frontiers | Frontiers for Young Minds

SPARK-ing Big Questions: What is the Future of Health Technology?

Edited by
Claudia Marcelloni, James Gillies and Ana Godinho

SPARKS! Serendipity Forum at CERN

ISSN 2296-6846
ISBN 978-2-8325-4972-8
DOI 10.3389/978-2-8325-4972-8

About Frontiers

Frontiers is more than just an open-access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

About Frontiers for Young Minds

Frontiers for Young Minds believes that the best way to make cutting-edge science discoveries available to younger audiences is to enable young people and scientists to work together to create articles that are both accurate and exciting. That is why distinguished scientists are invited to write about their cutting-edge discoveries in a language that is accessible for young readers, and it is then up to the kids themselves – with the help of a science mentor – to provide feedback and explain to the authors how to best improve the articles before publication. As a result, Frontiers for Young Minds provides a collection of freely available scientific articles by distinguished scientists that are shaped for younger audiences by the input of their own young peers.

What are Frontiers for Young Minds Collections?

A Collection is a series of articles published on a single theme of research and curated by experts in the field. By offering a more comprehensive coverage of perspectives and results around an important subject of research, we hope to provide materials that lead to a higher level of understanding of fundamental science. Alternatively, a collection could feature articles by scientists who received special recognition, such as a Nobel Prize. Frontiers for Young Minds Collections offer our international community of Young Minds access to the latest and most fundamental research; and, most importantly, empowering kids to have their say in how it reaches their peers and the wider public. Every article is peer reviewed according to the Frontiers for Young Minds principles. Find out more on how to host your own Frontiers for Young Minds Collection or contribute to one as an author by contacting the Frontiers Editorial Office: kids@frontiersin.org

SPARK-ing Big Questions: What is the Future of Health Technology?

Collection editors
Claudia Marcelloni — European Organization for Nuclear Research (CERN), Switzerland
James Gillies — European Organization for Nuclear Research (CERN), Switzerland
Ana Godinho — European Organization for Nuclear Research (CERN), Switzerland

Citation
Marcelloni, C., Gillies, J., Godinho, A., eds. (2024). *SPARK-ing Big Questions: What is the Future of Health Technology?* Lausanne: Frontiers Media SA.
doi: 10.3389/978-2-8325-4972-8

Cover image
FourPlus Studio

Participating sections

Human Health

Engineering and Technology

About this collection

Have you ever been assigned a group project in which your team had to work together to solve some sort of problem? Although not everyone always agrees, you may have learned that collaborating with people who have unique perspectives and interests is a really effective way to generate new, exciting solutions—solutions that nobody could have come up with alone! This is the idea behind an event called SPARKS! Future Technology for Health, which was held at CERN —one of the world's largest and most respected centers for scientific research. A group of around 50 experts, in diverse fields ranging from medicine to computer science to nuclear physics, joined forces to collaborate, learn and unlearn together—all in the name of improving human health.

Technologies with the power to change human lives come with tremendous responsibility. After short talks on cutting-edge health advances, SPARKS! participants broke into smaller groups to discuss and debate big, unanswered questions about these new technologies. Who owns the health data generated by smart watches and other devices? What role should artificial intelligence play in health care? How can we make sure that non-scientists trust new health technologies? These and other tough questions do not have simple answers. For new health technologies to be accepted and used responsibly, society—including you, the next generation —will need to grapple with such questions for years to come.

This Collection highlights some groundbreaking health-related technologies discussed at the SPARKS! Forum, with a focus on the unanswered questions that must be addressed before these life-changing advances can responsibly impact human lives. If you enjoy learning about exciting, health-related advances and like to think about difficult, big-picture questions involving science and society, this collection is for you. Like all Frontiers for Young Minds articles, this collection is reviewed by young students. We hope this collection SPARKS! your interest in the future of human health!

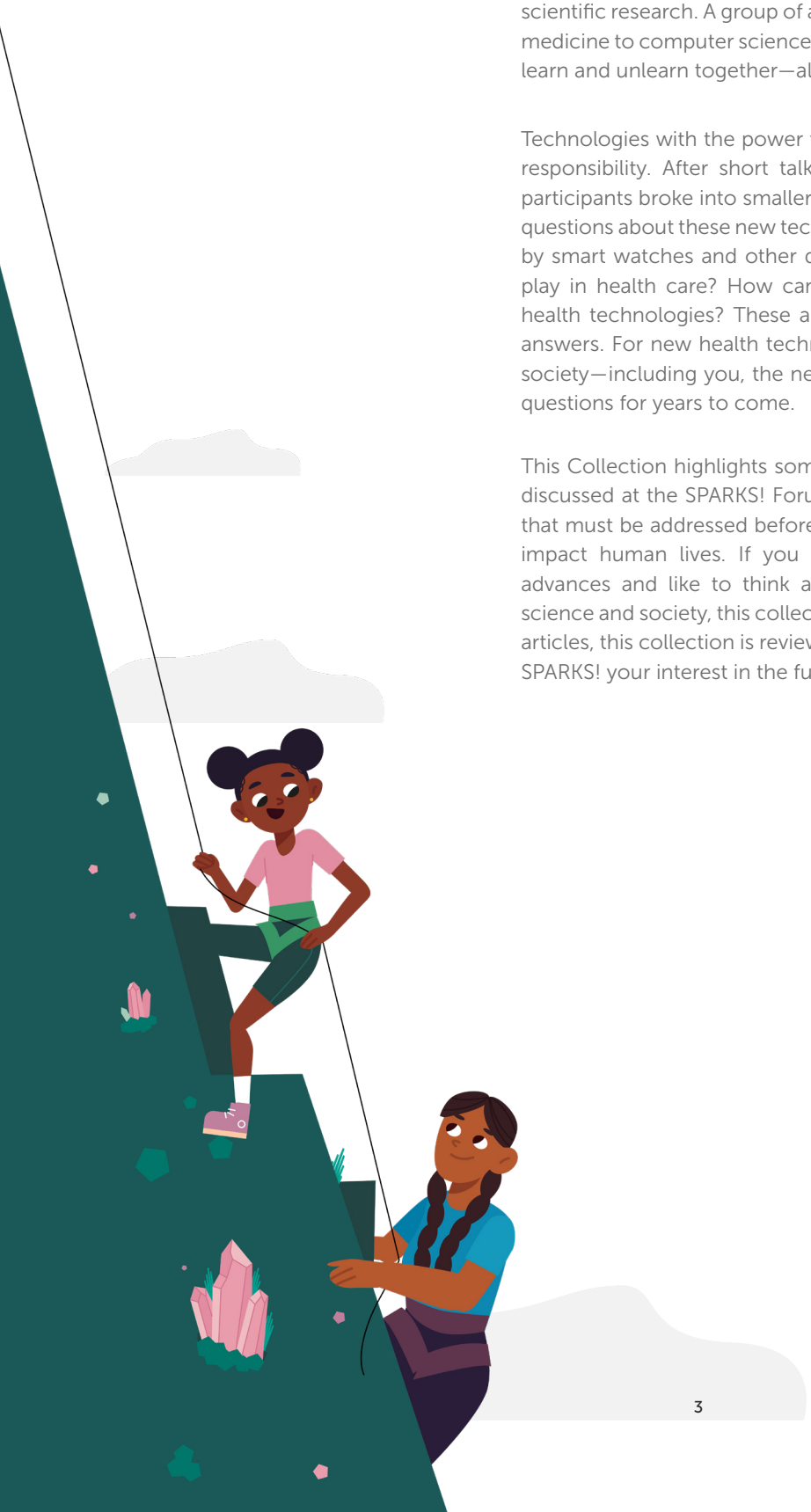
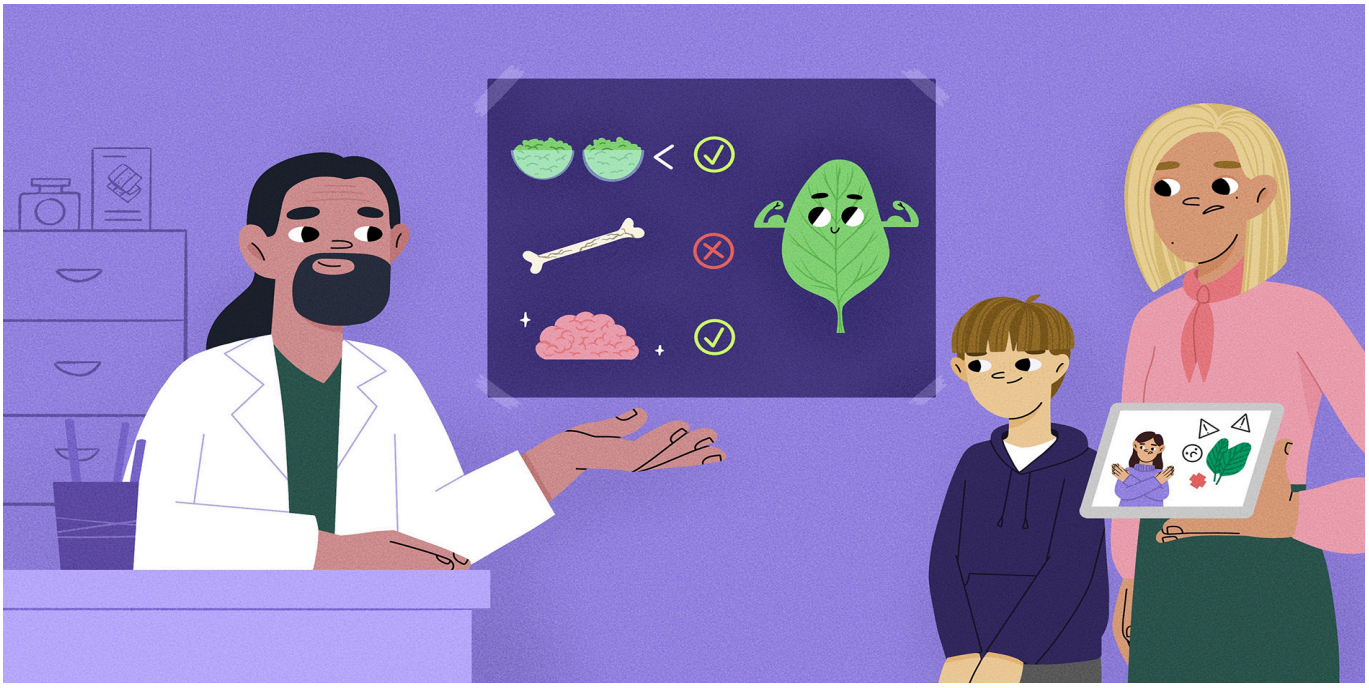


Table of contents

HUMAN HEALTH
Published: 21 May 2024
doi: 10.3389/frym.2024.1303836



HEALTH LITERACY: A TWO-WAY STREET

Susan J. Debad [1*] ***and Kristi Holmes*** [2,3]

[1] *SJD Consulting, LLC, Ijamsville, MD, United States*

[2] *Department of Preventive Medicine, Northwestern University Feinberg School of Medicine, Chicago, IL, United States*

[3] *Galter Health Sciences Library and Learning Center, Northwestern University Feinberg School of Medicine, Chicago, IL, United States*

YOUNG REVIEWERS:

LAUREN
AGE: 11

ROHAN
AGE: 15

SAHANA
AGE: 11

Health information spreads quickly these days, but not all of it is true. That is why it is important to build your health literacy—your ability to find and understand evidence-based health information. When you learn the basics of health topics, it is easier to tell fact from fiction. Understanding science also helps you trust experts like health professionals and scientists. You can boost your health literacy by staying informed, learning how science works, and double-checking new information with knowledgeable and trusted sources. Health experts have responsibilities, too. They should try to explain things clearly using simple words, make themselves available to answer questions, and share their work openly. The more the public understands science, the more they will trust good health advice. If you can learn from reliable sources and make smart choices to the best of your ability, you can help to keep yourself and your community healthy. Working together to increase health literacy can improve lives. Keep reading, asking questions, and learning—a healthy future starts with you!

UNDERSTANDING CAN BOOST TRUST

Imagine you see a new post from your favorite social media influencer saying that spinach is unhealthy. Wow—maybe you now have an excuse not to eat it the next time it shows up on your dinner plate! But you also know that the influencer is not a scientist or health professional, and he did not say *why* spinach is bad... so can you trust what he said? After all, you have always heard that spinach is good for you. The next day in school, you ask your science teacher if she has heard this new spinach rumor. She explains that spinach contains a substance called oxalic acid. In very large amounts, this substance can prevent the body from absorbing minerals properly—however, you would have to eat over two *pounds* of spinach *every day* for that to happen! So, she says, enjoying spinach in normal amounts is perfectly healthy and provides important nutrients, like iron.

Even if you *would* like to avoid eating your spinach, who are you more likely to believe: your science teacher or the influencer? If you chose your teacher, your choice probably came down to two main factors: knowledge and trust. Your teacher gave you important knowledge about spinach—she took the time to explain the details so that you understood where the influencer's claim came from. You also recognize that, unlike the influencer, your teacher has a background in science and knows what she is talking about. You trust her and remember that she has given you correct information in the past.

As you can see, having knowledge about a health-related topic and trusting health information (and health experts) go together. Building knowledge and trust is a two-way street: we have a role to play by learning all we can, but scientists and health professionals such as nurses, doctors, dentists, dieticians, and others have responsibilities, too. In the rest of this article, we will describe why it is important to trust science and how our knowledge of health-related topics can boost our trust in expert advice, helping us to make the best possible health decisions. We will explain how you can improve your health literacy, and the important things that scientists and health professionals can do to help people build this knowledge and trust.

WHY IS IT IMPORTANT TO TRUST SCIENCE?

Why is it so important to trust science in the first place? Maybe that is easiest to understand by looking at an example of what can happen when people do *not* have this trust.

During the early stages of the COVID-19 pandemic, there was a huge amount of information about the disease. You may have seen news stories and social media posts, or heard things your classmates said, or things adults were talking about. Some of the information was helpful

but some of it was incorrect or was even dangerous. The information came so quickly that it came to be called an **infodemic** [1]. Just like a pandemic, in which a disease spreads very quickly, an infodemic is when information and rumors spread so fast that it is hard to know what is true. Some of the false information scared people, such as rumors claiming that the vaccines did not work, were unsafe, or even that they contained microchips that could track people. Scary rumors that spread during the infodemic contributed to **vaccine hesitancy**, which is when people do not trust what health experts tell them about a vaccine, so they are unsure (or "hesitant") about getting the shot. Vaccine hesitancy is not limited to the COVID-19 pandemic—some people choose not to get vaccines that could protect them against other dangerous diseases, too [2].

INFODEMIC

When false information and rumors spread very quickly online and in the news, making it hard to know what is true. It is like a disease outbreak of bad information.

VACCINE HESITANCY

When people do not trust what health experts say about vaccines, so they are unsure or hesitant about getting the shot. This can put themselves and others at risk of getting sick.

Lack of understanding or trust in science can also show up in other health behaviors. For instance, during the COVID-19 pandemic, some people did not believe it was important to wear masks or follow social distancing guidelines. Beyond COVID-19, people who do not trust the guidance provided by health experts might choose to participate in unhealthy or risky behaviors like smoking or unprotected sex, or they may refuse to get checkups, cancer screenings, or other types of medical care, even if that care is readily available. Overall, public trust in science is critical for keeping people healthy.

HEALTHY PEOPLE MAKE HEALTHY COMMUNITIES

Not all people have the option to make choices about things that affect their health, like what they eat or whether they get vaccinated. Many people live in areas with limited access to healthcare or may not be able to afford healthy food, for example. But even people who *do* have those options might not make the healthiest choices. You might be thinking, "So what? If some people do not want to get vaccinated or wear masks, or if they choose to smoke, that is their decision!". However, some people feel that certain health-related decisions go beyond personal choice because we have a responsibility toward others in society. For example, when most people in a population can and do get vaccinated, something called **herd immunity** can happen [3]. This means that enough people are protected from catching or spreading the sickness that it cannot grow out of control. Herd immunity keeps vulnerable people safe, like the elderly or those who are too sick or too young to be vaccinated. Vaccination and other precautions like masking and social distancing can help get a pandemic like COVID-19 under control. One human disease, smallpox, has even been completely eliminated because enough people got vaccinated [4].

HERD IMMUNITY

When enough people in a community are vaccinated that a disease cannot easily spread. Even people who cannot get vaccinated are protected because there are no infected people to transmit the illness.

When many people in a community are sick, the whole society can suffer. People might be too sick to go to work, and businesses could struggle if there are not enough healthy workers or customers.

Hospitals can become overwhelmed trying to care for too many patients at once, as happened early in the COVID-19 pandemic. Kids might miss more school days and could fall behind in their education. And the economy might suffer too, as healthcare costs rise, and people spend less money at local stores and restaurants because they do not feel well. In some cases, the impacts can really add up, making day-to-day life harder for everyone.

So, the more we understand about science, the more likely we are to trust the good advice that health experts give us. When we have healthy options available to us, a better understanding could lead to better personal health decisions—which could combine to keep whole societies healthy and functioning well (Figure 1). The ability to find, understand, and use scientific and health-related information to make informed decisions about health is called **health literacy**. There are two sides to increasing health literacy: there are things the public can do, and things that scientists and health professionals can do. Both sides have important roles to play in this critical goal (Figure 2).

HEALTH LITERACY

The ability to find, understand, and use information to make good choices about your health. When you are health literate, it is easier to know fact from fiction when it comes to health info.

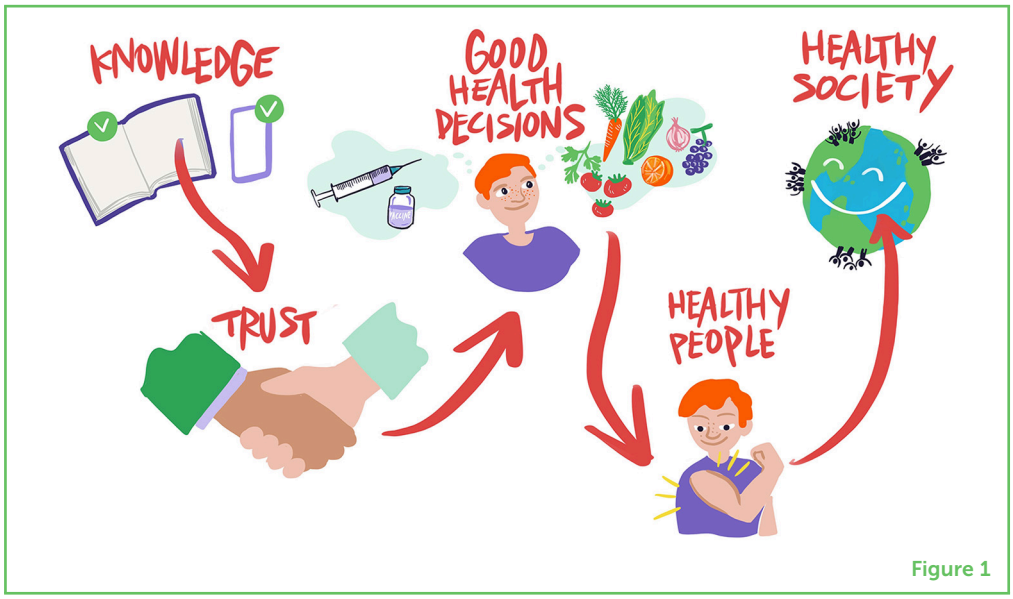


Figure 1

Health literacy is important because it can help to keep the whole world as healthy as possible. The more we understand about health-related topics, the more we can trust the health advice that experts give us. When healthy options are available, trust can lead to good health decisions, such as getting vaccinated, going for regular checkups, and eating healthy foods. Healthy choices make healthy bodies—and when there are many healthy people around, it is easier for entire societies to be healthy, happy, and productive. Figure created by carlottacat.com.

WHAT CAN PEOPLE DO TO BOOST HEALTH LITERACY?

People can work on their health literacy at any age, but starting young is especially helpful. To become health literate, we must use whatever resources we have available to learn at least the basics of health-related topics. While some kids might find science topics intimidating, there are lots of easy ways to boost health literacy. Here are just a few:

- **Stay informed**. Exploring reliable websites, podcasts, books, and magazines written by scientists, doctors, or other health experts is a great way to learn about health and science. Some great

Figure 2

Increasing health literacy, which can improve trust in science, is a two-way street. Both health experts and the public have responsibilities. Kids, you can boost your health literacy by staying informed: learn as much as possible about both health-related topics and about the way science works. Also, be sure to verify information. Health experts, be sure to communicate clearly, using simple words and images to make topics easy to understand and interesting. Make yourselves available to the public so people can get to know you and ask questions. Practice open science so that your work will seem less mysterious. Figure created by carlottacat.com.

resources include Your Life, Your Health, MedlinePlus/MedlinePlus /MedlinePlus en Español, MedlinePlus tutorials, BAM! Body and Mind, HHMI Biointeractive, Crash Course Biology/Crash Course Biología, The Walking Classroom, the Diverse Voices in Health and Medicine Collections toolkit, the National Library of Medicine Bookshelf, and Frontiers for Young Minds. You can also ask your parents, teachers, and health professionals any health questions you might have. Adults can often help you to better understand health and science topics, so you can make sure you are doing the right things to stay healthy.

