the highest levels of proof. Studies that seek to determine the accuracy, sensitivity, specificity, or other measures of correctness, should meet the highest scientific standards and be based on standardized processes for evidence generation and evaluation. More research and global action are required in this important field. The ITU's Focus Group on AI for Health is leading the way with a working group on regulatory considerations and evidence standards.

Fairness

Bias and representativeness questions ask about the impact of technologies and their underlying assumptions, and how these affect individuals globally. Fairness principles ask for AI systems to be designed and used to maximize impartiality and promote inclusivity by design and by policy, and to ensure that inclusiveness of impact and access are safeguarded. This includes the standardized generation of evidence with an equity aim and operationalizing feedback loops based on the feedback of those affected by the AI solutions. Critical research into how fairness can be made a system feature of AI is a much-needed north star.

General liability and accountability frameworks

Policy and legal frameworks for liability and accountability mechanisms for AI in health need to be developed and discussed on the national and international stage. This includes general questions on accountability and liability, but also on verifiability, replicability, monitoring, and impact assessment norms.

AI in health tradeoffs

The AI in health community should clearly define a set of foundational questions that help countries quantitatively and qualitatively assess if a health problem can benefit from AI capabilities and identify potentially important tradeoffs. Such a framework should guide any country in its assessments for where to deploy AI in healthcare settings.

Secure and privacy-preserving data monetization

Innovative, sustainable business models for AI in health partly hinge on the monetization of data and insights. Yet, both data and insights need to be commercialized with the consent of data owners and should be aligned with their interests. Research in this field is much needed, including exploring different forms of consent (e.g., auto-consent, opt-in/opt-out), easy-to-use patient data platforms, or a fair data marketplace for personal data management.

Leapfrogging

LMICs have the ability to leapfrog HICs through the use of technologies, and many LMICs have done so. Mobile phones, e-banking, e-commerce, and even blockchain applications are all technologies that users in LMICs have often adopted faster and more comprehensively than their peers in HICs. More research is needed to study the extent to which the ability to leapfrog also applies to AI, both in the application of AI solutions and even more so in their development.

Building a maturity toolkit

This report has built a detailed roadmap based on six areas for AI maturity, outlining a step-by-step, high-level roadmap with critical milestones and key enablers. Further developing this roadmap into a detailed and interactive toolkit that governments and other actors can use to guide their investments is a critical next step.

Today’s new realities

COVID-19 is reshaping the world and LMICs may end up some of the hardest hit by the pandemic and its aftermath. The virus has shown that while the physical world has come to a near standstill, the digital world is booming and impactful collaborations are fast increasing. The COVID-19 world has seen governments fast-track emergency approvals and mechanisms for digitally-enabled testing and diagnosis, drug development, clinical trials, and tracking and management tools.[169] Similarly, new collaboration ecosystems are helping to drive critical investments in digital infrastructure. These trends can help us build more resilient healthcare systems for the future – enabled through digital technologies like AI. Ongoing and sustainable action is needed in LMICs if we aim to truly harness the potential of AI in health. Policymakers, the private sector, INGOs, and other stakeholders have a wealth of experience and knowledge to contribute, and collaboration will be critical if we aim to create an AI-enabling environment that ensures health for all.

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54. Possible Health, SP Kalaunee
55. Republic of Rwanda, Erick Gaju
56. Rockefeller Foundation, Manisha Bhinge
57. RockHealth, Bill Evans
58. Scripps Research, Eric Topol
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Appendix

Appendix 1: Acronyms and abbreviations

AI (Artificial Intelligence)

AIME (Artificial Intelligence for Medical Epidemiology)

AMR (Antimicrobial Resistance)

API (Application Programming Interface)

CVD (Cardiovascular Diseases)

CoE (Centers of Excellence)

CHICA (Child Health Improvement through Computer Automation)

CPT (Cure Parkinson's Trust)

CS (Computer Science)

DSAI (Data Science and AI)

EENA (European Emergency Number Association)

EFPIA (European Pharmaceutical Industries and Associations)

EU (European Union)

EMA (European Medicines Agency)

FDA (US Food and Drug Administration)

FHIR (Fast Healthcare Interoperability Resources)

GDB (Global Disease Burden)