- **Understand how science works**. Health literacy also involves understanding how science works. Science is an ongoing process of learning and discovery, and sometimes it is a little messy. What scientists "know" about a topic can change as they gather more evidence and do more research. Think back to the early months of the COVID-19 pandemic. At first, scientists were still figuring out how the virus spreads and how to best protect people. As they learned more, suggestions about things like wearing masks changed. This frustrated some people who thought scientists did not know what they were talking about, but that is just how science works—as scientists make new discoveries, they update their recommendations. When guidelines or ideas change, it does not mean the experts are wrong or cannot be trusted. It means our understanding is improving thanks to new research.
- **Check your information**. Being health literate means keeping an open but critical mind as the evidence develops. When you

hear or see new health-related information, be curious and investigate to make sure it is true. Ask an expert (like your science teacher) or try to verify the information using more than one trustworthy source, like well-respected health websites from hospitals, research institutes, and government agencies, or science and health articles from major journals or newspapers.

HOW CAN SCIENTISTS AND HEALTH PROFESSIONALS BOOST HEALTH LITERACY?

In our earlier example, remember how your science teacher took the time to explain the science behind the spinach rumor? In the same way, scientists and health professionals have a key role to play in making sure as many people as possible can understand health-related topics. Here are some things these experts can do to help gain the public's trust and increase health literacy:

- **Build communication skills**. Many scientific concepts are complex, so health experts must often use precise, technical terms that may sound really complicated. But this does not mean these topics are impossible for non-experts to understand. Health experts should learn how to explain health and science topics simply, using easy words. Experts can create fun science videos, books, comics, websites, or apps, including colorful illustrations or animations, that make learning about health and science fun and exciting. The more "public friendly" health and science information is, the more people will learn about the topics.
- **Be available and down to earth**. Sometimes, experts like scientists and health professionals can seem a little intimidating to the rest of us because they have so much specialized knowledge. But they are people just like us! To help us get to know and trust them, scientists and health professionals can visit schools and libraries to talk with kids about important health topics and answer kids' questions in person. They can also organize fun events where kids and their parents can do cool science experiments or learn about staying healthy through games and activities. When people feel they can trust health experts, they are more willing to follow expert advice for staying healthy.
- **Support and practice open science**. By making their data and experimental methods available to the public and publishing their work in journals where anyone can read it for free, health experts can help people to understand health-related topics *and* the way science works. **Open science** gives people a "window" into the scientific process, allowing them to see how ideas can change based on evidence, which can make science seem less mysterious and increase people's trust. In this way, open science can help to fight misinformation so that it is easier for

OPEN SCIENCE

When scientists share their data and methods freely, so anyone can understand how they do research. This openness helps people learn about and participate in science and builds trust.

people to make informed decisions about their health. For more information on open science, see this article in this Collection.

KNOWLEDGE IS POWER

Many factors can influence people's trust in science, including awareness, religion, political beliefs, education, and personality traits, but knowledge is one very important aspect. Health literacy is critical for the health of both people and whole societies. When people understand health-related topics, they can make smarter choices based on the options available to them—choices that can help to keep themselves and their communities safe and functioning.

But knowledge is power only if it comes from reliable sources. Kids, make sure to keep learning about science and health from experts you trust. Ask questions, dig deeper, and verify information. Do not be afraid to admit when you simply do not know something—being curious is great! And remember to help boost the health literacy of your friends and family by sharing the interesting things that you learn. Health experts, keep communicating openly. Simplify complex topics and make learning interactive. The more the public knows about your work, the more they will understand and trust you.

We all have a role to play in boosting health literacy. When people are empowered with knowledge, it improves lives, strengthens communities, and benefits society. So, keep reading, asking, sharing, and learning. Together, we can build a future of trust, understanding, and health for all!

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talk by Soumya Swaminathan. The authors wish to acknowledge curious kids who learn about health by asking great questions and using trustworthy sources of information. The work in this publication was made possible, in part, by the Network of the National Library of Medicine National Evaluation Center U24LM013751 and Region 5 UG4LM013725.

REFERENCES

1. Cinelli, M., Quattrociocchi, W., Galeazzi, A., Valensise, C. M., Brugnoli, E., Schmidt, A. L., et al. 2020. The COVID-19 social media infodemic. *Sci. Rep.* 10:16598. doi: 10.1038/s41598-020-73510-5
2. Nuwarda, R. F., Ramzan, I., Weekes, L., and Kayser, V. 2022. Vaccine hesitancy: contemporary issues and historical background. *Vaccines* 10:1595. doi: 10.3390/vaccines10101595

3. McDermott, A. 2021. Core concept: herd immunity is an important-and often misunderstood-public health phenomenon. *Proc. Natl. Acad. Sci. U. S. A.* 118:e2107692118. doi: 10.1073/pnas.2107692118
4. Meyer, H., Ehmann, R., and Smith, G. L. 2020. Smallpox in the post-eradication era. *Viruses*. 12:138. doi: 10.3390/v12020138

SUBMITTED: 28 September 2023; **ACCEPTED:** 12 January 2024;
PUBLISHED ONLINE: 21 May 2024.

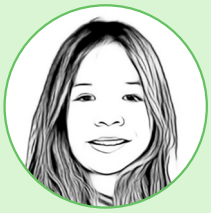
EDITOR: James Gillies, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Ribhav Gupta and Linda Yip

CITATION: Debad SJ and Holmes K (2024) Health Literacy: A Two-Way Street. Front. Young Minds 12:1303836. doi: 10.3389/frym.2024.1303836

CONFLICT OF INTEREST: SD was employed by SJD Consulting LLC.
The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS



LAUREN, AGE: 11
I am 11 years old and really like science, especially physics and biology. My hobbies include track and field, writing, reading, and chess. I also enjoy programming, geography, and exploring new places. I live with my parents, my little sister, and my two cats.

ROHAN, AGE: 15
Rohan is a high school student with a passion for medical innovation. When not learning about medical technology he can be found listening to a diverse musical catalog or attempting free-throws on the basketball court. He is excited to serve as a young reviewer and help promote scientific education for the next generation of leaders.

SAHANA, AGE: 11
I like science, especially chemistry. Now that I am in 6th grade, I also like biology. I love going off track while doing experiments and reading about what happened. I sometimes experiment on my dog.

AUTHORS

SUSAN J. DEBAD

Susan Debad has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard." She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has more than four dogs! In her spare time, she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

KRISTI HOLMES

Dr. Kristi Holmes is a professor of Preventive Medicine, director of Galter Health Sciences Library, and Associate Dean of Knowledge Management and Strategy at Northwestern University Feinberg School of Medicine in Chicago. Her work is collaborative and focuses on information discovery, use, and impact. This includes open science projects to grow a vibrant information ecosystem and make information FAIR (Findable, Accessible, Interoperable, and Reusable). When not at work, she enjoys spending time with her family and traveling to new places.

frontiers | Frontiers for Young Minds

HUMAN HEALTH
Published: 21 May 2024
doi: 10.3389/frym.2024.1302457

"BUILDING" HUMAN HEALTH: WHEN DOCTORS AND PHYSICISTS WORK TOGETHER

Susan J. Debad [1*] ***and Magdalena Kowalska*** [2*]

[1] *SJD Consulting LLC, Ijamsville, MD, United States*

[2] *European Organization for Nuclear Research (CERN), University of Geneva, Meyrin, Switzerland*

YOUNG REVIEWERS:

FILIP
AGE: 13

MIA AURELIA
AGE: 11

THE FUTURE LEADERS OF STEM
AGES: 8–12

In this article, we explore the importance of cooperation in science. Just as various construction trades must work together to build a skyscraper, scientists from separate fields can cooperate to tackle complex scientific challenges. This is called interdisciplinary collaboration, and it is a great way to do science. By bringing together knowledge and tools from multiple fields, scientists can uncover creative solutions and make meaningful connections that they might not have reached on their own. We give an example of how collaboration between particle physics and medicine—two fields that seem very different from one another—come together to improve healthcare. Using the tools of particle physics, scientists are enhancing cancer diagnosis and treatment. Interdisciplinary collaboration is the best way to address many of the complex issues we face today, like controlling climate change or fighting cancer, and it can help scientists and doctors make a lasting impact on human lives and the health of our planet.

Take a moment to look around at the building you are in right now. Buildings are such a normal part of our daily lives that it is easy to forget how complex they are and how many unique skills are required to create them. To construct any building, people from multiple construction trades must work together, each bringing their specialized tools and knowledge to produce various aspects of the structure: architects design the plans, a construction team creates a concrete foundation, carpenters construct walls and roofs and may also add woodworking details to each room, plumbers install the pipes for running water, and electricians do the wiring that allows you to plug in a computer and read this article. On their own, plumbers could not build an entire building, and neither could electricians, concrete pourers, or carpenters—but when they collaborate, they can build anything—houses, office buildings, hospitals, schools, or even brand-new kinds of buildings that no one has thought of before!

In this article, we will think about *science* as a big architectural project—a complex "building" that requires the expertise and collaboration of various "trades" to bring it to life and build solutions to some of the big challenges facing our world today.

SCIENCE IS DISCIPLINED

If you have ever told a parent or teacher that you would like to become a scientist or doctor someday, that adult might have asked you, "what type?". That is because science and medicine are huge topics, with so much to learn that no one person can master every aspect—that would be like a single person trying to build an entire skyscraper on their own. Just as a carpenter becomes an expert in woodworking or an electrician becomes a master of electrical systems, scientists choose a subject, also called a discipline, and then specialize in it. They dedicate their time to mastering their craft and understanding the minute details of that subject. There are literally *hundreds* of scientific disciplines to choose from.

Becoming specialized in a discipline is part of the very nature of science. Specializing allows a scientist to do a "deep dive" into their topic and focus all their time and energy on learning about it, which can lead to fascinating discoveries and sometimes big scientific breakthroughs. But what about building the skyscraper? How do some of the really big scientific problems get solved?

"CONSTRUCTING" CONNECTIONS: INTERDISCIPLINARY SCIENCE

Just as constructing a safe and functional building requires the collaboration of many trades, science thrives when experts from diverse disciplines come together to collaborate. Some types of

scientific questions are like skyscrapers—knowledge and tools from more than one discipline are needed to "build" complete answers (Figure 1). For example, say scientists want to understand why a certain bird species is disappearing. Biologists might study the birds' behavior and habitats, while chemists might look at the pollutants in the environment that could be harming the birds, and mathematicians might analyze the patterns of rising and falling bird populations. By bringing their unique knowledge and tools together and working as a team, each discipline adds a crucial piece to the overall process. This collaboration helps scientists to make interesting connections that they might not have made on their own and could allow them to discover the full reason behind the bird's disappearance—and maybe even figure out how to protect the species. Collaborating to bring together scientific knowledge, methods, and ideas from multiple disciplines to solve scientific or medical problems is called **interdisciplinary** science—and it is a really good way to tackle complex scientific challenges and some of the real-world problems facing us today.

INTERDISCIPLINARY

Experts from various fields working together to solve big problems, like scientists and doctors joining forces to make new discoveries and find solutions.

Figure 1

To build a building, experts in many trades must come together and combine their expertise—architects, carpenters, electricians, plumbers, and painters, for example. Something similar happens in interdisciplinary science! Scientists from separate disciplines collaborate to "build" the answers to big scientific problems that could not be solved by any one discipline on its own. Each scientist brings the "tools" and ideas from their specific discipline and, together, they can produce creative solutions (figure created by carlottacat.com).

BRINGING PHYSICS INTO THE DOCTOR'S OFFICE?

Did you know that some extremely important medical advances have come from interdisciplinary collaboration, sometimes involving disciplines that seem to have nothing to do with keeping people healthy? The rest of this article will describe how physicists, particularly those who study **particle physics** and **nuclear physics**, have joined forces with doctors in exciting ways that could improve, and maybe even save, many lives.

PARTICLE PHYSICS

The study of the tiniest pieces of matter and energy that make up everything in the universe, like protons, electrons, and photons. Particle physicists study a broader range of particles than nuclear physicists.

NUCLEAR PHYSICS

The study of the particles inside the nuclei of atoms. Nuclear physicists often study radioactive isotopes because understanding those isotopes tells them about what is happening in atomic nuclei.

PARTICLE ACCELERATOR

A huge machine that makes tiny particles move really fast and crash into each other. Scientists use it to learn about the smallest building blocks of the universe.

DETECTOR

A special tool or device used by scientists to observe and collect information about particles and their behavior, helping them learn more about how the universe works on the tiniest level.

RADIOACTIVE ISOTOPE

A special kind of atom that gives off a type of energy called radiation. Scientists use it in medicine and research to study and treat diseases like cancer.

HADRON THERAPY

A type of cancer treatment that uses high-speed particles called protons to target and destroy tumor cells while minimizing damage to healthy tissue, helping patients fight cancer.

Particle physics is a scientific discipline that tries to understand the tiniest building blocks of the universe. These particles are so small that we cannot see them with our eyes or even with advanced microscopes. To study them, particle physicists use huge, powerful machines called **particle accelerators**, which get particles moving at very high speeds and then smash them into each other. Examining what comes out of these collisions, using giant **detectors**, can teach scientists a lot about the tiny particles that make up atoms, like electrons and quarks, and even the famous Higgs boson. Nuclear physicists can also use and study **radioactive isotopes**—atoms that give off a kind of energy called radiation—in their experiments.

On the surface, particle physics and medicine might seem as different as plumbing and carpentry. But some particle physicists have the same goal as doctors—they would ultimately like to see their research improve human lives. Working together, doctors and particle physicists can combine tools and ideas from these two separate disciplines to improve the way diseases, like cancer for instance, are diagnosed and treated. When particle physicists collaborate with doctors, the sky(scraper) is the limit!

TREATING CANCER USING THE TOOLS OF PARTICLE PHYSICS

The three tools that we just described—particle accelerators, detectors, and radioactive isotopes—might all be useful in the fight against cancer. Medical techniques based on these tools could improve the ability of doctors to both diagnose (find) and treat some kinds of tumors.

To treat tumors and hopefully cure a patient's cancer, **hadron therapy** uses special particle accelerators to get tiny particles, like protons and carbon ions (a form of a carbon atom with an electrical charge), moving at very high speeds (Figure 2A). These particles, which carry a lot of energy, can then be focused on the tumor like a laser beam, damaging the tumor cells with the energy they carry, while sparing the nearby healthy tissue. Hadron therapy with protons is currently being used in about 100 locations around the world. A similar technique, called Flash, delivers an ultra-high dose of radiation (X-rays, protons, ions, or electrons) in a very short pulse. The Flash technique causes more damage to cancer cells than it does to healthy tissues, which could minimize the side effects of radiation therapy. The first Flash facility will soon be built in Lausanne, Switzerland.

Smaller versions of the fast, sensitive detectors used by particle physicists in their experiments are being created to diagnose diseases (Figure 2B). For example, advanced detectors being developed at the European Organization for Nuclear Research (CERN) have shown amazing results in terms of improving the amount of information

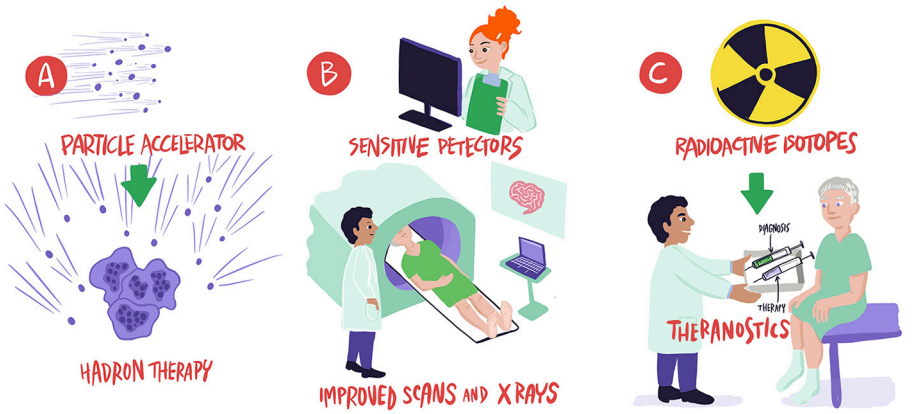


Figure 2

Figure 2

Tools from particle and nuclear physics, which study the tiniest building blocks of the universe, can be used to help diagnose and treat certain kinds of cancer. **(A)** In hadron therapy, particle accelerators can create high-speed particles, like protons or electrons, that can damage tumor cells. **(B)** Sensitive detectors can improve imaging techniques like PET scans and X-rays, so that doctors can diagnose cancers earlier and more accurately. **(C)** In theranostics, radioactive isotopes are attached to molecules that stick specifically to cancer cells and are injected into the patient's bloodstream. One type of isotope can help doctors see the tumor, and another type can kill cancer cells (figure created by carlottacat.com).

doctors can get from X-rays. Sensitive detectors can also be used to help take detailed pictures of the inside of the body, using a method called positron emission tomography (PET) scans (for more information on PET, see this Frontiers for Young Minds article). Special crystals, similar to those being studied for detectors at CERN, could make PET scan images extremely clear and detailed, which could help doctors to diagnose cancers earlier and start treatments sooner—potentially saving patients' lives [1–3].

Finally, radioactive isotopes can be used in a technique called **theranostics**. The name "theranostics" comes from a combination of the words "therapy" (treatment) and "diagnosis" (Figure 2C). In traditional cancer treatment, doctors diagnose and treat cancer using various medical procedures. They might diagnose the disease using blood tests, X-rays, or PET scans, for example, and then treat the disease using surgery, medicines called chemotherapies, or radiation therapy. But with theranostics, the story is a little different. Some cancer cells have structures on their surfaces that healthy cells generally lack. If researchers can design molecules that stick *only* to those cancer-specific structures, they can attach radioactive isotopes to the molecules and inject them into the patient, so that they travel all over the patient's body. One type of radioactive isotope can allow doctors to *detect* where the cancer is in the body (using PET), and then a second type of radioactive isotope can be injected to *treat* the cancer, by sticking to the cancer cells and killing them, while leaving normal, healthy cells unharmed [4]. A theranostics approach using radioisotopes of a substance called terbium is currently being tested in patients.

THERANOSTICS

A medical technique where diagnosis and treatment happen at the same time, using special molecules that stick to cancer cells and deliver treatment while helping doctors see where the cancer is located.

BUILDING FOR THE FUTURE

Our next generation of scientists and doctors (maybe you?) will face some extremely complex issues during their careers: the climate crisis, protecting the Earth and its species from harm as the human

population continues to grow, and dealing with serious human health concerns like cancer and pandemics, just to name a few. These are extraordinarily challenging problems that cannot be answered by a single discipline.

But when scientists from various disciplines join forces, it is like a construction site that brings together the efforts of many trades. Everyone collaborates, combining their specialized knowledge and skills, to construct the building from its foundation to its intricate details. In interdisciplinary science, the disciplines of biology, chemistry, physics, mathematics, and more work in tandem to solve big problems and build a strong, integrated understanding of the world. By appreciating the unique contributions of each discipline and boosting understanding across fields, scientists and doctors can construct a scientific skyscraper that could never have been built by one discipline alone—one that stands the test of time and makes a lasting impact on human lives and the health of our planet.

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talks by Charlotte Warakaulle and Magdalena Kowalska. The study was funded by CERN.

REFERENCES

1. Doroud, K., Liu, Z., and Williams, M. C. S. 2019. A new geometry of scintillating crystals with strip SiPMs: a PET detector with precise position and time determination. *J. Instrum.* 14:P01016. doi: 10.1088/1748-0221/14/01/P01016
2. Amirhossein Sanaat, A., Ashrafi-Belgabad, A., and Zaidi, H. 2020. Polaroid-PET: a PET scanner with detectors fitted with Polaroid for filtering unpolarized optical photons—a Monte Carlo simulation study. *Phys. Med. Biol.* 65:045013. doi: 10.1088/1361-6560/abaeb8
3. Vandenberghe, S., Moskal, P., and Karp, J. S. 2020. State of the art in total body PET. *Eur. J. Nucl. Med. Mol. Imaging Phys*. 7:35. doi: 10.1186/s40658-020-00290-2
4. Mori, Y., Kratochwil, C., Haberkorn, U., and Giesel, F. L. 2023. Fibroblast activation protein inhibitor theranostics: early clinical translation. *PET Clin*. 18:419–28. doi: 10.1016/j.cpet.2023.02.007

SUBMITTED: 26 September 2023; **ACCEPTED:** 11 March 2024;
PUBLISHED ONLINE: 21 May 2024.

EDITOR: James Gillies, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Alina Nico West and Malgorzata Lisowska

CITATION: Debad SJ and Kowalska M (2024) "Building" Human Health: When Doctors and Physicists Work Together. Front. Young Minds 12:1302457. doi: 10.3389/frym.2024.1302457

CONFLICT OF INTEREST: SD was employed by SJD Consulting LLC.
The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

FILIP, AGE: 13
My name is Filip, I am 13 years old. I like football, chemistry, math and physics. I also like drawing and in my free time I practice football tricks. In the future I would like to be a professional football player or a chemist. I would like to invent how to stop the climate catastrophe.

MIA AURELIA, AGE: 11
I am 11 years old and My name is Mia Aurelia. I love reading adventure books and I like writing stories. I live in Luxembourg and I speak Romanian, Polish, English, French, German and a tiny bit of Luxembourgish. My favorite subjects in school are: English, science and math. I am in 7th grade and I go to the Lycée Michel Lucius school.

THE FUTURE LEADERS OF STEM, AGES: 8–12
The Future Leaders of STEM from John P. Freeman K-8 Optional School is an after-school program for students who identify with STEM and love to dream BIG.

AUTHORS

SUSAN J. DEBAD
Susan has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard". She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has more than four dogs! In her spare time, she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

MAGDALENA KOWALSKA

Originally from Poland, I was always curious about the world around me. Therefore, I liked science and I liked traveling as a tourist and as physics student. After my studies I moved to Geneva, where I started my doctorate in experimental physics, working with unstable isotopes at CERN. Since then, I have worked on and led several projects at CERN using such isotopes. Some of them are linked to biology and medical diagnosis. In addition, I like explaining science to non-scientists, especially school pupils, just like my daughters who are 8 and 11. I still love traveling to understand other cultures and to appreciate the nature around us.
*Magdalena.Kowalska@cern.ch

HUMAN HEALTH
Published: 21 May 2024
doi: 10.3389/frym.2024.1338446

THE MIND-BENDING WORLD OF NEW BRAIN TECHNOLOGIES

Susan J. Debad [1*], ***Olaf Blanke*** [2] ***and Bruno Herbelin*** [2]

[1] *SJD Consulting LLC, Ijamsville, MD, United States*

[2] *Laboratory of Cognitive Neuroscience, Neuro-X Institute, Faculty of Life Sciences, Swiss Federal Institute of Technology (EPFL), Geneva, Switzerland*

YOUNG REVIEWERS:

ELLIOT
AGE: 13

KONSTANTIA
AGE: 10

Our amazing brains allow us to do incredible things, yet they remain mysterious in many ways. Researchers have discovered some situations in which the brain can be "fooled", and these insights into the brain's inner workings have led to some exciting new technologies, including virtual reality (VR). In addition to its well-known role in gaming and entertainment, VR has some amazing uses in the field of medicine. VR can help patients manage pain, and it can also help surgeons practice delicate procedures and guide them during operations. Other advances called brain-machine interfaces can listen to the brain's chatter and translate thoughts into commands for computers or even robotic limbs, which could greatly improve the lives of people with certain disabilities. In this article, we will explain how researchers are using findings from cutting-edge brain research to produce exciting new technologies that can heal or even enhance the brain's functions.

LEARNING ABOUT THE BRAIN BY "TRICKING" IT

Do you like to fool your brain? Many people love things like optical illusions, magic tricks, and other effects that change the way we see reality. Some popular museum exhibits even include distorted rooms that make people appear to grow or shrink as they move around, mirrors that create the illusion of endless corridors, or holographic images that seem to float in space (for examples, see here and here). Beyond a fun type of entertainment, however, studying the ways the brain can be fooled can help researchers understand how this critical organ works and how they can help certain brain problems.

One famous brain-tricking science experiment is called the rubber hand illusion. In this experiment, which you can watch here, a volunteer sits at a table with one of his arms hidden behind a partition, replaced by a fake-looking rubber arm lying on the table in front of him. The scientist gives the same touch cues (gentle stroking with a paint brush) to both the fake and the real hand, which tricks the volunteer's brain into perceiving the fake hand is part of his own body. Suddenly, another experimenter hits or stabs the fake hand, causing the volunteer to jump and react as if his hand were threatened. Do you think *your* brain would be fooled by this experiment? Chances are, it would. But that is not a bad thing, because figuring out how the brain can be "tricked" in this way gives scientists important information, as you will see as you keep reading.

THE AMAZING BRAIN

The brain is an amazing, complex organ. It controls everything we do, from moving and breathing to thinking, feeling, and remembering. It is also the source of our creativity, imagination, and intelligence—important characteristics that help make us who we are.

NEUROSCIENTIST

A scientist who studies the brain and how it helps us think, feel, and do everything we do.

How does one organ do all these things? **Neuroscientists** are still trying to understand exactly how the brain works, and many mysteries remain unsolved. What *is* known is that the brain is made up of billions of cells called neurons, which communicate with each other using electrical and chemical signals. Neurons are connected in intricate networks that form the basis for the brain's functions. We also know that specific areas of the brain are primarily responsible for certain functions, like vision, touch, hearing, movement, and emotions, to name just a few.

All this complexity makes the brain extremely difficult to treat when it gets sick or injured. Problems that originate in the brain can cause pain, memory loss, mood disorders, or movement difficulties. In addition, the brain is extremely delicate and sensitive, so it is not easy for doctors to work on—especially since it is so well-protected by the skull.

Neuroscientists and doctors are working hard to improve their understanding of the brain so that they can develop new ways to help this vital organ heal and improve. One clever way to study something complex is to find its limits. Observing situations in which the brain "fails" or does not work as expected can help scientists to understand how it *normally* functions. For example, in the rubber hand illusion, the brain "fails" at telling a rubber hand apart from its own hand. Investigating how this happens can teach scientists about the way the brain perceives the body. What is more, learnings from such experiments are leading to cool brain-related technologies that can make life better for both doctors and patients.

VIRTUAL REALITY CAN AID BRAIN SURGERY

VIRTUAL REALITY

Advanced technology that puts you inside a computer-generated, 3D world, making it feel like you are in a totally different place.

ROBOTICS

The science of designing and using robots—machines that can be programmed to perform tasks, often mimicking actions of humans, to help make our lives easier.

MINIMALLY INVASIVE SURGERY

Surgery that involves using tiny cuts and specialized tools to fix health problems, causing less pain and quicker recovery compared to traditional surgery.

AVATAR

A virtual representation of oneself in a computer-generated environment.

Have you experienced **virtual reality** (VR)? Maybe you have played computer games using a VR headset or visited a museum featuring an immersive or interactive VR-based exhibit designed to show you the world through the eyes of a certain artist or allow you to examine objects in a virtual collection. VR is a computer-generated 3D environment that you can experience as if you were there. VR can make you feel like you are in another place or world, where you can explore and interact with objects or even other people. There are many exciting applications of VR technology.

For example, neurosurgery is a type of surgery that involves operating on the brain or the nerves. Due to the complexity and fragility of the brain, neurosurgery requires an extremely high degree of skill and lots of training. Neurosurgeons can use VR to view a 3D map of a patient's brain, to help them plan for surgery or to guide them during surgery, so that they know where to cut and how to get to the problem area without damaging healthy brain tissue. VR images can be combined with **robotics**, in what is called robotic-assisted **minimally invasive surgery**. "Minimally invasive" means that the incisions are smaller than those made in "regular" surgery, and it is usually easier for a patient to recover after the operation. In robotic-assisted minimally invasive surgery, the surgeon does not actually touch the patient—the robot has tiny tools and a camera, and the surgeon controls the robot kind of like a tiny drone, by watching a screen and moving specialized controllers that tell the robot exactly what to do. Although the surgeon might be sitting a meter or more away from the patient, VR allows them to feel like they are in another body, or **avatar**, actually operating on the patient. The better the VR technology, the more the avatar will feel like the surgeon's own body as they use the robotic tools, and the more accurate and safer the surgery will be. (To see what robotic-assisted minimally invasive surgery looks like, watch this video or this one.)

Virtual reality can also be used to train doctors as they learn to become surgeons. Practicing delicate surgeries in a VR environment

before attempting them on real patients helps surgeons to have more confidence in themselves and improves their surgical skills [1]. As VR technology continues to improve, more training programs are likely to start using VR to prepare their surgeons for the operating room.

VIRTUAL REALITY CAN HELP MANAGE PAIN

If you *have* experienced VR, you know that it can be very effective at "tricking" the brain—sometimes you can forget where you really are as you fully imagine yourself in the virtual setting. As the rubber hand illusion illustrated, scientists know that the brain can be tricked into thinking a fake hand is their own hand. Could we similarly trick the brain into not feeling pain? Research tells us that the answer is yes! Neuroscientists are finding that VR can help to reduce or control several kinds of pain, including the pain and anxiety patients (even kids!) feel during certain medical procedures. VR may also help patients cope with **chronic pain**, which is pain that often begins with an injury but keeps happening even years after the injury has healed. Managing chronic pain can be extremely challenging, and it is a serious problem because the pain can make it hard for people to do normal activities, like go to work or school, have fun with friends, or even sleep.

CHRONIC PAIN

A type of pain that does not go away, lasting for months or even years, and can affect both the body and emotions, making everyday life challenging.

How exactly does VR help with pain? For one thing, VR is really good at distracting people from their pain by focusing all of their attention on the VR environment. However, the pain-relief effects of VR go beyond distraction. When a person in a VR setting feels strongly that their avatar is their actual body, they switch to perceiving the avatar's body as their body - and feel less pain at their real body. Instead, the person's brain pays attention to the information coming from the avatar. Since the avatar is not feeling pain, the brain "learns" that the body is pain free... and this "lesson" that the brain learned can carry over into reality, when the person stops using VR (Figure 1).

Figure 1

(A) If a person has chronic pain in their leg, for example, the brain pays attention to that pain and "learns" that the leg hurts. **(B)** If the person uses VR that makes them feel strongly that their avatar is their own body, the brain stops paying attention to signals from the actual body and pays attention to signals from the avatar instead. Since the avatar does not have leg pain, the brain "learns" that the leg is pain free. **(C)** The pain-reducing effect of the VR treatment can sometimes last for hours (figure created by carlottacat.com).

While some people have no pain for hours after a VR "treatment", most neuroscientists and doctors agree that VR only temporarily reduces pain—it does not cure it. VR can be used in other ways to help people to cope with their pain, for example by immersing them in peaceful

scenes that make them feel relaxed, or by guiding them through meditations and breathing exercises [2, 3]. One big advantage of some VR-based pain-management technologies is their convenience—if patients have a VR headset, many of these treatments can be done from home.

CONTROLLING MACHINES WITH OUR THOUGHTS?

Beyond VR, there are other cutting-edge technologies being developed to help the brain. Have you ever wondered what it would be like to control a robot with your mind? This might sound like science fiction, but it is possible with **brain-machine interfaces (BMIs)**. BMIs involve technologies that can read brain activity and programs that can translate the brain's messages into commands for computers or robotic devices. Such devices include **neuroprosthetics** designed to replace or restore the function of a missing or damaged body part, like a paralyzed arm. To read the brain's electrical signals, small devices called electrodes are often used. The electrodes are inserted into the brain or attached to the brain's surface. If a person has a neuroprosthetic arm and wants to move it, the electrodes pick up the brain's electrical message from the thought "move arm", and those messages are translated into signals telling the neuroprosthetic arm to move. In addition to helping people with neuroprosthetic limbs move around, eat, and get dressed, for example, BMIs can also be used to help people who have issues hearing, speaking, or even seeing [4].

BRAIN-MACHINE INTERFACE

A direct communication pathway between the brain and an external device, allowing a person to control or communicate with computers or machines using only their brain activity.

NEUROPROSTHETICS

Advanced devices that replace or enhance nerves or brain areas that do not work properly, helping people regain lost abilities like movement or hearing.

A new advance in the field of BMI research involves *flexible* BMIs. Instead of being made of hard, uncomfortable materials, like the chips inside a laptop or phone, flexible BMIs have soft, bendable electrodes that can adapt to the brain's shape and movements, making BMIs more effective, accurate, and comfortable [5]. BMIs are still in the early stages of development, but with further research, they could help make the lives of people with disabilities much easier and help many people to regain their independence. Using BMIs to make normal brain abilities better is another exciting area of research. For example, BMIs could be used to send signals *into* the brain, to boost certain brain functions like movement control, memory, mood, or attention.

THE FUTURE IS MIND BLOWING!

When it comes to new technologies that could help our brains, the future looks bright (Figure 2)! Early research tells us that these technologies hold a lot of promise for everything from training surgeons to improving the lives of people with pain or disabilities. Although more research is needed to make brain-assisting technologies widely usable, scientists are dreaming big. In the future, with the help of these technologies, our brains might have some

cool new "superpowers". We might be able to control machines with our thoughts, virtual reality might help us learn new skills faster and remember more than ever before, and we might find new ways to heal and help the brain in conditions like dementia, depression, or anxiety. Some of these technologies could even help us to understand the mysteries of consciousness. The possibilities for improving health and quality of life are virtually endless—the future of brain tech is going to be mind blowing!

Figure 2

Figure 2

Researchers are working on many promising new technologies that could heal or even improve the brain. These include techniques to help people manage pain and anxiety, neuroprosthetics that can help people with disabilities regain important functions, and systems to train surgeons to perform delicate surgeries, just to name a few. Together, these advances could help many people live happier, healthier lives (figure created by carlottacat.com).

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talk by Olad Blanke.

REFERENCES

1. Paro, M. R., Hersh, D. S., and Bulsara, K. R. 2022. History of virtual reality and augmented reality in neurosurgical training. *World Neurosurg.* 167:37–43. doi: 10.1016/j.wneu.2022.08.042
2. Wynn, P. 2022. *Could Virtual Reality Replace Your Next Pain Pill? U.S. News and World Report*. Available online at: https://health.usnews.com/health-care/patient-advice/article/virtual-reality-and-pain-management (accessed May 13, 2024).
3. McNeil, T. 2023. *How Virtual Reality Can Help Relieve Chronic Pain*. Tufts Now. Available online at: https://now.tufts.edu/2023/04/10/how-virtual-reality-can-help-relieve-chronic-pain (accessed May 13, 2024).
4. Ptito, M., Bleau, M., Djerourou, I., Paré, S., Schneider, F. C., and Chebat, D. R. 2021. Brain-machine interfaces to assist the blind. *Front. Hum. Neurosci.* 15:638887. doi: 10.3389/fnhum.2021.638887
5. Tang, X., Shen, H., Zhao, S., Li, N., and Liu, J. 2023. Flexible brain–computer interfaces. *Nat. Electron.* 6:109–18. doi: 10.1038/s41928-022-00913-9

SUBMITTED: 15 February 2024; **ACCEPTED:** 06 May 2024;
PUBLISHED ONLINE: 21 May 2024.

EDITOR: Ana Godinho, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Andreas Skiadopoulos and Wendy E. Huddleston

CITATION: Debad SJ, Blanke O and Herbelin B (2024) The Mind-Bending World of New Brain Technologies. Front. Young Minds 12:1338446. doi: 10.3389/frym.2024.1338446

CONFLICT OF INTEREST: SD was employed by SJD Consulting LLC. OB is co-founder and shareholder of Metaphysiks Engineering SA and a member of the board and shareholder of Mindmaze SA.
The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ELLIOT, AGE: 13
Elliot is a 13-year-old cello playing soccer player and just earned the rank of Eagle Scout. In his free time he likes to code video games and teach himself math.

KONSTANTIA, AGE: 10
Konstantia is a curious 10-year-old girl who loves reading as much as the next person! Her passion for reading excites her whenever she discovers a good book. Having lived in various places around the globe, she has mastered already three languages. Konstantia adores interacting with other kids. If it were up to her, she would play all day long!

AUTHORS

SUSAN J. DEBAD
Susan has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard". She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan

lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has more than four dogs! In her spare time, she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

OLAF BLANKE

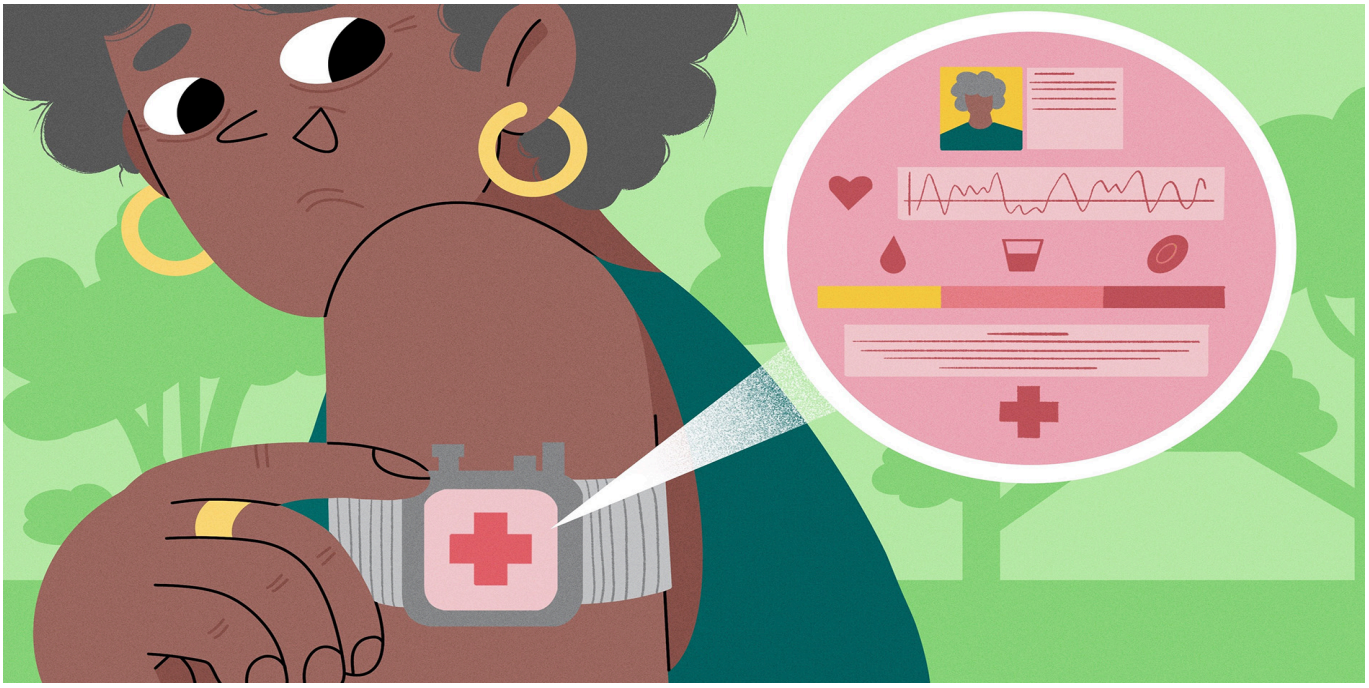
Olaf Blanke is Neuro-X Professor at the Swiss Federal Institute of Technology in Geneva. A medical doctor by training, he combines robotic, digital, and neurobiological methods to understand consciousness and the self. He has studied what happens in the brain when a person feels like they leave their body (a mental state called out-of-body experience); he also studied ghost sensations (such as feeling the presence of another person next to you when there is nobody there). Olaf has developed technologies in his laboratory to cause and investigate such experiences and many other body illusions. In his free time, he enjoys playing basketball, skiing, and reading.

BRUNO HERBELIN

Bruno Herbelin is a senior researcher in virtual reality (VR) and cognitive neuroscience in the laboratory of Prof. Blanke at the Swiss Federal Institute of Technology. He started working with VR in 1997, and his Ph.D. research showed that immersive VR therapy can help people with social phobia. He uses VR in clinical applications to alleviate pain or breathing discomfort, and he is developing a virtual laboratory approach for cognitive neuroscience research. In his free time, he goes to the mountains to climb, hike, or collect mushrooms.

frontiers | Frontiers for Young Minds

HUMAN HEALTH
Published: 06 February 2024
doi: 10.3389/frym.2024.1229690



WEARING YOUR HEART (MONITOR) ON YOUR SLEEVE: WILL DATA BE THE NEW DOCTOR?

***Susan J. Debad*[1*], *Ariel Ganz*[2] *and Michael Snyder*[2]**

[1] *SJD Consulting LLC, Ijamsville, MD, United States*

[2] *Department of Genetics, Stanford University School of Medicine, Stanford, CA, United States*

YOUNG REVIEWERS:

ERIC
AGE: 12

GRESHMA
AGE: 13

Imagine wearing a shirt or a wristband that tells you how hard you are exercising or warns you if you are getting sick. These are simple examples of wearable medical devices that could transform healthcare—either by helping people to manage serious diseases that they already have, or by spotting the early signs of a disease so that it can be treated before the person even feels sick. This article will focus on two examples of wearables: one for the management of diabetes and another that may be able to prevent heart attacks. Wearables like these and many others that are being developed could greatly improve human health. However, these technologies come with some big challenges, because they collect a lot of personal data. We need to find ways to protect people's privacy by keeping that sensitive data safe. In the future, wearables will certainly help doctors do their jobs... but might they even replace doctors altogether?