GDP (Gross Domestic Product)

GDPR (General Data Protection Regulation)

GVA (Gross Value Added)

HICs (High-Income Countries)

HIPAA (Health Insurance Portability and Accountability Act)

HIS (Health information systems)

ICT (Information and communications technology)

IHAN (International Human Account Network)

IMI (Innovative Medicines Initiative)

INGO (International Non-Governmental Organization)

IOs (International Organizations)

IoT (Internet of Things)

ICT (Information and Communication Technologies)

IP (Intellectual Property)

ITU (Interational Telecommunication Union)

LDCs (Least developed countries)

LMICs (Low- and middle-income countries)

Melloddy (Machine Learning Ledger Orchestration for Drug Discovery)

NAM (US National Academy of Medicine)

NCDs (Noncommunicable Diseases)

Niramai (Non-invasive risk assessment with machine-learning and artificial intelligence)

NLP (Natural Language Processing)

OCT (Optical Coherence Tomography)

OHCA (Out of Hospital Cardiac Arrests)

P2P (Peer-to-Peer)

PPP (Public-Private Partnership)

R&D (Research and development)

RCTs (Randomized Controlled Trials)

RWD (Real-World Data)

RWE (Real-World Evidence)

SDGs (Sustainable Development Goals)

UHC (Universal Health Coverage)

UNCTAD (United Nations Conference on Trade and Development)

UNESCO (United Nations Educational, Scientific and Cultural Organization)

UNICEF (United Nations International Children's Emergency Fund)

USAID (United States Agency for international Development)

US NASEM (US National Academies of Sciences, Engineering, and Medicine)

WEF (World Economic Forum)

WHO (World Health Organization)

Appendix 2: List of solutions for detailed analysis

1. **Ada Health App**	Ada Health
2. **Babyl Rwanda**	Babylon Health
3. **Casalud**	Carlos Slim Foundation
4. **Ping An Good Doctor**	Ping An Good Doctor
5. **Niramai**	Niramai Health Analytix Private Limited
6. **Harmony & Melloddy**	Innovative Medicines Initiative (IMI)
7. **BenevolentAI**	BenevolentAI
8. **AIME**	AIME
9. **Magic Box**	UNICEF Office of Innovation
10. **Corti**	Corti
11. **Predictive Supply Chain for Vaccines**	macro-eyes
12. **APOLLO**	Microsoft & Apollo Hospitals
13. **Akili Interactive**	Akili Interactive Labs
14. **CANTAB**	Cambridge Cognition
15. **Curemetrix**	Curemetrix
16. **3Nethra**	Forus Health
17. **Critical Care Suite**	GE Healthcare & Intel
18. **AI for Rostering**	Hong Kong Hospital (Hong Kong)
19. **AI Breast Cancer Prediction**	MIT CSAIL and Massachusetts General Hospital
20. **Optina Diagnostics**	Optina Diagnostics
21. **ZZapp**	Zzapp Malaria
22. **Accu-Chek SugarView**	Roche
23. **Manthana**	SigTuple
24. **Cicer**	Ten 3T Healthcare
25. **IeDA**	Terre des Hommes
26. **Wysa**	Touchkin
27. **Ubenwa**	Ubenwa
28. **Walklake**	Walklake
29. **X2AI**	X2 Foundation
30. **Visualize No Malaria**	PATH
31. **AI for Leprosy**	Novartis Foundation & Microsoft
32. **Possible Health/NepalEHR**	Possible Health
33. **Premonition**	Microsoft
34. **AfyaData**	Partnership South Africa and Sokoine University of Agriculture, Tanzania
35. **Singapore dengue prediction**	Singapore Government & two local universities
36. **RxScanner**	RxAll
37. **TrueSpec Africa**	TrueSpec Africa
38. **Deep Genomics**	Deep Genomics
39. **DL Inference Solution**	Intel, Zhejiang DE Image Solutions Company
40. **Symphony AI**	Concerto HealthAI
41. **Alibaba Health Information Technology**	Alibaba Group
42. **Pneumococcal Conjugate Vaccine Impact Study (PCVIS)**	Gavi Alliance
43. **Butterfly iQ**	Butterfly iQ
44. **iCarbonX**	iCarbonX

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