THE FUTURE OF HEALTH IS WEARABLE

Have you ever gone for a long walk or hike and then checked your phone or smart watch to see how far you went or how many steps you got in? Or maybe you have used an app to monitor your sleep patterns or to help you manage your nutrition. These seem like pretty routine things to do these days, right? Now imagine a future in which you put on a tight-fitting undershirt before exercising, to constantly monitor exactly how hard you are working and update your workout in real time, depending on how you are feeling. Or maybe someday you will get up each morning and put on earrings or a wristband that can quickly warn you if you are developing COVID-19 or even cancer—before you feel even the slightest symptom!

Does this sound like it could happen? While many of these technologies are still in the early stages of development, **wearable medical devices** (or wearables, for short) are a hot new development likely to transform the way healthcare works. As you read, you will learn about two examples of wearables: one that currently exists and can help people *manage* a disease that they already have, and one that is still experimental but may help to *prevent* a disease, keeping people healthy. Together, wearables that help manage and prevent diseases may allow many people live longer, healthier lives. But, as you will see, these technologies also give us some complicated issues to think about, particularly in terms of what happens to all the data collected by wearables. Could wearable devices, and all the data they generate, replace actual doctors? You might already have an opinion on this, but keep reading—we will revisit this question at the end of the article, and maybe something you learn along the way will change your mind!

WEARABLE MEDICAL DEVICES

Electronic devices worn on the body to monitor health and medical information, such as heart rate, steps taken, and blood glucose levels.

DIABETES

A condition in which the body has trouble using sugar for energy, causing high blood sugar levels and sometimes requiring treatment with insulin.

GLUCOSE

A type of sugar that comes from food; an important source of energy for the body's cells.

BLOOD SUGAR MANAGEMENT—HOW SWEET IT IS

Diabetes is a condition in which the amount of **glucose** circulating in the blood is too high. About 422 million people worldwide have diabetes, and it causes at least 1.5 million deaths each year. Cells normally use glucose, a type of sugar, for energy. Normally, the body produces a substance called insulin that "pushes" glucose from the foods people eat into their cells, so the cells can use it. People with diabetes, however, do not make enough insulin, so the glucose stays in the blood where it does not belong. Many people with diabetes must check their blood glucose levels several times a day, to figure out how much insulin to take. This is often done by pricking a finger and squeezing a drop of blood onto a small testing device—ouch! Blood glucose levels can change very quickly, so checking blood sugar only a few times a day might not catch important changes that occur between finger sticks.

CONTINUOUS GLUCOSE MONITOR

A device that measures glucose levels in the body continuously throughout the day and night to help people with diabetes manage their blood sugar levels.

Then, in 1999, the first **continuous glucose monitor** (CGM) was approved for use, and it has made life a lot easier for people with diabetes [1]. A CGM is a small, stick-on device, about the size of a quarter, that measures glucose using a tiny needle that reaches just under the skin (Figure 1A). The CGM, which can stay stuck to the skin for up to 2 weeks, collects glucose data *every few minutes* and sends the data to an app on the wearer's phone—and even to a family member, if needed. The app can create graphs that show trends in the wearer's glucose levels and can alert the wearer with an alarm when glucose levels are too high or too low. CGMs can make managing diabetes so much easier and more effective. More advanced wearables can do more than just monitor. For example, people with diabetes can wear a CGM with an insulin pump that actually administers insulin whenever blood glucose is too high!

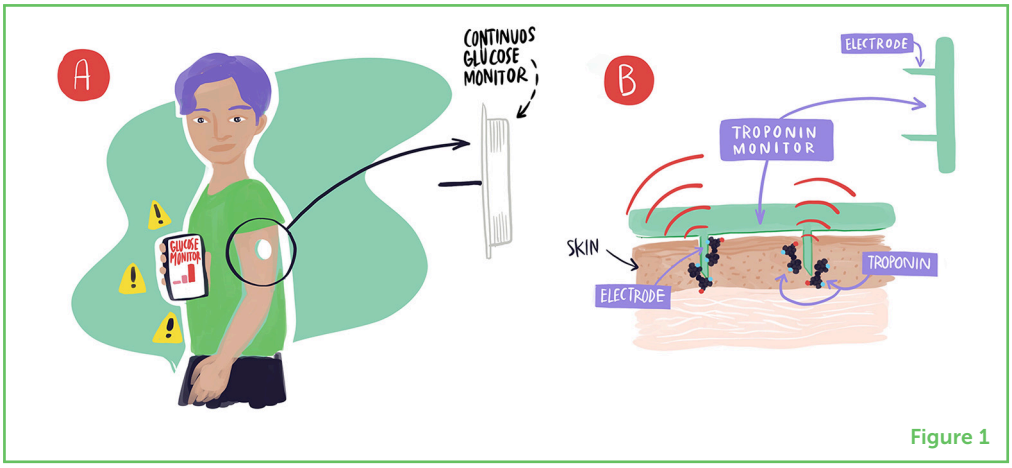


Figure 1

(A) A CGM is a small, stick-on device with a tiny needle, used to track blood sugar levels in people with diabetes. The device connects wirelessly to an app that can provide the user with blood glucose data as often as every few minutes—warning them if levels are too high or low. **(B)** New wearables may protect people from heart attacks. Unhealthy heart cells release troponin into the blood. The electrodes on the wearable (troponin monitor), which barely penetrate the skin's surface, are "sticky" for troponin. When troponin sticks to them, a signal is generated—warning the wearer to see a doctor. (Figure created by carlottacat.com).

HEART ATTACK

A serious medical emergency when blood flow to the heart is blocked, causing damage to the heart muscle.

PREVENTING HEART ATTACKS—EARLY DETECTION SAVES LIVES

What if you are healthy and just want to avoid getting sick? Well, other cool wearables are being developed that monitor wearers constantly, while they are healthy, to detect small changes in certain chemicals or vital signs (heart rate, blood pressure, temperature, etc.) that might indicate the very early stages of an illness—before wearers feel even minor symptoms. Early detection can help doctors start treatments early, which can help to prevent many illnesses and deaths.

Heart attacks are a good example of a health problem that could be preventable by a wearable. A heart attack happens when the heart does not get enough oxygen due to a blockage in one or more blood vessels. Without oxygen, heart muscle cells start to die, which can lead to permanent heart damage and even death. However, many heart attacks could actually be prevented. How? Heart cells contain a protein called **troponin**, which is not found in the blood when the heart is healthy. When heart cells start to get sick, some of them break open and release troponin into the blood stream [2]. Blood tests can detect

TROPONIN

A type of protein found in the heart muscle. When the heart is damaged, troponin is released into the blood and can be measured to help diagnose a heart attack.

troponin in the blood—even long before patients have any signs of a heart attack. If troponin is found, doctors can quickly treat patients to prevent heart attacks from happening. But even if doctors check their patients for troponin during their normal yearly check-ups, there is a whole year between visits when things could go wrong!

Fortunately, a company called WearOptimo is creating a wearable that may make heart attacks a thing of the past. The new wearable, which is still being tested, has tiny electrodes coated with a detector substance that can bind to troponin, like two Lego bricks sticking together. When the wearable is placed on the skin, the tiny electrodes barely penetrate the skin's surface (Figure 1B). If troponin is present and sticks to the electrodes, a signal is produced. An app analyzes the data and can warn the wearer if troponin is discovered, so the person can then go immediately to the doctor for treatment—hopefully long before a heart attack begins.

Other cool examples of wearables that help people avoid getting sick include one that can measure body chemicals associated with anxiety and stress, and one that can tell wearers if they are properly hydrated. Wearables that can measure more and more things are constantly being developed, and these devices are also getting smaller and more convenient to wear.

A FLOOD OF DATA

From step trackers to the most advanced wearables, new health technologies have one thing in common: data—and *lots* of it. Just imagine: if a CGM collects blood glucose data every 5 min for 2 weeks, that equals 4,032 data points—for just ONE health parameter for ONE person! When thousands or even millions of people are wearing monitors that track *multiple* health parameters all day, every day of their lives, this rapidly becomes a tsunami of health data (Figure 2).

Figure 2

Figure 2

New health technologies like wearables are generating a flood of health data. Data are saved in large data-storage centers, where researchers and companies can often access data for their own purposes. All these data are generating many questions that scientists, lawmakers, and companies are still struggling to answer. Who "owns" health data, and who should get to use it? How do we keep health data safe and protect people's privacy? And of course, the big question: will wearable devices and the data they generate eventually replace human doctors? Do you think this might happen? Would it be good or bad? (Figure created by carlottacat.com).

Data collected from health apps or wearables do not just sit there on your phone. Most apps transfer data to data-storage centers where it is saved on servers, sometimes forever. Companies and researchers can get permission to access and use that valuable information, for example to target their advertising campaigns at certain groups of people; and researchers may use health data to study diseases or treatments.

Do you think the data generated from your health apps or wearables are yours—do you own those data? You might think you should, since those data come from *you*! If you own a physical object, like a car, you usually get to make decisions about who drives the car, or where to park it so it will be safe and not get stolen. But even if you think you should own your data, you generally cannot control where the data from your wearables are stored, or exactly which companies or researchers can use those data. Furthermore, if you sold a car that you owned, you would get the money. Should you also get some of the money when researchers or companies buy your data from the company that makes your favorite fitness-tracking app?

Researchers, companies, and lawmakers are currently wrestling with complicated questions like these, and there are still no clear answers. These issues are complicated because we know that the more data we have, the better we will understand diseases and thus be able to develop preventions and treatments—but at the same time, we need to make sure sensitive data are managed in ways that most people are comfortable with. What do you think? Is it OK for companies to use your health data to develop or sell new products and services? What about researchers—is it OK for them to use your data, if their goal is to improve public health?

HEY, THAT IS PRIVATE!

Most of us do not want the world to know our health details—we would rather keep certain things private. You might not want everyone at school to know that your doctor removed a big hairy wart from your bum, for instance! Fortunately, there are laws to protect the privacy of medical information, preventing doctors from sharing medical records without the patient's permission. But the regulations are not so strong for data collected from health apps or most wearables.

Maybe you are thinking, "Who cares if the world knows how many steps I took this week?". But as wearables begin to track many aspects of health, this problem becomes more serious. For example, what if life insurance companies could access troponin data and then refuse to insure anyone who has ever had troponin in their blood, because people with heart issues might be at greater risk of dying young and costing the insurance company money? Or what if employers could access data from wearables and decide not to hire people

with certain conditions, like high blood glucose or high cholesterol, because they think those people might get sick and take too many days off?

Even if laws are eventually created to fully protect the privacy of health app and wearable data, we all know that servers can be hacked by criminals who want to use or sell people's personal information. To keep private health data safe and to help users to trust their wearable products, companies must have strong data security measures.

PROTECTION OF HEALTH DATA

Luckily, there are already some common practices in place to protect the privacy of health data collected from fitness apps and wearables, with more protections likely to appear as these technologies become more popular. For example, have you ever tried to install a new app and been prompted to read the company's privacy policy and click "I agree" before the app installs? A good privacy policy should spell out what data the app will collect, how the data will be kept private, and how the company intends to use the data—including who they plan to share it with. This allows you to make an informed decision as to whether you want the app on your device.

Once the app or wearable has your data and transfers it to a server, one common strategy to protect the privacy of health data is called **data de-identification**. This involves removing any personally identifiable information (such as name, email address, and home address) from the data before storage. That way, researchers and companies (and possibly hackers!) will only see anonymous data that cannot be traced back to any one person. Unfortunately, hackers are getting better at finding ways of re-identifying data, so even stronger security measures must be developed. **Encryption** is another privacy method commonly used in healthcare. Encryption is like converting data into a secret code, so that it is unreadable to anyone who does not have the "key".

DATA DE-IDENTIFICATION

The process of removing personal information from data to protect people's privacy.

ENCRYPTION

A way to keep information private and secure by using a special code to scramble it. Only someone with the key can unscramble it.

DATA: THE NEW DOCTOR?

Are doctors about to be replaced with health apps, wearable medical devices, and maybe even artificial intelligence? Could it be that someday you will never need to visit a doctor again? While the number and types of things that wearable devices can do will certainly continue to grow, wearables alone will probably never totally replace doctors because doctors need to check many things that can only be done in person. However, the health data generated by wearables can *definitely* make doctors' jobs easier and patients' visits more efficient and effective. Perhaps, in the future, the combination of data and

doctors will provide patients with the best possible healthcare—what do you think?

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talks by Ariel Ganz and Mark Kendall.

REFERENCES

1. Reddy, N., Verma, N., and Dungan, K. 2000. "Monitoring technologies-continuous glucose monitoring, mobile technology, biomarkers of glycemic control", in *Endotext [Internet]*, eds Feingold, K. R., Anawalt, B., Blackman, M. R., Boyce, A., Chrousos, G., Corpas, E., et al. (South Dartmouth, MA: MDText.com, Inc.). Available online at: https://www.ncbi.nlm.nih.gov/books/NBK279046/ (accessed January 16, 2024).
2. Wu, A. H. B. 2017. Release of cardiac troponin from healthy and damaged myocardium. *Front. Lab. Med.* 1:114–50. doi: 10.1016/j.flm.2017.09.003

SUBMITTED: 26 May 2023; **ACCEPTED:** 12 January 2024;
PUBLISHED ONLINE: 06 February 2024.

EDITOR: James Gillies, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Ambika M. V. Murthy and Ishita Choudhary

CITATION: Debad SJ, Ganz A and Snyder M (2024) Wearing Your Heart (Monitor) on Your Sleeve: Will Data Be the New Doctor? Front. Young Minds 12:1229690. doi: 10.3389/frym.2024.1229690

CONFLICT OF INTEREST: SD was employed by SJD Consulting LLC. AG is a co-founder of Arben Ventures and Xthena Partners. MS is a cofounder and scientific advisor of Personalis, SensOmics, Qbio, January AI, Fodsel, Filtricine, Protos, RTHM, Iollo, Marble Therapeutics, Crosshair Therapeutics, NextThought and Mirvie. He is a scientific advisor of Jupiter, Neuvivo, Swaza, Mitrix, Yuvan, TranscribeGlass, and Applied Cognition.

YOUNG REVIEWERS

ERIC, AGE: 12

My name is Eric and I live in Adelaide, Australia. I am 12 years old and have just finished year 6. I have a passion for science and technology, and since early childhood I have been interested in all the latest technology. I was always exposed to these topics as my parents are scientists who are active in medical research. I think that science and technology are integral for development and improving lifestyle. The recent advances have hugely impacted our way of life and is the reason I find science very interesting and my passion will only continue to grow.

GRESHMA, AGE: 13

Hello! My name is Greshma, and I am in 8th grade. I love reading, playing tennis, traveling, and hanging out with my friends. I hope to be a forensic scientist someday!

AUTHORS

SUSAN J. DEBAD

Susan has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard". She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has more than four dogs! In her spare time, she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

ARIEL GANZ

Dr. Ganz is a postdoctoral scientist in Dr. Michael Snyder's lab at Stanford University researching Mental Health and Precision Medicine, especially focusing on wellness practices that improve wellbeing. She also started a venture fund, Arben Ventures, to invest in the next generation of innovators. In her free time, Ariel enjoys yoga, horseback riding, tennis, and playing with her cat and dog.

MICHAEL SNYDER

Dr. Snyder is a professor and Chair of Genetics at Stanford University. He is a pioneer in personalized and precision medicine and was the first to use watches like the Fitbit and Apple watch to monitor health and detect disease. Mike tracked his own health and found a risk factor for diabetes. After he then got diabetes, he tracked his health while he took medications and did lifestyle interventions to reverse his diabetes. He also detected his own Lyme disease with a smartwatch. In his free time, he enjoys working out and spending time with his family and two dogs.

frontiers | Frontiers for Young Minds

HUMAN HEALTH
Published: 06 February 2024
doi: 10.3389/frym.2024.1235059

BIOINFORMATICS: USING "BIG" DATA TO SOLVE HEALTH MYSTERIES

Susan J. Debad [1*] ***and Rolf Apweiler*** [2]

[1] *SJD Consulting LLC, Ijamsville, MD, United States*

[2] *European Molecular Biology Laboratory–European Bioinformatics Institute (EMBL-EBI), Wellcome Genome Campus, Hinxton, United Kingdom*

YOUNG REVIEWERS:

CADEY
AGE: 12

KEIRA
AGE: 12

MARYSOL
AGE: 13

MIA
AGE: 13

Health data—information from sources like medical records, surveys, and even electronic devices like smartwatches—are becoming increasingly important for keeping people healthy. Computers and the internet make it easy to store and share health data. Scientists and researchers can use these data to understand and prevent diseases or to develop better treatments. To do so, they combine biology, computer science, and math to understand data and find patterns. But using health data is not easy. Scientists must first find the right information among the many data sources available. They also need to make sure the data are "clean" and correct. Once health data are collected and checked, scientists analyze those data to make important discoveries. Health data are both personal and valuable, so they must be kept safe and private. By protecting people's privacy, we encourage even more data sharing, which helps scientists learn *even more* and continue to improve human health.

DATA = HEALTH?

If you were to make a list of things that help you to stay healthy, what would be on it? You might include things like exercise, healthy food, plenty of sleep, and getting medical check-ups. But what about data, is that on your list? No? Well, maybe you will want to add it after reading this article! Health-related data—and lots of it—are becoming increasingly important for treating diseases and for keeping people from getting sick in the first place. The amount of health data being collected is growing exponentially. But what exactly *is* **health data**? And how can these data help keep people healthy? In this article, we will explain how some scientists are like data detectives, solving health mysteries with the help of data. If you are interested in how biology, medicine, and computer science can all work together to solve health puzzles, maybe you would like to be a data detective, too!

HEALTH DATA

Information about our bodies and how we take care of them. It helps scientists and doctors keep us healthy and find better treatments.

DATA: NOT JUST FOR LABORATORY EXPERIMENTS ANY MORE

"Data" used to be a term that was used mainly when talking about experiments done by laboratory scientists. Scientists would collect data from their experiments, analyze those data to see if they supported their hypotheses, and then use the data to plan their next experiments. Maybe a scientist's data would *eventually* lead to a new medicine or a better understanding of a disease, but often the data (such as how many mice got better in response to a new drug, for example) were only used by the experimenters themselves.

The world of data, particularly health data, is changing. The term "health data" refers to any information related to people's health. Health data can come from a variety of sources in addition to scientific research studies, including electronic medical records, patient surveys, **DNA sequences**, and data collected from a growing number of wearable devices, like smartwatches and blood sugar monitors. This is a HUGE amount of data, and thanks to computers and the internet, data are easier than ever to share. Data sharing allows many people—not just the scientists who created the data—to use data for things that can improve human health.

DNA SEQUENCES

A special code in all cells that holds important information about our bodies. Scientists use DNA sequences to understand how our genes affect our health and to find ways to prevent or treat diseases.

FROM "BIG" DATA TO BETTER HEALTH

The amount of health data being collected is so great that it can no longer simply be stored on a thumb drive—or even on a personal computer [1]. This incredible amount of data is often called "big data", and it needs to be kept safe and organized. These huge sets of data are often stored on powerful computers called servers, which are meant to handle many tasks and "serve" many users at the same time. Servers are like huge digital libraries where scientists can keep and access their

information (for more information on how servers work and to see what they look like, check out this video).

Health data on servers can also be shared with other researchers, who can act like detectives by analyzing the data to answer *their own* research questions—questions that the original data creators may never have even thought about! Using data in these new ways is called **repurposing** data, and it is very useful because researchers can come up with new discoveries without the need to do their own experiments from scratch. Repurposing data saves money and effort, and it can speed up the pace of scientific discoveries [2]. Discoveries made using health data can improve human health in many ways. For example, such discoveries could help prevent diseases from happening, detect and diagnose diseases that people already have, and treat diseases to help people get better—with fewer side effects (Figure 1).

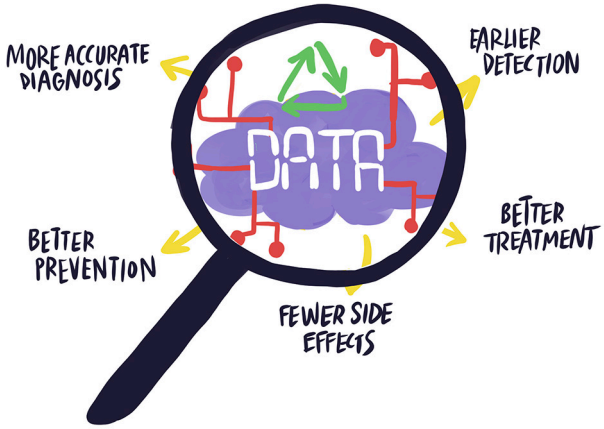


Figure 1

However, getting from health data to actual improvements in people's health is not an easy task—it requires a lot of detective work! An entire field of science, called **bioinformatics**, has developed to help with these discoveries. Bioinformatics combines aspects of biology, medicine, computer science, and mathematics to work with huge amounts of stored health data. In simple terms, bioinformatics is like a special kind of detective work that helps scientists sift through tons of data to solve mysteries about genes, proteins, and other important things that play a role in human health. Just as a detective uses clues to solve a case, bioinformaticians use computers and special software to find "clues" in "piles" of health data. But how do bioinformaticians help to make the leap from big data to better human health?

DATA DISCOVERY: FINDING THE NECESSARY DATA

Imagine you were a data detective working in bioinformatics and you wanted to do a study on heart disease, for example. The first step is discovery—collecting all the data that are available on your

REPURPOSING

Using existing data in new ways to make discoveries and improve our health without starting from scratch. It saves money and speeds up the pace of research.

Figure 1

Huge amounts of health data are collected from many sources and stored on powerful computers called servers, which are like huge digital libraries. "Data detectives" who work in bioinformatics can access the servers and analyze these data to answer their own research questions, which may be quite different from the original purpose of the data. This is called data repurposing, and it can save money and time, speeding up scientific discoveries. Many important discoveries can be made from studying health data, including new ways to diagnose and detect diseases, better treatments for diseases, and even methods of preventing diseases altogether. Figure created by carlottacat.com.

BIOINFORMATICS

A field that combines biology, computer science, and math. Scientists called bioinformaticians use computers to study and understand large amounts of data about our bodies and health.

topic. Like a detective working on a case, you must find the right data sources, depending on the type of data you need to solve your heart disease "puzzle". Maybe some of the puzzle pieces in your heart disease mystery come from experiments and research that scientists have done in labs all around the world, in the form of DNA sequences or information about molecules related to heart disease. Other pieces of your puzzle might come from the electronic medical records of heart disease patients, or studies of how various drugs have affected such patients. Once you have found the right data sources, you must then make sure you can actually use those data. Some databases are open access, which means that anyone can use the data for free at any time and for any purpose, while other sources may be "closed", meaning researchers must request access and meet certain requirements before they can use the data.

Say you have access to all your data sources. Remember that these sources contain data produced by other scientists or doctors, who might have been working on questions totally different from yours. That means there are probably all kinds of data you *do not* need mixed up with the data you *do* need—like pieces from a bunch of jigsaw puzzles, all mixed together. The challenge is finding your specific puzzle pieces amidst all the other data. Special bioinformatics tools are used to "ask questions" of the data, to pull out only the data that relate to your research question. For example, you could separate all the DNA sequences (or medical records) of people with heart disease from those of healthy people or people with other diseases.

COMBINING AND CLEANING DATA: FITTING THE PIECES TOGETHER

As mentioned above, just like a detective must collect clues from multiple sources and suspects, chances are you will need more than one data source to solve your heart disease mystery. For instance, if you want to find out whether a mutation in a certain gene is linked to heart disease, you might need to combine electronic medical records (information about patients' health histories and medical conditions) from one data source with DNA sequence data from a totally different database. The process of combining data from multiple sources is called **data integration**, and it helps bioinformaticians to spot relationships and patterns that they might not see using only one data source. Data integration can be complicated because data sources can use different formats, and they may not always be compatible with each other. Units of measurement might be different (pounds vs. kilograms or age vs. date of birth, for example) or the same kind of data might be called by different names in each source (last name vs. surname, for example). Data from separate sources must be made consistent before the sources can be combined.

DATA INTEGRATION

The process of combining information from separate sources. Integration allows bioinformaticians to find connections and patterns that they would not see looking at just one source.

To return to the puzzle analogy, imagine you were trying to assemble a puzzle, but you had extra copies of some of the pieces, and others were bent or broken so that they did not fit together well. You would probably want clean up the pieces as best you could, and remove the extra ones, to give yourself the best chance of successfully putting together the puzzle. In bioinformatics, this is where **data cleaning** comes in. Bioinformaticians must make sure, to the best of their ability, that all data are correct and ready to study. They use special computer programs and techniques to "clean up" the data and get rid of any mistakes or errors, like removing the same information that might have accidentally gotten into the data twice, or removing data points that are obviously wrong (for example, if a person's age is listed as 273). Data cleaning is an especially important step, because errors in data can lead to incorrect conclusions—the way your puzzle might not look right if the pieces were messed up.

DATA CLEANING

The process of making sure that the information in a dataset is accurate and reliable by fixing errors and removing duplicates, for example, to prepare data for analysis.

DATA ANALYSIS

Examining and studying data to find patterns, relationships, and important insights. Scientists use special tools and methods to make sense of the data and draw meaningful conclusions.

DATA ANALYSIS: SEEING THE WHOLE PICTURE

Once your data are clean and ready, it is time for the fun part—**data analysis**. Bioinformaticians use powerful computers and clever mathematical procedures to do the "detective work" of looking for patterns and clues in data and drawing conclusions from their observations. This is the stage where you finally put your puzzle pieces together to reveal the overall picture—or the stage where the detective solves the mystery! In your study, you might discover that, of all people with heart disease, those with a certain gene are more likely to live longer if they take a certain drug, for instance. This type of conclusion would have been impossible to draw from looking at *just* medical records or *just* DNA sequences—but by using bioinformatics techniques to find, combine, clean, and analyze data, new relationships can be discovered that might eventually save patients' lives (Figure 2).

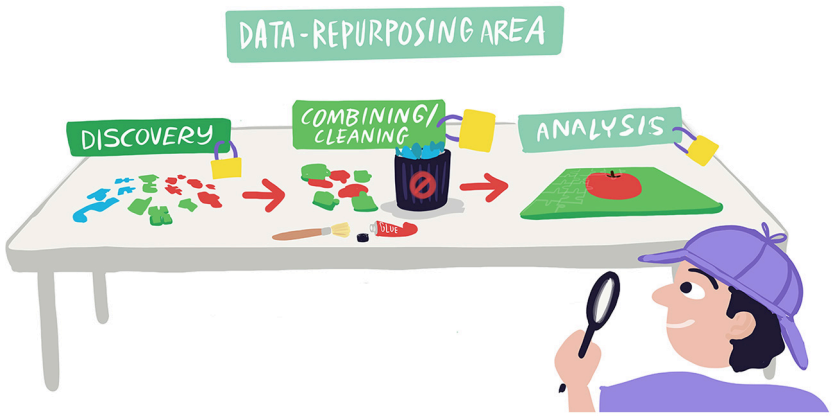


Figure 2

As "data detectives", bioinformaticians must follow three basic steps when repurposing data. First, the right sources of data must be discovered. This is like gathering all the possible pieces to build a jigsaw puzzle. Data from various sources must be combined and cleaned, to make sure they are correct. This is like getting rid of any puzzle pieces that do not belong or fixing damaged pieces. Finally, data are analyzed to draw conclusions—like putting the puzzle together to see the whole picture! In each step of the process, there are important methods in place to keep personal health information safe and private. Figure created by carlottacat.com.

KEEPING DATA SAFE AND PRIVATE

Health data contain lots of personal information, so while this information is very important for the work of bioinformaticians and doctors, it must be kept safe and private. One way to keep data safe is to have special "locks" on the servers, to keep out everyone who does not have permission to see or use the information. **Encryption** is a process that can be used to protect health data, by turning the data into a kind of "secret code" that can only be decoded by people who have the "key" to the code (for more information on how encryption works, see this site). This way, even if a hacker or someone who is not authorized breaks the "locks" on a server and gets their hands on the encrypted data, they will not be able to understand it because it will look like gibberish. Sometimes, instead of (or along with) encryption, personal information such as name, address, or phone number can be removed from health data, so that no one will know who the remaining data belong to. Back-up copies of the data are also made, so that if something unexpected happens, like a computer problem or a serious natural disaster, the data will not be totally lost. For more information on heath data and issues of data privacy, see another article in this Collection.

ENCRYPTION

A way of turning data into a secret code. Encryption keeps data safe and private because encrypted data can only be understood by those who have the special "key" to decode it.

While keeping health data safe and protected can be a big challenge, these steps are necessary to protect people's privacy. When people trust that data-protection measures work and that their data are safe and anonymous, they may be more willing to share their data [3]. The more data sharing there is, the more information bioinformatics "data detectives" and other researchers have available to work with, as they continue to use data to solve mysteries that will improve human health!

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talk by Rolf Apweiler.

REFERENCES

1. Culbertson, N. 2021. *The Skyrocketing Volume of Healthcare Data Makes Privacy Imperative*. Forbes Technology Council, Forbes (2021). Available online at: https://www.forbes.com/sites/forbestechcouncil/2021/08/06/the-skyrocketing-volume-of-healthcare-data-makes-privacy-imperative/?sh=3a724a606555 (accessed January 16, 2024).
2. Sielemann, K., Hafner, A., and Pucker, B. 2020. The reuse of public datasets in the life sciences: potential risks and rewards. *PeerJ Life Environ.* 8:e9954. doi: 10.7717/peerj.9954

3. Gille, F., Smith, S., and Mays, N. 2022. Evidence-based guiding principles to build public trust in personal data use in health systems. *Digit. Health* 8:20552076221111947. doi: 10.1177/20552076221111947

SUBMITTED: 05 June 2023; **ACCEPTED:** 12 January 2024;
PUBLISHED ONLINE: 06 February 2024.

EDITOR: Claudia Marcelloni, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Parvathy Venugopal and Pamela T. Wong

CITATION: Debad SJ and Apweiler R (2024) Bioinformatics: Using "Big" Data to Solve Health Mysteries. Front. Young Minds 12:1235059. doi: 10.3389/frym.2024.1235059

CONFLICT OF INTEREST: SD was employed by SJD Consulting LLC.
The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

CADEY, AGE: 12
My name is Cadey. I like science and being creative. I love reading and Keeper of the Lost Cities is my favorite series at the moment. I like writing stories and I love to dance. I went to Junior theater festival with the Parks Youth Theater and we won the most outstanding performance. I really care about the environment and when I was 7 I staged a protest outside Parliament House.

KEIRA, AGE: 12
My name is Keira and I am a student in Ms. Frantom's class at Tappan middle School in Ann Arbor, Michigan. I like science because you can experiment with things and learn about our planet. I love running competitively, sailing races and playing soccer.

MARYSOL, AGE: 13
My name is MarySol, I am a student in Ms. Frantom's seventh grade science class at Tappan middle school in Ann Arbor, USA. I think science is cool because it covers so much and it can help explain and answer questions in tons of different topics, I also love to do labs (science experiments) because you never can fully predict what

will happen. I play travel soccer and used to rock climb competitively. I love reading, listening to music, and most especially hanging out with my dog Chez (pronounced shea) and going on late night walks with her. In the future I hope to have a big job that has a positive effect on other people's lives, and I would also like to travel to a bunch of historic sites all over the world.

MIA, AGE: 13

I am Mia, I really like to read, write, and play music. I play the violin and flute and enjoy public speaking (I am on my school's debate team). I also volunteer in different organizations to teach chess, play violin, etc.

AUTHORS

SUSAN J. DEBAD

Susan has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard." She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has more than four dogs! In her spare time, she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

ROLF APWEILER

I was born in Germany and studied biology in both Heidelberg, Germany, and Bath, UK. Since 1987, during my studies, I worked as a student helper at EMBL in Heidelberg, reading articles about functions of proteins and adding this information into a database. That was my start in bioinformatics and, in 1994, I moved with my wife and our two children to Cambridge to set up (with a few colleagues from EMBL Heidelberg) a new institute of EMBL, called the European Bioinformatics Institute (EBI). Now, for 8 years, I have been one of the two directors of this institute, which has grown to nearly 900 staff members and handles more than 100 million daily web requests to our databases from millions of researchers worldwide.

ENGINEERING AND TECHNOLOGY
Published: 06 February 2024
doi: 10.3389/frym.2024.1244349

UNLOCKING THE WONDERS IN THE GRAND LIBRARY OF OPEN SCIENCE

Susan J. Debad [1*] ***and Rolf Apweiler*** [2]

[1] *SJD Consulting LLC, Ijamsville, MD, United States*

[2] *European Molecular Biology Laboratory, Wellcome Genome Campus, European Bioinformatics Institute (EMBL-EBI), Hinxton, United Kingdom*

YOUNG REVIEWERS:

MANANYA
AGE: 8

ZI-AN
AGE: 8

In a world where scientists often guard their research like hidden treasures, open science is a new and exciting concept. Rather than keeping experiments and results secret, open science encourages the wide sharing of scientific knowledge, to speed up research and improve human lives. Imagine a grand library where scientists unlock their safes and deposit their valuable information where everyone can access it! The power of open science was clearly seen during the response to the COVID-19 pandemic, and it is central to important scientific collaborations like the Human Cell Atlas project, which aims to map all the cells in the human body. By embracing open science, we unlock a world where knowledge is freely accessible, collaboration thrives, and scientific discoveries are accelerated, leading to a brighter future for everyone.

OPENING THE SAFE

Imagine a world in which every scientist has a secret safe, hidden away in their laboratory. Inside each safe, scientists store their most precious treasures—their experimental procedures and research data. These scientists keep their safes tightly locked, guarding their discoveries like hidden gems. While this "high security" may protect their life's work, it also makes it difficult for scientists to know what other scientists are doing, or whether any other labs have generated information that might help them to answer their own scientific questions. Now imagine a world in which all scientists unlock their safes and deposit their important information into a giant library. Further, imagine that *anyone* can visit this library. Scientists can browse shelves of data and "borrow" any information that might be helpful to them—kind of like checking out a library book. Even non-scientists can spend time in this library, exploring topics that interest them or even adding to the library's collection!

OPEN SCIENCE

The practice of sharing scientific publications and data freely, so that everyone can learn and discover new things together.

Which seems like the more effective way of improving human lives through science—keeping scientific experiments and results "secret" or sharing them openly, so that everyone can learn from them? Supporters of the **open science** movement believe that sharing information openly is a much better way to do science. Get ready to open the doors of this grand library and reveal the wonders within (Figure 1)!

Figure 1

Instead of keeping their research data locked up in "secret safes" in their laboratories, open science encourages scientists to share their publications and data openly and for free. This is like a grand library where anyone—even kids!—can learn from the latest scientific findings and even see the valuable data they are based on. We think open science is a much better way to do science, because it can save time and money and allow everyone to access fascinating scientific information! (figure created by carlottacat.com).

WHY KEEP SCIENCE SECRET?

In certain situations, keeping scientific data "secret" is definitely the right thing to do—and in some cases it is even illegal to share such information. For example, the information in patients' medical records, or other kinds of data that can be linked to a specific person (like names, addresses, or phone numbers of study participants), is personal and should be kept secret to protect people's privacy (to

learn more about data privacy, see this article and this one, from the same Collection).

In the past, scientists had other good reasons for keeping their information secret, too. Scientific research can be highly competitive, and researchers often work extremely hard to be the first to make significant discoveries. Like all of us, scientists want to be recognized for their efforts—but that is not all. Have you ever heard the phrase "publish or perish"? This expression refers to the pressure researchers often feel to continuously publish new results. Publications in prestigious scientific journals often help researchers get money to do more research, get promotions, and be seen as successful in the scientific community. By keeping their data private and not talking openly to others about their discoveries, scientists give themselves enough time to write articles before others can publish first and take the credit.

Some scientists might have exciting ideas that they want to turn into products or technologies that can be sold. In such cases, keeping their data secret gives them an advantage when working with companies or investors. Other scientists may want to keep their data secret until they have double checked to make sure their findings are correct—so that others do not find errors in their data and question the quality of their research.

While some kinds of "secretive" practices were seen as normal for many years, things are changing, thanks to open science! Many scientists are beginning to open their safes, tearing down the walls of secrecy and creating the worldwide science "library" where knowledge is freely available to everyone. But how exactly do we create such a "library"... and what is in it?

OPEN ACCESS PUBLISHING: THE "BOOKS" IN THE "LIBRARY"

One very important aspect of open science is called **open access publishing**. This is the process that adds the books to the library! When scientists get enough results from their experiments to support their hypotheses, they write articles describing their results and explaining what those results mean. As we mentioned earlier, scientists try to get those articles published in prestigious scientific journals. In the past, most journals had expensive subscription fees, so anyone who wanted to read one of the articles had to pay to do so—or be part of a university that paid the subscription fees. This drastically limited the number of people who could access the information—which means the information was not as useful as it could be.

OPEN ACCESS PUBLISHING

A process used by some scientific journals, in which they provide scientists' research papers for free, so that anyone can read them and learn from them without having to pay a fee.

Well, some brave scientists decided to create their own journals that are open to everyone—open access journals. With open access

publishing, anyone, anywhere, can read scientific articles—without paying a cent! Somewhere between 28 and 54% of all scientific journals are currently open access, and this number is growing [1]. Did you know that Frontiers for Young Minds is part of a family of Frontiers journals containing more than 200 journals on many topics—and every single one of them is open access online? Open access publishing allows other scientists, students, teachers, and anyone else with an internet connection and a curious mind to enter the science "library", explore the latest research, learn new things, and get inspired.

OPEN DATA: LOGGING ON TO THE LIBRARY'S COMPUTERS

Open science is not just about free access to research articles—it is also about sharing the valuable scientific data that research articles are based on—or even data from experiments that never make it into a publication. This is called **open data**. Instead of keeping their data secret in a locked-up lab notebook, scientists deposit their data with large organizations that organize, analyze, store, and share that data with other scientists and the public. This is like having free wi-fi in the grand library of science—you can log on any time to get all the information that you need to do projects at school or at home. The amount of open data that exist—and thus the amount of data sharing—is enormous. For example, one data-handling organization, the European Molecular Biology Laboratory's European Bioinformatics Institute (EMBL-EBI) is working hard to be one of the top open libraries for biological data in Europe. EMBL-EBI receives 100 million web requests for data *per day*. *Every 5 min*, a scientific article is published that uses EMBL-EBI data, and *every 3 s*, this organization receives new data from scientists! (For more information on EMBL-EBI, see this talk.)

When data are open, they become shared global knowledge—anyone can examine them, analyze them, and use them to design new experiments or create new things. Using data to answer a question other than the one those data were collected to answer is called **repurposing** the data. Repurposing shared data can save lots of time and money that scientists would otherwise have to spend collecting those data themselves. Thus, open data can speed up the pace of scientific research, helping scientists to solve big problems more quickly (for more information on using and repurposing scientific data, see another article in this Collection).

In addition to speeding up the pace of science, open data also contribute to data **transparency** and **reproducibility**. Transparency means that everyone can easily see and understand the data that scientists use to reach their conclusions. This helps people to trust scientists and their findings. Reproducibility means that other scientists

OPEN DATA

Valuable research information and experimental data that are shared openly with everyone, allowing anyone to access, analyze, and use those data for their own projects and discoveries.

REPURPOSING

Using shared data in new ways, beyond its original purpose, to answer new questions, solve problems, or create something new. Data repurposing saves time and resources.

TRANSPARENCY

A quality of scientific findings that makes them clear and easy for everyone to understand, so that people can see how research was conducted and reach their own conclusions. Transparency increases trust in science.

REPRODUCIBILITY

The ability to repeat a study and get similar results. Reproducibility helps ensure that scientific findings are reliable, increasing trust in science.

in totally different labs, or with different types of equipment, can try to replicate the data to make sure that it is correct.

THE POWER OF OPENNESS

We will now briefly explore two examples that showcase the tremendous power of open science to improve human health and change the world for the better!

The global response to the COVID-19 pandemic is a dramatic example of how openly shared scientific publications and data can save lives. The genetic sequence of the SARS-CoV-2 virus was figured out and openly shared only *weeks* after COVID-19 was first reported in China. The development of sensitive ways to detect the virus and the creation of a vaccine began almost immediately. Sharing of COVID-related research between scientists, governments, and vaccine-development companies resulted in the fastest development, testing, and approval of a vaccine ever seen in human history [2, 3]! This amazingly speedy response, clearly boosted by open science and worldwide collaboration, is estimated to have saved millions of lives [4, 5].

A project called the Human Cell Atlas is another excellent example of how open science can help people to cooperate and do great things. As you know, the human body is made of many kinds of cells—but does it surprise you to learn that, even after many years of research, scientists still do not know all of the cell types that make up the body? To understand topics like how to keep people healthy or how a disease like COVID-19 makes people sick, scientists and doctors need a deep understanding of all of the body's 37 trillion cells—where they are located and what they do. The aim of the Human Cell Atlas project, which began in 2016, is to create something like a Google Map of the human body, allowing users to view the body at various levels of detail, from a "planet-wide" view of the body as a whole, to a "street view" showing specific cell types present in a tiny area (Figure 2). To create this Atlas, more than 2,000 groups are working together, sharing their varied data and expertise about various systems of the body (nervous system, reproductive system, immune system, etc.) When the Human Cell Atlas is complete, anyone will be able to use it to learn more about the cell types that make us human! (To learn more about the Human Cell Atlas, see this talk.)

ENCOURAGING OPEN SCIENCE

While the shift toward open science is steadily opening the secret safes and moving information to the grand library, there are still scientists who choose to keep their scientific information private, often for the reasons mentioned earlier in this article. Many journals remain subscription based and much scientific data is still not open, either. It

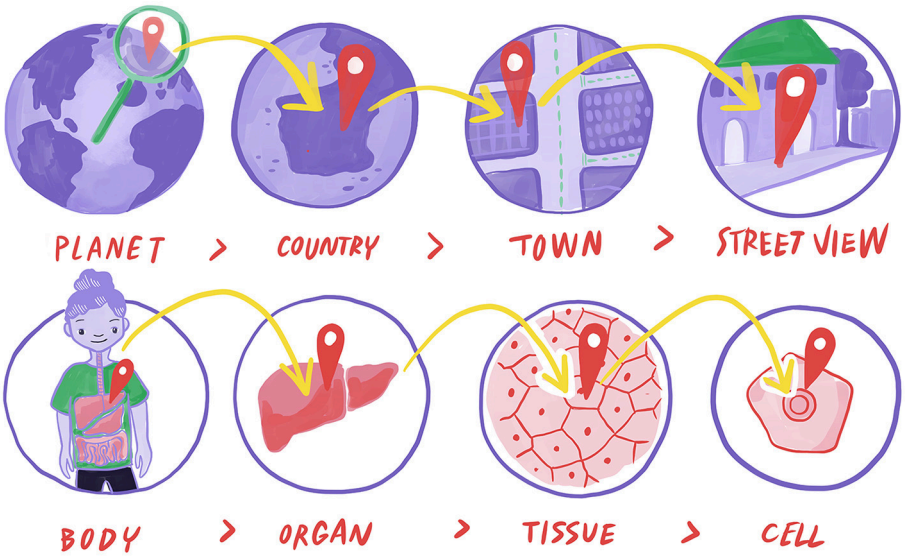


Figure 2

The Human Cell Atlas project aims to identify all of the cell types and map them—kind of like a Google Map of the human body, where you can "zoom in" from a "planet-wide" view of the whole body all the way down to a "street view" showing the specific types of cells in a tiny area! More than 2,000 groups are working together to create this Atlas. (figure created by carlottacat.com).

can be quite difficult for scientists to find the right balance between openness and protecting their work. Some scientists are motivated to publish in open access journals because they want their work to be accessible to a broader audience—not just scientists. What more can be done to encourage all scientists to join the open science movement? This is an important question and, all over the world, universities, funding organizations, and governments are trying to find ways to get *all* scientists to embrace open science, so that it eventually becomes the new normal.

For example, Horizon Europe, which provides research money to scientists in the European Union, looks at the open science practices of scientists who apply to them for funding. By using open science as one of their requirements, this organization encourages more labs to switch to open practices. Researchers who receive funding from Horizon Europe agree to publish their results in open access journals and to make their data as open as possible. The scientific community is also exploring new prizes or other ways to recognize scientists—ways that are more closely aligned with the values of open science. For instance, IBM Quantum sponsors an Open Science Prize, offering $30,000 (in 2023) to recognize "the best open source solutions to some of quantum computing's most pressing problems".

OPEN SCIENCE, OPEN MINDS

To sum up, open science is when scientists share their research with everyone (including kids!) so that everyone can learn and discover new things. It is like having a grand library where all the books are free to read, and anyone can come in, learn, and contribute! Open science has unlocked a new era of exploration, collaboration, and discovery.

With open access publishing, open data, and open minds, scientists and curious minds from all over the world can work together to solve the mysteries of the universe. This "new" way of doing science has many advantages over the old "secretive" way. Everyone can learn from each other, build upon each other's discoveries, invent new things more quickly, and generally make the world a better place. The secrets of science are waiting to be discovered, and you hold the key to the grand library!

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talks by Muzlifah Haniffa and Rolf Apweiler.

REFERENCES

1. Basson, I., Simard, M.-A., Aubierge Ouangré, Z., Sugimoto, C. R., and Larivière, V. 2022. The effect of data sources on the measurement of open access: a comparison of dimensions and the web of science. *PLoS ONE*. 17:e0265545. doi: 10.1371/journal.pone.0265545
2. Saag, M. S. 2023. Development of COVID-19 vaccines—An unanticipated moon shot achieved at warp speed. *JAMA Netwo. Open*. 6:e2251983. doi: 10.1001/jamanetworkopen.2022.51983
3. Saag, M. S. 2022. Wonder of wonders, miracle of miracles: the unprecedented speed of COVID-19 science. *Physiol. Rev.* 102:1569–77 doi: 10.1152/physrev.00010.2022
4. Mesle, M. M., Brown, J., Mook, P., Hagan, J., Pastore, R., Bundle, N., et al. 2021. Estimated number of deaths directly averted in people 60 years and older as a result of COVID-19 vaccination in the WHO European Region, December 2020 to November 2021. *Euro Surveill.* 26:2101021. doi: 10.2807/1560-7917.ES.2021.26.47.2101021
5. Vilches, T. N., Sah, P., Moghadas, S. M., Shoukat, A., Fitzpatrick, M. C., Hotez, P. J., et al. 2022. COVID-19 hospitalizations and deaths averted under an accelerated vaccination program in northeastern and southern regions of the USA. *Lancet Reg. Health Am.* 6:100147. doi: 10.1016/j.lana.2021.100147

SUBMITTED: 15 September 2023; **ACCEPTED:** 12 January 2024;
PUBLISHED ONLINE: 06 February 2024.

EDITOR: Claudia Marcelloni, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Yunchao Tang and Anjan Debnath

CITATION: Debad SJ and Apweiler R (2024) Unlocking the Wonders in the Grand Library of Open Science. Front. Young Minds 12:1244349. doi: 10.3389/frym.2024.1244349

CONFLICT OF INTEREST: SD works for SJD Consulting LLC.
The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

MANANYA, AGE: 8
Hello, I am Mananya and I am in third grade. I love doing piano and art. I enjoy swimming, acting and reading comics. I have not thought about my career yet, but I do like science and engineering.

ZI-AN , AGE: 8
Hi, I am Zi-An, 8 years old, coming from a family of teachers, I have inherited a love for knowledge and learning. But my biggest joy? That is definitely my little brother. I absolutely love goofing around and making him laugh! I am fascinated about science. I want to research the secrets of everlasting life, so that people I love will never grow old or die.

AUTHORS

SUSAN J. DEBAD
Susan has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard". She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has more than four dogs! In her spare time, she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

ROLF APWEILER
I was born in Germany and studied biology in both Heidelberg, Germany, and Bath, UK. Since 1987, during my studies, I worked as a student helper at EMBL in Heidelberg, reading articles about functions of proteins and adding this information into a database. That was my start in bioinformatics and, in 1994, I moved with my wife and our two children to Cambridge to set up (with a few colleagues from EMBL Heidelberg) a new institute of EMBL, called the European Bioinformatics Institute

(EBI). Now, for 8 years, I have been one of the two directors of this institute, which has grown to nearly 900 staff members and handles more than 100 million daily web requests to our databases from millions of researchers worldwide.

frontiers | Frontiers for Young Minds

HUMAN HEALTH
Published: 08 December 2023
doi: 10.3389/frym.2023.1229078

MEDICINE GETS PROACTIVE: PREVENTION IS BETTER THAN CURE

Susan J. Debad [1*], ***Michael Snyder*** [2*] ***and Ariel Ganz*** [2*]

[1] *SJD Consulting LLC, Ijamsville, MD, United States*

[2] *Department of Genetics, Stanford University School of Medicine, Stanford, CA, United States*

YOUNG REVIEWERS:

ARADHYA

AGE: 12

RIZVIAN

AGES: 9–13

If you have ever looked at a car's dashboard, you probably know that it can provide lots of important information about the car's health—information that can help the owner keep the car running well. But did you know that our bodies need the same kind of attention? For a long time, doctors have typically diagnosed and treated patients *after* they get sick. But what if doctors could catch illnesses early, before they even cause symptoms? New technologies, including wearable devices like smartwatches and health-tracking apps, can help with this. Devices that monitor our bodies constantly will know what is "normal" for each person, so they can warn us of small changes happening in our bodies that might mean we are starting to get sick—before we even have symptoms! This approach is called precision medicine, and could have many benefits for healthcare, from controlling future pandemics to possibly even helping humans live longer!

HOW IS YOUR CAR RUNNING?

Beyond the speedometer and the gas gauge, have you ever taken a good look at the dashboard of your family's car? Dashboard gauges provide lots of important information, ranging from how much air is in the tires, to the oil pressure in the engine, to the engine temperature, to the charge in the battery (in the case of an electric car) (Figure 1A). The dashboards of some newer cars can even tell us when it is time to take the car in for regular maintenance, or when the brake pads need to be replaced. The purpose of all this information is to help us to be **proactive** about keeping our cars healthy. If we notice that one of the measurements is "off," we can take the car in for service *before* it breaks down and leaves us stranded.

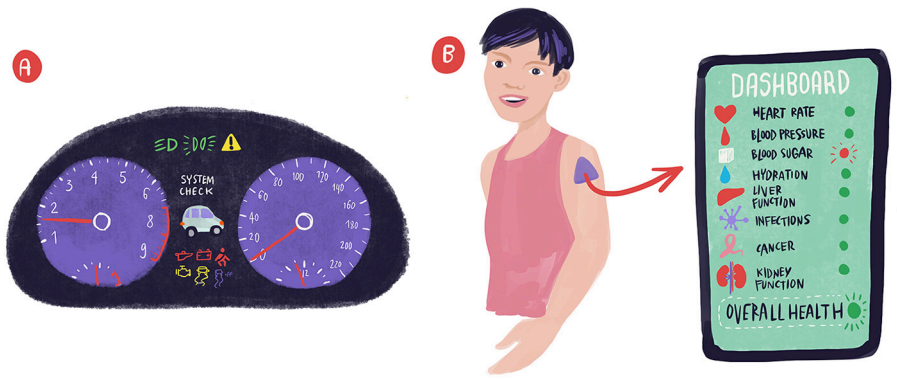


Figure 1

PROACTIVE

A healthcare approach focused on preventing health problems before they occur, rather than just treating them after they happen.

Figure 1

(A) A car's dashboard provides the driver with lots of information about the car's health, so that the driver can proactively address any problems with the car before it breaks down and leaves them stranded. **(B)** In the future, wearable medical devices could monitor many aspects of our health and provide a "human dashboard" that could warn us of health problems before they cause symptoms. That way, we could see the doctor for treatment before we even feel sick (Figure created by carlottacat.com).

REACTIVE

The traditional approach to healthcare that focuses on treating illnesses and other health problems after they occur.

This is quite different from the **reactive** way that many people deal with their own health. While some people go to the doctor for a checkup once a year or so, others only go when they are already sick—when something in their bodies has broken down. At that point, the doctor generally diagnoses the problem (with some laboratory tests) and prescribes some sort of treatment, like a medicine, operation, or therapy, to get the body operating properly again. Healthcare has worked this way for a long time, and it might seem normal—but it is like waiting until the car breaks down on the side of the road! Even if people get regular checkups, a year in between visits is a long time. Imagine a car dashboard that only provides the owner with vehicle data once a year. In between, the car could easily run out of gas, or it could be leaking oil, and no one would know. During the time between visits to the doctor, a whole range of diseases could begin to develop, and some of them could be serious. Think about heart attacks, strokes, or cancer, for example.

What if we had a kind of "dashboard" for the human body that could help us to catch illnesses *early*, even before they cause any symptoms (Figure 1B)? If you have a cell phone or a smart watch with health-tracking apps, you already have the beginnings of a human dashboard on your device. These apps can help us become proactive

about certain aspects of our fitness, like how much exercise we get and how many calories we eat vs. burn each day. Also, **wearable medical devices** that stick to the skin can collect data about things going on inside the body, using either tiny needles or electrodes. For example, wearable glucose monitors can measure blood sugar levels in people with diabetes (for more about wearables and the flood of data they collect, see this Frontiers for Young Minds article). Wearables eliminate the need for a blood sample, and they can also collect data as frequently as every few minutes, to notify people of small changes happening in their bodies before they get sick! A "dashboard" made from health app and wearable device data would help doctors and patients switch from a *reactive* way of managing health to one that is more *proactive*.

WEARABLE MEDICAL DEVICES

Electronic devices worn on the body to monitor health and medical information, such as heart rate, steps taken, and blood glucose levels.

GETTING PERSONAL

Imagine you go to the doctor because you are feeling sick and feverish. The doctor takes your temperature and reports that it is 98.6°F/37°C, so you do not have a fever. But you *feel* feverish—what is going on? Although it is widely accepted that 98.6°F/37°C is the normal temperature of a healthy human, this is not entirely true. There is a range of normal body temperatures [1], and *your* normal healthy temperature might be a degree or two different from that of your friend or a family member. If your normal healthy temperature is 97°F, then a temperature of 98.6°F *is* a fever for you! This means that the doctor could give you an incorrect **diagnosis**.

DIAGNOSIS

The process of identifying a disease or condition based on its signs, symptoms, and test results.

This is true for more than just body temperature—people differ in what is "normal" for many health parameters, which means that doctors run the risk of messing up the diagnosis if they only compare a patient's values to a population "average." Those doctors might be missing important changes in that specific patient's values over the past few months or days—changes that could indicate that the patient is in the very early stages of an illness.

BASELINE

The state of a person's normal bodily measurements (temperature, blood pressure, heart rate, etc.) when they are not sick.

This is another advantage of a health dashboard fueled by data from wearables—it could establish a healthy **baseline** for *each person*, which would allow doctors to see when something is "off" for that specific person and prescribe the right treatments proactively, maybe even before the person feels sick. This personalized approach is called **precision medicine**. There are a number of ways that precision medicine can help keep humans healthy, and we will focus on two of them. First, we will tell you about how precision medicine could help to control future pandemics, and then we will explain how a human health dashboard might help to slow down (or possibly reverse!) the aging process.

PRECISION MEDICINE

A medical approach that considers individual variations in vital signs, genes, environment, and lifestyle to prevent, diagnose, and treat diseases.

PROACTIVE DETECTION OF INFECTIONS CAN SAVE LIVES

How do you know when you are getting sick with a virus like a cold or the flu? You might start to feel feverish, or maybe your throat is sore, or your nose is stuffed up. But did you know that the virus might already be reproducing in your body several days before your symptoms show up? This means that you could spread the virus to your friends at school, your sports teammates, and maybe even your aging relatives, if you visit them—all before you even know you are sick! What if you had an early-warning system that could tell you when you were about to get sick? Maybe you would choose to stay home and get some rest or visit a doctor for some medicine—actions that would also help to keep your friends and relatives healthy.

A human dashboard that continuously watches your health parameters and knows your healthy baseline could notice very slight changes that might mean the start of an infection or other illness. A study of over 3,000 people using wearable devices like Fitbits, Apple Watches, and Oura Rings showed that slight changes in heart rate and number of steps taken predicted 80% of COVID-19 cases about 3 days before people had any symptoms [2, 3]! This is important because early detection of life-threatening viruses, especially during a pandemic, can save lives and decrease the number of people who get infected—helping health officials to get the pandemic under control.

STAYING YOUNG WITH PRECISION MEDICINE

When cars age and eventually break down, they do not all die for the same reason. Some die because their electronics fail, in others an important part of the engine might stop functioning, or in still others the frame might rust away even while their engines are still running fine. A recent study collecting personalized medical data on 43 people for 2 years has demonstrated that something similar happens in humans [4]. Like cars, people can be divided into groups depending on which of their bodily systems are aging the fastest and are likely to break down first. For example, some people's immune systems may fail first, making them more vulnerable to dangerous infections, even though their other body systems are working normally. In others, the kidneys fail first, or the liver, or the heart.

MEDICAL INTERVENTION

Any treatment or action taken to address a health issue or disease, such as medication, surgery, or therapy.

If a health dashboard could help people understand their personal aging profiles, they might be able to take simple steps *before* they get old, like changes in diet or exercise, to better support the "weakest link" in their bodily systems. For example, liver agers might pay particular attention to what they eat and drink, avoiding fatty foods and alcohol to keep their livers as healthy as possible. Early **medical interventions** might be able to slow, or even reverse, the body's aging

process—all while the person is still young and healthy. Understanding and proactively addressing the specific problems you are most likely to face as you age is like keeping an extra close eye on your car's engine temperature and coolant levels if you know that it is prone to overheating.

HEALTHIER INDIVIDUALS, HEALTHIER SOCIETIES

The switch from traditional, reactive healthcare to a more proactive version is one of the most exciting changes that precision medicine will bring about (Figure 2). Instead of waiting for people to get sick and then treating them, more and more doctors will be able to use wearable medical devices and other new technologies to predict which of their healthy patients are likely to develop certain diseases. In addition to the uses discussed in this article, a personalized, proactive approach could also help to identify people who are at high risk for conditions like cancer, heart disease, or stroke. Doctors could then take steps to prevent or treat at-risk people long before their diseases become a problem. These diseases can be very expensive to treat, so being proactive can save money and help to keep healthcare costs down. In the long run, by being proactive and providing the right treatments to the right people at the right time, the "human dashboard" powered by precision medicine could improve and prolong many human lives.

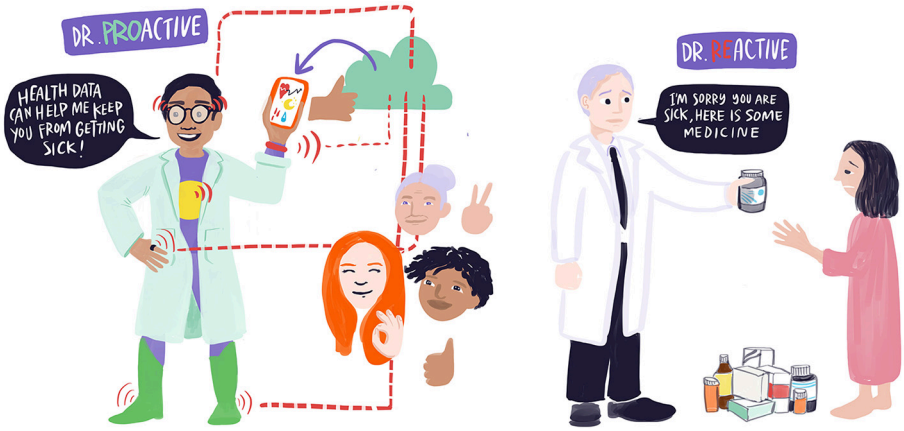


Figure 2

Figure 2

In a proactive approach to healthcare, doctors could monitor data from advanced wearable medical devices to understand the healthy baseline for each of their patients. Then they would be able to spot small changes in a patient's health data that might mean a patient is about to get sick—and treat them before the patient even feels symptoms. This proactive approach aims to keep people healthy, in contrast to the traditional, reactive approach to healthcare in which patients wait until they are already sick to go to the doctor and get treatment (Figure created by carlottacat.com).

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talks by Ariel Ganz and Mark Kendall.

REFERENCES

1. Sund-Levander, M., Forsberg, C., and Wahren, L. K. 2002. Normal oral, rectal, tympanic and axillary body temperature in adult men and women: a systematic literature review. *Scandin. J. Car. Sci.* 16:122–128. doi: 10.1046/j.1471-6712.2002.00069.x
2. Mishra, T., Wang, M., Metwally, A. A., Bogu, G. K., Brooks, A. W., Bahmani, A., et al. 2020. Pre-symptomatic detection of COVID-19 from smartwatch data. *Nat. Biomed. Eng.* 4:1208–1220. doi: 10.1038/s41551-020-00640-6
3. Alavi, A., Bogu, G.K., Wang, M., Rangan, E. S., Brooks, A. W., Wang Q., et al. 2022. Real-time alerting system for COVID-19 and other stress events using wearable data. *Nat. Med.* 28:175–184. doi: 10.1038/s41591-021-01593-2
4. Ahadi, S., Zhou, W., Schüssler-Fiorenza Rose, S. M., Sailani, M. R., Contrepois, K., Avina, M., et al. 2020. Personal aging markers and ageotypes revealed by deep longitudinal profiling. *Nat. Med.* 26:83–90. doi: 10.1038/s41591-019-0719-5

SUBMITTED: 25 May 2023; **ACCEPTED:** 21 November 2023;
PUBLISHED ONLINE: 08 December 2023.

EDITOR: James Gillies, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Tayyaba Zainab and Rashmi Panigrahi

CITATION: Debad SJ, Snyder M and Ganz A (2023) Medicine Gets Proactive: Prevention Is Better Than Cure. Front. Young Minds 11:1229078. doi: 10.3389/frym.2023.1229078

CONFLICT OF INTEREST: SD was employed by SJD Consulting LLC. AG is a co-founder of Arben Ventures and Xthena Partners. MS is a cofounder and scientific advisor of Personalis, SensOmics, Qbio, January AI, Fodsel, Filtricine, Protos, RTHM, Iollo, Marble Therapeutics, Crosshair Therapeutics, NextThought and Mirvie. He is a scientific advisor of Jupiter, Neuvivo, Swaza, Mitrix, Yuvan, TranscribeGlass, and Applied Cognition.

YOUNG REVIEWERS

ARADHYA, AGE: 12

I like playing, reading, and dancing. I like to travel to new places and know about their history. I love to paint natural life forms. I like to play volleyball and badminton. I like to perform classical dance as it represents my culture.

RIZVIAN, AGES: 9–13

We are young science enthusiasts. We love learning about how the world works, and we are always up for a new experiment. In our free time, you can find us reading science books, watching documentaries, or building things with our Dad. Our dream is to one day become a scientist and make new discoveries that help people.

AUTHORS

SUSAN J. DEBAD

Susan has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard." She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has more than four dogs! In her spare time she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

MICHAEL SNYDER

Dr. Snyder is a professor and Chair of Genetics at Stanford University. He is a pioneer in personalized and precision medicine and was the first to use watches like the Fitbit and Apple watch to monitor health and detect disease. Mike tracked his own health and found a risk factor for diabetes. After he then got diabetes, he tracked his health while he took medications and did lifestyle interventions to reverse his diabetes. He also detected his own Lyme disease with a smartwatch. In his free time, he enjoys working out and spending time with his family and two dogs. *mpsnyder@stanford.edu

ARIEL GANZ

Dr. Ganz is a postdoctoral scientist in Dr. Michael Snyder's lab at Stanford University researching Mental Health and Precision Medicine, especially focusing on wellness practices that improve wellbeing. She also started a venture fund, Arben Ventures, to invest in the next generation of innovators. In her free time, Ariel enjoys yoga, horseback riding, tennis, and playing with her cat and dog. *abganz@stanford.edu

ENGINEERING AND TECHNOLOGY
Published: 08 December 2023
doi: 10.3389/frym.2023.1303154

NEW SCIENTIFIC TECHNOLOGIES: NAVIGATING THE PATH OF RIGHT AND WRONG

Susan J. Debad [1*] ***and Juan Enriquez*** [2*]

[1] *SJD Consulting LLC, Ijamsville, MD, United States*

[2] *Excel Venture Management, Boston, MA, United States*

YOUNG REVIEWERS:

ALESSANDRO
AGE: 12

ÇAĞAN
AGE: 11

ÇAĞLA
AGE: 9

To guide our decisions and actions in our daily lives, we often rely on our internal sense of right and wrong, called ethics. Our ethics help us to be kind, truthful, and fair. Scientists also have ethical "rules" to follow to ensure that their research—and the powerful technologies that spring from it—are used to help people, not harm them. Ethical guidelines for scientists include respecting human rights, limiting harm to animals, keeping the public safe, and being honest and truthful about their work. In this article, we will explain what scientific ethics are and why strong ethics are particularly important as powerful new technologies develop more quickly. We will give examples of what can happen if scientists do not follow ethical rules and explain how these situations are not always simple. Finally, we will describe how new technologies may change which behaviors societies consider ethical. Join us in an exploration of the "conscience" of science!

WHAT IS ETHICS?

How do you know right from wrong? Is it simply because of the rules you must follow at home or at school and the laws of the town or country you live in, or is there more to it? Is it because of what you learn in church, or from watching how people you respect act and treat others? Maybe you make your choices based on your conscience—the little inner voice that guides you and helps you to feel good when you do the right things and guilty when you go against your values. Generally, all these factors and more combine to form a person's sense of right and wrong.

ETHICS

The guidelines in a person's mind and heart that help them make good choices and avoid harming others. Ethics help people do the right thing.

Ethics are like an invisible guidebook in our minds and hearts that helps us decide what is the right and kind thing to do. Ethics help us think about our actions and how they might make others feel. In some situations, the choice between right and wrong can seem obvious, such as in clear cases of harm like stealing or hitting for no reason. For example, you know how it is sometimes hard to tell the truth, especially if you think you might get in trouble? But deep down, if a little voice tells you it is better to be honest, that voice is your ethics talking! Also, if you see someone feeling left out and you invite them to play, your ethical voice is urging you to be caring and considerate. But there are also times when the line between right and wrong is difficult to draw. In these less certain situations, ethical "rules" can help guide our choices.

TECHNOLOGIES

Tools, equipment, and methods that scientists develop to solve problems and improve lives. Many technologies can help or harm people, so they must be used carefully and ethically.

Ethics are important in all aspects of our lives, including work. And ethics are especially critical in jobs that involve new **technologies** that can directly impact people, society, or the environment—like science.

POWERFUL TECHNOLOGIES NEED POWERFUL ETHICS

Science has incredible power to make discoveries and inventions that can improve human health, solve environmental problems, and generally make our lives easier and more enjoyable. But just as a hammer can be used to do the "right" thing (drive in a nail) or the "wrong" thing (break a neighbor's window), many scientific tools developed with only the best purposes in mind could be misused for evil purposes if they get into the wrong hands. This is especially worrying because as science advances, technologies are becoming easier to access, more powerful, and potentially dangerous. Scientists must have a strong code of ethics in place, guiding their work and ensuring that new technologies are used to help, not harm people.

SYNTHETIC VIRUSES

Lab-made viruses designed to help treat diseases by targeting and destroying bad cells without harming the good ones.

Synthetic viruses are an example of a developing technology that could be used to help or to harm. You can think of a virus as a USB stick that needs a computer—a cell—to run its programs, except that viruses can only "plug into" specific types of cells. If viruses can be

designed to specifically plug into cancer cells and load a "program" (a **gene**) that says, "cancer cell, you must die," then these viruses could be injected directly into the tumor, or maybe even into the bloodstream, to help cure the patient. This would be a great tool for doctors and could help many people. But just as a USB stick could deliver either a useful program or damaging malware to a computer, in the wrong hands dangerous synthetic viruses could be created that spread easily between humans (through the air or through human contact, for example). These viruses could cause diseases or contain genes that would harm or even kill people.

GENE

Instructions inside cells that determine how an organism looks and all of its functions.

Scientific ethics are the set of moral principles and values that serve as the conscience of science, guiding the work of scientists and helping to make sure powerful scientific and medical technologies are not used for the wrong purposes (Figure 1). These ethical principles are often made into laws and regulations that help keep the use of new technologies safe, accurate, and fair, and ensure that scientific discoveries are used in responsible ways that protect the rights and wellbeing of humans, animals, and the environment.

SCIENTIFIC ETHICS

The guidelines and values that help scientists make sure their work is honest, safe, and used to help, not harm, people, animals, and the planet.

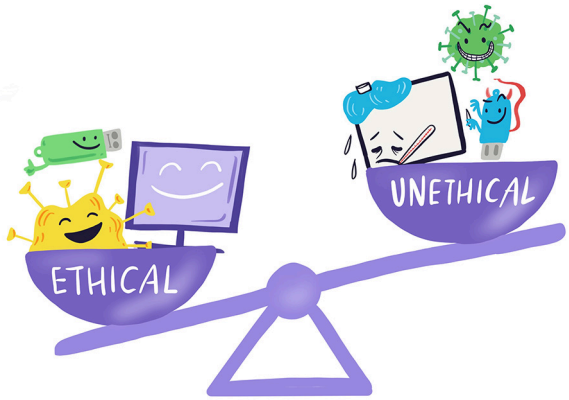


Figure 1

Figure 1

Scientific ethics act as the "conscience" of science, to make sure that scientific discoveries are used to help people, not harm them. For example, just as a USB stick could carry a helpful program or dangerous malware, synthetic viruses could contain beneficial genes to fight cancer, for example, or, in the wrong hands, they could be used to harm or even kill humans. Strong scientific ethics can help tip the scale toward responsible, ethical use of powerful new technologies (Figure created by carlottacat.com).

GUIDING PRINCIPLES FOR SCIENTISTS

While the exact ethical guidelines that scientists should follow can differ based on many factors, including the type of science (medical science vs. plant science, for example), the university or institute where the research is happening, or the local culture, there are some commonly accepted guidelines that all scientists should follow (Figure 2). Here are a few:

- **Respect human rights**: Scientists should protect the wellbeing, dignity, and independence of anyone involved in their research studies. They must clearly explain a study's risks and benefits and make sure that all participants agree to be in the study. This is

INFORMED CONSENT

When people freely choose to take part in a scientific study and fully understand its purpose, risks, and benefits. Scientists have the ethical responsibility to explain everything clearly.

called **informed consent**, and it ensures that people are joining a study by their own choice and not being pressured to take part.

- **Use animals ethically**. If animals must be used in research, they should be treated humanely, by minimizing their pain and suffering.
- **Report dangers promptly**. If researchers discover any health risks or safety concerns of a new treatment or technology, they should report them immediately. Safety should be a primary concern, especially if studies involve vulnerable groups like children, prisoners, pregnant women, or other at-risk populations.
- **Consider the broad impacts**. Scientists should think about how their work might affect society and the environment, not just immediately but in the longer term. Scientists have a responsibility to minimize any negative outcomes their research might have.
- **Be honest**. Scientists should be truthful and open about all aspects of their work. This includes making sure their results are accurate and never falsifying (making up) data. They should clearly give others credit for their work, and never **plagiarize** the work of other scientists**.** Finally, they should be open about any factors that might bias their research, such as personal relationships or sources of funding.

PLAGIARIZE

To copy someone else's work and pretend it is your own. Plagiarism is wrong because it is stealing another person's ideas.

Figure 2

Ethical principles that guide the work of scientists include treating animals kindly, respecting human rights, being honest, considering the broader impacts of the work, and reporting any dangers promptly (Figure created by carlottacat.com).

BREAKING THE RULES

You might be wondering whether there are any real-life examples of situations in which scientists have ignored the principles of scientific ethics, leading to negative consequences. Examples of unethical

scientific conduct certainly *do* exist because scientists are humans who can sometimes make bad choices, just like the rest of us.

One famous example is the Tuskegee Syphilis Study, which took place from 1932 to 1972. In this experiment, hundreds of African American men who had a sexually transmitted disease called syphilis were deliberately left untreated by researchers. The researchers wanted to study the way syphilis affected the body. A look back at our list clearly shows that this study was unethical on many levels. The men were generally poor and could not read and did not provide informed consent. They were also lied to about their condition—they were not told that they had syphilis or that it was sexually transmitted—and they were given fake treatments, even after penicillin became available and could have cured them. Many of the men died or suffered from serious complications, like blindness, because of the experiment.

A more recent example of unethical scientific conduct occurred in 2018, when a scientist announced that he had edited the genes of twin girls before they were born, using a powerful new technology called CRISPR-Cas9 [1]. The scientist claimed he wanted to make the babies resistant to HIV infection by disabling the gene that allows HIV to enter cells. While this might sound like a good idea, many other researchers and the public were shocked and worried about the twins' futures. The scientist faked some important approval paperwork and did this experiment without the support or agreement of local authorities or the scientific community. Many researchers felt that he did not consider the potential long-term effects his experiment could have on the girls and their future children. Finally, some felt this experiment was unnecessary because there are other, less risky ways to prevent HIV infection without altering human DNA.

RIGHT OR WRONG? IT IS COMPLICATED!

It is important to remember that, in some cases, scientific ethics are different from the rules of a game or a school's dress code. What is considered right or wrong can differ across cultures, and can also change over time, as a society's knowledge and values develop. As an extreme example, when the Tuskegee Syphilis Study started, there were no official guidelines governing ethical research on humans. This in no way makes those actions right, but there were no formal rules to protect people from such unethical experimentation.

Technology is a particularly powerful factor that can change a society's notion of right and wrong. New technologies can give us options that we did not have before, making our old choices look wrong or unethical. For example, gasoline-powered cars have been the norm for over a century, despite their damaging effects on the environment—we simply did not have any other good options for transportation. But as electric vehicles continue to improve, more

people may begin to feel that it is unethical to drive polluting, gas-powered vehicles. The same may be true for eating meat. As synthetic meats become less expensive and tastier, there may come a day when even meat eaters feel it is ethically unacceptable to eat animals. As norms evolve, many future generations will judge the past through their standards, criticizing and judging people for past behaviors that, looking back, were clearly wrong. Today, the number and power of technologies that are available to us is increasing more rapidly than ever, which means that our ethics may begin to change exponentially, too. Maybe there will even be a future in which it will seem unethical *not* to alter the genes of our unborn children, to protect them against cancer or other diseases that people commonly suffer from today!

WRAPPING UP: THE POWER OF CHOICES

Science can be a powerful force, with the potential to bring incredible advances that benefit humanity. Scientific ethics is the guiding light that helps scientists navigate the complexities of their work, making sure new technologies serve society without causing harm or violating human rights. While laws and regulations can provide scientists with ethical guidance, technology is advancing so rapidly that official laws and codes of conduct often lag way behind. This means it is critical for individual scientists to have strong ethics and to take personal responsibility for their behavior. Adding ethics training as a regular part of a scientific education could help scientists understand the guidelines they are expected to follow in their work.

The future of science depends on maintaining the public's trust (to learn more about trust in science, see this Frontiers for Young Minds article). If people see that scientists have strong ethics and conduct their research in a responsible, honest, and respectful way, it will be easier for the public to trust and support science and to follow scientific advice that could keep them healthy.

As science and society continue to evolve, new technologies will continue to change our options, and our ideas about what is acceptable and what is not will change, too. Science gives us amazing tools, but it is up to us how we use them. With ethical minds guiding research, the wonders of science can bloom while protecting human lives and the health of the planet.

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talks by Juan Enriquez and Andrew Hessel, and Enriquez's book [2].

REFERENCES

1. Adli, M. 2018. The CRISPR tool kit for genome editing and beyond. *Nat. Commun*. 9:1911. doi: 10.1038/s41467-018-04252-2
2. Enriquez, J. 2021. *Right/Wrong - How Technology Transforms Our Ethics*. ISBN 9780262542814.

SUBMITTED: 27 September 2023; **ACCEPTED:** 21 November 2023;
PUBLISHED ONLINE: 08 December 2023.

EDITOR: Claudia Marcelloni, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Sezgin Ersoy and Marco Montemurro

CITATION: Debad SJ and Enriquez J (2023) New Scientific Technologies: Navigating the Path of Right and Wrong. Front. Young Minds 11:1303154. doi: 10.3389/frym.2023.1303154

CONFLICT OF INTEREST: SD was employed by SJD Consulting LLC. JE was employed by Excel Venture Management.

YOUNG REVIEWERS

ALESSANDRO, AGE: 12

I am Alessandro, a 12-year-old student from Italy. I started to get interested in science when I was a kid. I wanted to become a scientific researcher, so my parents bought me the "kit of the little scientist." With that, I made my first experiment. I was proud of myself. My passion has still continued and I started studying to follow my dream.

ÇAĞAN, AGE: 11

My name is Çağan. I am in fifth grade. Some of the things I enjoy doing are reading, playing football and basketball, science, ancient languages, and computer science. I love reading adventure novels, especially the Harry Potter book series. I played the piano for 4 years, now I am interested in other instruments. I love nature, plants, and animals.

ÇAĞLA, AGE: 9

My name is Çağla, I am in the 3rd grade. Things I like to do are gymnastics, reading, painting, and listening to music. I enjoy science fiction and fantasy books. I did ballet for 3 years. I am playing piano. I really enjoy playing games. I love nature, animals, and plants.

AUTHORS

SUSAN J. DEBAD

Susan has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard." She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has *more* than four dogs! In her spare time she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

JUAN ENRIQUEZ

Juan is interested in how life sciences and brain research can change businesses and society. He earned a B.A. and an M.B.A. from Harvard University. Juan was the founding director of the Harvard Business School's Life Sciences Project and is a research affiliate at MIT's synthetic neurobiology lab. He now works for Excel Venture Management, which helps to build companies that use life-sciences technologies to solve big problems in healthcare and beyond. Juan has given 9 TED talks on a variety of topics, and he is the author of several books, including *Right/Wrong: How Technology Transforms Our Ethics*. *jenriquez@excelvm.com

frontiers | Frontiers for Young Minds

ENGINEERING AND TECHNOLOGY
Published: 08 December 2023
doi: 10.3389/frym.2023.1297688

DOCTORS AND ARTIFICIAL INTELLIGENCE: WORKING TOGETHER FOR A HEALTHIER FUTURE

Susan J. Debad [1*] ***and Jane Metcalfe*** [2*]

[1] *SJD Consulting LLC, Ijamsville, MD, United States*

[2] *proto.life, Berkeley, CA, United States*

YOUNG REVIEWERS:

ESHAAN
AGE: 11

HARKIRAT
AGE: 9

VIHAAN
AGE: 8

Artificial intelligence (AI) is changing healthcare in some amazing ways. AI is like a smart computer brain that can learn and think almost like we do. It helps scientists study diseases and make new medicines. AI can schedule doctor appointments appointments easily and shorten the amount of time patients must wait at the clinic. AI chatbots can translate languages so doctors and patients can easily understand each other, and can answer patients' health questions from home. In the future, it might become common to "see" virtual doctors online instead of going to the clinic. Doctors and AI make a great team to keep people healthy. AI can scan test results, spot problems early, and help doctors understand tons of health data quickly. While AI is super helpful, it is important to remember that it is still a tool. Just like we trust our doctors, we can learn to trust AI as we see it in action, making lives better and healthier.

Imagine this scenario: it is a rainy weekend, and you are hanging around the house, bored. Maybe there is a good movie playing at

a local theater? Your phone is across the room, but you simply say, "Hey, Siri! What movies are playing nearby today?" A new film with your favorite actor is showing later that afternoon, and since you have a couple of hours to kill before the movie, you decide to check out YouTube to see if any new videos are recommended for you based on your watch history. As showtime approaches, you use a navigation app to see how long it will take you to get to the theater.

ARTIFICIAL INTELLIGENCE

A technology that allows machines like computers to learn, think, and solve problems almost like humans do.

Did you know that **artificial intelligence** (AI) powers all these seemingly ordinary activities? AI is a special kind of technology that allows machines, like computers and robots, to learn and think almost like humans do. Just as we learn from our experiences and get better at the things we practice, AI can do the same. AI is becoming so much a part of our lives that many of us cannot imagine getting through the day without it!

While AI-powered technologies can make our lives easier and more fun, AI has many other very important uses. For one, it is an increasingly valuable tool for scientists and doctors who are trying to improve human health. In the rest of this article, we will take you on a journey through each stage of healthcare, from the science lab all the way through medical treatment, highlighting the ways AI currently helps doctors and describing some of the exciting developments we might see in the future (Figure 1).

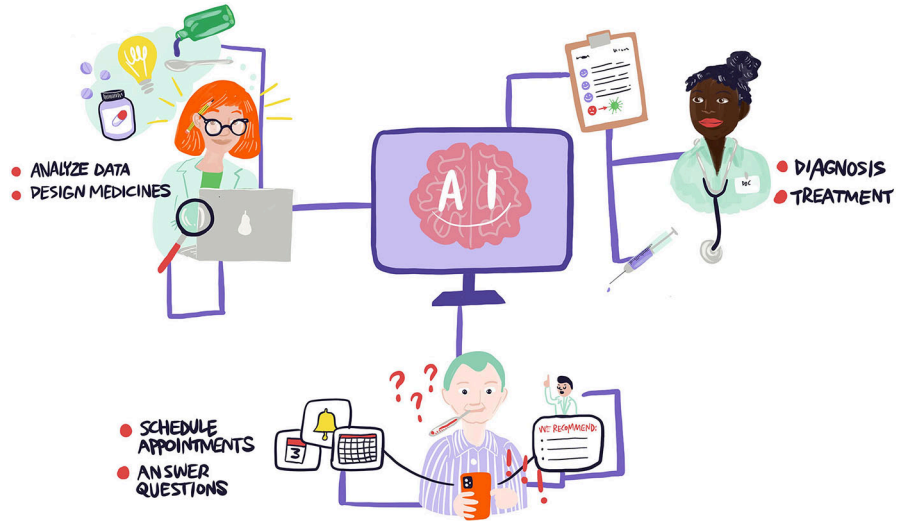


Figure 1

AI-powered healthcare technologies are becoming increasingly useful for scientists, doctors, and patients. AI helps scientists by analyzing enormous amounts of data and finding patterns that humans could not see on their own. It can also help them to design new medicines. AI can help doctors to examine patient data to figure out what is wrong, and it can also assist in finding the best treatment for each patient. For patients, AI can help them schedule medical appointments and decrease wait times in the office. Telemedicine and virtual doctors can help patients get health information from home (figure created by carlottacat.com).

BEHIND THE SCENES: SCIENTISTS' BRILLIANT FRIEND

Much of the knowledge needed to develop medicines, treatments, and medical equipment originally comes from the hard work of scientists in research labs. Modern research projects, doctor visits, and wearable devices like smartwatches can generate tons of data—so much that

it would take scientists a lifetime (or more!) to analyze it on their own. Scientists who study organisms' genes, for instance, often use efficient, cutting-edge equipment that can generate *terabytes* of data in a relatively short time (a terabyte is equivalent to about 500 h-worth of movies, or around 200,000 songs—so that is *a lot* of experimental data!). AI is a fantastic assistant for scientists—like a genius lab partner who can quickly process and analyze reams of data, and who can spot patterns and clues that humans would probably miss.

A company called DeepMind has trained an AI system (AlphaFold) to quickly and accurately predict the shapes of proteins, long considered one of the most difficult problems in computing. AlphaFold's work is important because the shapes of proteins determine their functions, so knowing their shapes can help scientists to find the perfect proteins to be made into medicines to treat specific diseases, for example. Before AlphaFold technology came along, it took scientists multiple years to figure out the shape of even one protein, while AlphaFold has released over 200 million structures in just a few years (for more information on AlphaFold, see this video and this Frontiers for Young Minds article).

Have you tried out ChatGPT—maybe just to "chat" or ask it to write a silly poem, or maybe for homework help? ChatGPT uses a type of AI called **generative AI**. If you think of "regular" AI as a genius robot that knows a lot and can do specific tasks very well, generative AI is more like an artist that can create new things by itself—even things humans have never thought of before. When used in medical research, generative AI may be able to do cool things like *create* new medicines entirely from scratch. AI helps scientists design new drugs by quickly sorting through large amounts of data—like the structure of molecules, how they interact with different proteins in the body, results from past experiments, and information from scientific papers—to predict good medicine "recipes."

GENERATIVE AI

A type of AI that can create new things on its own, like art, music, or text, instead of just analyzing data.

Overall, with AI's "super brain," scientists can work faster and smarter, unlocking secrets of the human body and how to keep it healthy—the behind-the-scenes work that helps doctors give their patients the best possible care.

SCHEDULING AN APPOINTMENT...

Have you ever gone to a doctor's office or the hospital emergency department and spent *a lot* of time in the waiting room before seeing the doctor? Wait times can be a big problem, especially in places where there are not enough doctors or health clinics. Long wait times can discourage people from getting the medical care they need—whether they are sick and require treatment or just due for regular checkups or vaccines. Either way, people's health can suffer.

AI systems can help to make health facilities more efficient by analyzing data such as the length of visits, the number of doctors and nurses available, the number of exam rooms, availability of equipment, and more. This can shorten wait times [1], ensure that the people who are the sickest see doctors first, and even save the facilities money. One children's hospital in Toronto, Canada, is testing out an AI tool that can automatically order common medical tests (blood/urine tests, chest x-rays, etc.) based on patients' symptoms—right after they arrive at the hospital and before they even see a doctor. The test results are often ready when they *do* get in to see the doctor, which could shorten the overall time spent in the emergency department by 2–3 h. In the future, maybe none of us will have to wait!

SEEING THE "DOCTOR"

When you think of seeing a doctor, you probably picture yourself on an exam table, being checked by a human in a white coat, right? Thanks to AI, this is not the only way to "see" a doctor. Since the height of the COVID-19 pandemic, there has been a dramatic increase in **telemedicine**, which means "seeing" a healthcare provider using technology such as video calls, phone calls, or websites. In the U.S., there are roughly twice as many doctors practicing telemedicine now as there were before the pandemic [2]. While telemedicine often involves talking to a real person—a doctor or nurse—AI still helps with this type of medical care. For instance, if the doctor and patient do not speak the same language, an AI-based language translator can help them to understand each other—which can "translate" into better healthcare.

TELEMEDICINE

A way of providing healthcare remotely using technology like video calls, phone calls, or online platforms instead of in-person visits.

AI-powered **chatbots** are another increasingly common way to get health information. These chatbots are like friendly talking robots that can answer common health-related questions, as well as ask patients about their symptoms and help them to schedule appointments if they need to see a doctor. Even Google is developing a healthcare chatbot—Med-PaLM 2 is in the early stages of testing at several hospitals.

CHATBOT

An AI-powered program that can communicate with users through text or voice conversations, like a robot you can chat with.

In the future, advances in AI technology could lead to more sophisticated chatbots that might serve as virtual doctors—not just providing basic information, but actually diagnosing diseases and suggesting the most effective medicines and therapies, just like human doctors do. Chatbots and virtual doctors could be particularly valuable in remote areas where people do not have easy access to health clinics, or in areas where there are not enough doctors to see everyone. These technologies could make healthcare more accessible and convenient for all of us.

DIAGNOSIS AND TREATMENT

If you go to the doctor because you do not feel well, many times the doctor will provide a diagnosis describing what is wrong and then give you a treatment to help you feel better. Since AI is so great at analyzing vast amounts of information, it is perfectly suited for helping doctors figure out what is wrong with their patients. An AI-powered system can quickly compare a patient's health information (symptoms, test results, even scans like X-rays and other imaging) with a huge database of health information from other patients, to quickly find patterns that could point to what is making a patient unwell. In a real-life case, by analyzing images from eye-scans, AI helped doctors detect eye disease in patients with diabetes. The AI system spotted early signs that even experienced doctors might miss. Early detection allows early treatment, which saves people's eyesight [3].

PERSONALIZED MEDICINE

Medical care customized for each patient's unique characteristics instead of treating all patients with the same condition exactly the same way.

Once a diagnosis is made, AI can also help doctors design the best plans to help each patient feel better, based on that patient's unique characteristics. Creating "designer" treatments for specific individuals is called **personalized medicine**, and it could be much more effective than the typical method of giving every patient with a certain disease the same medicine, for instance.

DIGITAL TWIN

A virtual model of a person, organ, or system that uses real-world data to simulate how the real thing would behave.

But people are complicated, and there are hundreds of factors that make us different from each other—how can we know what is best for each patient? That is where AI-based **digital twins** might be able to help. A digital twin is a virtual version of a person that exists inside a computer, built using all kinds of data from the real person—not just their medical records but the foods they eat, the conditions of their environment, their genetic information, and information from wearable devices like smartwatches or other sensors (for more about wearable health devices, see this article from this Collection). It may still be years before full-body digital twins are a regular part of healthcare, but there are already digital twins of specific organs or diseases, like the heart and heart disease [4, 5]. In the future, doctors could use a patient's digital twin to test out various treatments to figure out which one will work best; or they could experiment with lifestyle habits like how much fruit and vegetables the patient eats, to see what will help that person stay the healthiest.

HOW DO *YOU* FEEL?

Many people find these developments exciting and inspiring, likening them to the invention of the computer or the internet. How do *you* feel? Would you want to be "seen" by a virtual doctor instead of a real person? Would you feel comfortable taking a medicine prescribed by an AI system instead of a human? What about having your X-rays or blood tests analyzed by an AI program? While AI has great potential in healthcare, it can also raise some worries. One concern is that

AI might not understand everything about our bodies as well as human doctors do, so it could make mistakes in treatment plans—for example, by giving us the wrong medicines or missing the symptoms of a developing disease. Some people also worry that relying too much on AI might take away the special connection between patients and doctors. Privacy is another worry. AI needs lots of information to help us, and much of that information is personal. Privacy laws and regulations must be followed to keep patients' personal data confidential and to make sure it is only used for good reasons (for more information on health-related data and how personal information is protected, see this article, and for a discussion about making sure that technologies are used for good purposes, see this one). Fortunately, many patients are happy to share their data with scientists and doctors once they know it might help other sick people, and experts are working hard every day to develop technologies that make sure data stay safe and secure.

We are only just starting to teach AI systems how to help scientists, doctors, and patients. Before AI can be a bigger part of healthcare, scientists need to make sure it is really safe and effective by testing it a lot, and we also need to figure out the best ways for doctors and computers to work together. To build trust in AI for medicine, you can treat AI like a new friend that you get to know step by step (Figure 2). One important step is learning as much as possible about AI and how it helps doctors and scientists. Knowledge about how

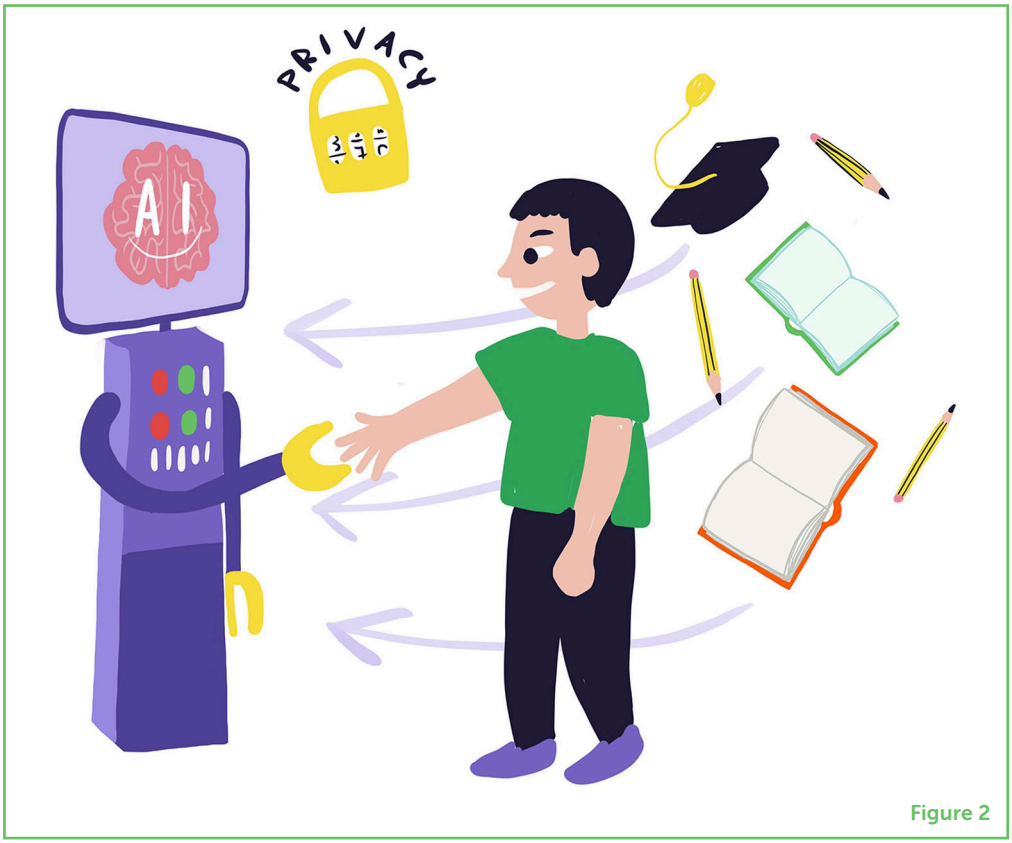


Figure 2

Figure 2

The success of AI in healthcare depends on building trust in these technologies. Knowledge and understanding are important components of trust, so health literacy—learning all you can about these new technologies—is important. If strong privacy rules are in place, people will feel more comfortable about sharing their personal information with AI systems. This is important because shared data are necessary to develop powerful, accurate AI systems. Finally, seeing AI in action—even in small ways—can help to build trust and confidence in its abilities (figure created by carlottacat.com).

HEALTH LITERACY

The ability to understand health information and services well enough to make good decisions about your health and medical care.

AI works can make you feel more comfortable and excited about its possibilities. Understanding health information so that you can make the best health-related decisions is called **health literacy**. Reading articles like this one can increase your health literacy and trust, as can talking to your doctors and asking them how they use AI to help us. When you can see AI-based medical technologies in action, working in helpful ways—like in chatbots that answer health questions—your trust and confidence in its abilities can grow. Finally, remember that, just like human doctors, AI is not perfect. It might not have all the answers and can sometimes make mistakes. But computer scientists, laboratory scientists, and doctors are continually working to make AI better, safer, and more helpful, so that the partnership between doctors and AI can help all people be as healthy as possible.

ACKNOWLEDGMENTS

Articled inspired by the Sparks! Serendipity Forum at CERN. For more info on this particular topic, see talks by Jane Metcalfe, Andrew Hessel, and Ankur Vora.

REFERENCES

1. Bin, K. J., Melo, A. A. R., da Rocha, J. G. M. F., de Almeida, R. P., Cobello Junior, V., Maia, F. L., et al. 2022. The impact of artificial intelligence on waiting time for medical care in an urgent care service for COVID-19: single-center prospective study. *JMIR Form Res*. 6:e29012. doi: 10.2196/29012
2. Shaver, J. 2022. The state of telehealth before and after the COVID-19 pandemic. *Prim Care*. 49:517–530. doi: 10.1016/j.pop.2022.04.002
3. Lim, J. I., Regillo, C. D., Sadd, S. R., Ramachnadra, C., Solanki, K. 2022. Artificial intelligence detection of diabetic retinopathy. *Ophthalmol. Sci.* 3:100288. doi: 10.1016/j.xops.2022.100228
4. Loewe, A., Martínez Díaz, P., Nagel, C., Sánchez, J. 2022. "Cardiac digital twin modeling," in *Innovative Treatment Strategies for Clinical Electrophysiology,* eds. T. Jadczyk, G. Caluori, A. Loewe, K. S. Golba (Singapore: Springer). doi: 10.1007/978-981-19-6649-1_7
5. Coorey, G., Figtree, G. A., Fletcher, D. F., Snelson, V. J., Vernon, S. T., Winlaw, D., et al. 2022. The health digital twin to tackle cardiovascular disease—a review of an emerging interdisciplinary field. *NPJ Digit. Med.* 5:126. doi: 10.1038/s41746-022-00640-7

SUBMITTED: 20 September 2023; **ACCEPTED:** 28 November 2023;
PUBLISHED ONLINE: 08 December 2023.

EDITOR: Claudia Marcelloni, European Organization for Nuclear Research (CERN), Switzerland

SCIENCE MENTORS: Jasleen Kaur and Vidya Rajagopalan

CITATION: Debad SJ and Metcalfe J (2023) Doctors and Artificial Intelligence: Working Together for A Healthier Future. Front. Young Minds 11:1297688. doi: 10.3389/frym.2023.1297688

CONFLICT OF INTEREST: SD was employed by SJD Consulting LLC. JM was employed by proto.life.

YOUNG REVIEWERS

ESHAAN, AGE: 11
Eshaan is an epic kid who enjoys reading and playing with his brother (Vihaan). Eshaan also enjoys writing stories and making stop-motion movies.

HARKIRAT, AGE: 9
Hi, I am a 4th grader who loves to dream, doodle, and solve puzzles! I really like unicorns, I am super good at hopscotch, and I can solve Rubik's cubes super-fast! One day, I want to try all the cookies and find the yummiest one. When I am not in school, I am either reading cool books, building awesome stuff with my Legos, or challenging myself with tricky puzzles.

VIHAAN, AGE: 8
Vihaan is a boy that loves to read and playing with his brother (Eshaan). Vihaan also loves to make oil clay figures and play games with his family.

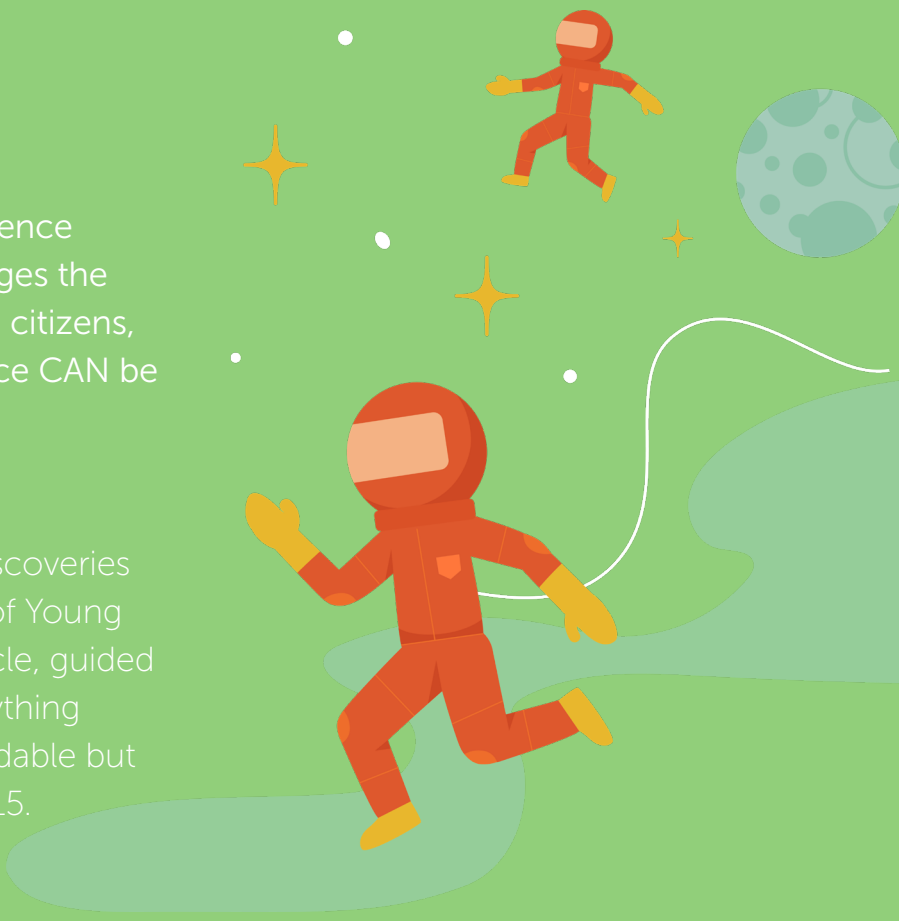
AUTHORS

SUSAN J. DEBAD
Susan has been the main editor for FYM since 2015, making all our science clear and interesting—so that nobody feels it is "boring" or "too hard." She has a Ph.D. in viral immunology (how the immune system protects us against viruses). Susan lives outside Washington, DC, and has a teenage son, two birds, and four dogs. She fosters beagles and helps them to get adopted, which means that sometimes she has more than four dogs! In her spare time, she enjoys reading, crossword puzzles, and being outdoors. *susan@sjdconsultingllc.com

JANE METCALFE

Jane Metcalfe is a successful entrepreneur and publisher. Her current passion is the impact of technology on our health, specifically how technology is pushing the frontiers of biology forward, showing us more and more about how our bodies, brains, and minds function, why we get sick, how we age… and how to intervene in all those processes. She is the founder and CEO of proto.life, a media company created to explore the radical changes taking place in humans as we harness the tools of engineering and computer science to alter our own biology. She was also a co-founder and president of Wired Ventures, creator of the magazine Wired. *jane@proto.life

Frontiers for Young Minds



Our Mission

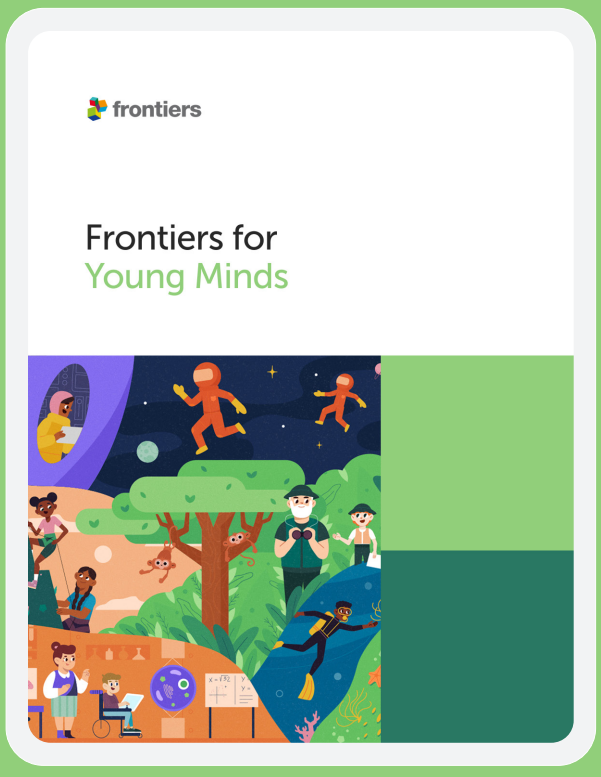
To publish high-quality, clear science which inspires and directly engages the next generation of scientists and citizens, sharing the revelation that science CAN be accessible for all.

How we do this?

Top researchers write up their discoveries for kids and our global network of Young Reviewers peer review every article, guided by their mentors, to ensure everything we publish is not only understandable but engaging for their peers aged 8-15.

Discover our latest Collections

See more →



Social Media

@FrontYoungMinds
@FrontiersForYoungMinds
@frontiersyoungminds
#frontiersforyoungminds

Contact us

+41 21 510 1788
kids@frontiersin.org