8 fascinating and fearsome frontiers of science you should know about

From quantum biology to mind control, these are the areas of research scientists are most excited about.

Image: Julian Litzel

09 Nov 2018

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This article is part of the **Annual Meeting of the Global Future Councils**

A range of technologies are coming of age all around us, transforming our world in complex ways that are hard to predict.

Anticipating what's to come requires paying attention to lesser-known yet important elements of the natural world before they catch us unprepared. Several of these are poised to generate game-changing technologies and create new understandings.

With this in mind, we called on a network of experts to tell us which corners of scientific research make them most excited and which most concerned. Six hundred and sixty replied. We think their answers will surprise you.

Future frontiers

As you might expect, the same technologies that many of us read and talk about are also top of experts' minds. The complex issues to surface included the usual suspects, such as artificial intelligence, human genome editing, sustainable energy and the future of weapons.

But if we are to get better at expecting the unexpected, we need to listen more closely. The Future Frontiers Survey aims to do just that. Deep in the data, we found voices whose hopes and fears were different from the rest.

From these intriguing responses, we distilled eight Future Frontiers of science and technology that we would all do well to know more about. Four of them hold great promise and four pose great risks.

The four most promising

1. Quantum biology

How can plants convert sunlight into chemical energy that they can live on in one billionth of a second? How can birds detect the Earth's magnetic field, in order to navigate over thousands of miles? How can our DNA randomly mutate with no apparent cause? What is consciousness?

Understanding how biology evolved to take advantage of manifestly quantum behaviour and what role quantum physics may have in the human brain is a nascent but growing area of research. It could answer some of science's biggest mysteries and lead to technologies beyond our imagination. Find out more in this article.

2. Machine learning through small data

Not a day goes by without news of how artificial intelligence will change our world. But today's AI has major limitations. For machines to learn, they require huge sets of training data. When confronted with scenarios that differ from the examples used in training, they break down. Human intelligence is the opposite. We see a surprising new situation, and with very small data, our brains are hardwired to generalize, mostly with excellent outcomes.

The AI systems we hear about today are still impressive, but they are likely one-trick ponies. A system that can learn with as much agility as a human and deliver valuable services without the need for huge amounts of training data would be a game-changer. It could lead to capabilities on a par with, or superior to, our own.

3. Room temperature superconductivity

Few things have changed the human condition more than our ability to harness electrical power. But when we store electricity in a battery it degrades over time, and when we transmit electricity over cables some energy is always lost. Superconducting materials can achieve lossless transmission and storage of electricity, and create powerful magnetic fields that never weaken.

Superconductors could power an energy revolution, writes Cambridge Professor Suchitra Sebastian in an article that aims to explain the mysteries of the material in accessible language. Imagine levitating trains that can reach incredible speeds; a world powered entirely by desert solar farms; ultra-fast computers; cheap MRI machines; technologies we haven't yet dreamed of.

However, the superconductors we have today only function when cooled down to hundreds of degrees below zero. This is a technically difficult feat that makes superconducting technology impossible to scale commercially. Achieving superconductivity at room temperature would transform the world in ways comparable to when we first started to use electricity.

4. Venomics

From spiders and scorpions to frogs and snails, there are more than 220,000 species that produce the complex cocktails of toxins called venom. Venoms contain powerful proteins which have evolved to act quickly and in very precise ways, binding to specific targets in the body like a lock and key, with devastating effect. In short, they are nature's perfect superdrugs. If human chemists were able to make drugs that perform as well as venom, we'd see a dramatic increase in drug efficacy and decrease in side-effects.

One of the reasons drug-makers haven't made more use of venoms is how difficult it is to untangle their complex chemistry to identify the active ingredients. But the application of new 'omics' technologies - tools that systematically characterise differences in DNA, RNA, proteins and the molecules involved in cellular structures and metabolism - are enabling scientists to decode and catalogue the structure of venom at a much faster rate. They could lead to a revolution in discovering drugs for treating human disease.

This article on the intoxicating science of venomics explains more.

Four concerning areas of research

1. Lethal autonomous weapons

Whether drones, guns or robots, what defines lethal autonomous weapon systems (LAWS) is that once deployed, they make their own decisions about when to use lethal force or not.

For the full story, read this article by Peter Maurer, President of the International Committee of the Red Cross.

2. Digital phenotyping

Science fiction fans have long dreamed of handheld devices that diagnose illness and ailments with a quick scan of the body. Such technology is now close to reality, with the advent of algorithms that can analyze video, text and audio recordings to identify subtle patterns or anomalies that human eyes and ears can't register.

While digital phenotyping could empower people, it could also be used for passively screening populations without their consent or awareness. Security and surveillance cameras have become a fact of life in cities, transport hubs, offices and even schools. Soon it will be possible for these systems to capture changes in our physical and mental health without us knowing about it.

The spread of digital devices that track our behaviour patterns could even be poised to change the field of psychiatry, writes Amit Etkin, Associate Professor of Psychiatry and Behavioral Sciences at Stanford University, in this article.

What companies, governments or third parties do with that data will open a new frontier in the already complicated debates on data privacy and digital rights.

3. Non-invasive neuromodulation

Intangible forces such as electrical currents, ultrasound waves and magnetic stimulation can be used to alter mental states, behaviours or the physiology of the brain in ways that used to require surgically entering the skull or ingesting drugs. This is leading to novel treatments for persistent depression or relief for Parkinson's tremors without having to implant a device deep in the patient's brain.

But without clear regulation, this technology is easy to use in unapproved ways which could put consumers at risk. There is already a small market developing around do-it-yourself brain stimulation kits. Taken to extreme conclusions, it's not hard to imagine a future where companies and governments might deploy devices to manipulate the mental states of workers, soldiers or citizens, regulating up or down their levels of wakefulness, subservience to authority, fears or inhibitions.

For more on the science of non-invasive mind control, take a look at our interview with Antoine Jerusalem, Professor in the Department of Engineering Science University of

Oxford.

4. Predictive justice

This is the ability to use artificial intelligence, neuro-imaging technologies and big data to identify individuals and scenarios where crime has a high probability of occurring. Artificial intelligence used in courtrooms could help make justice more efficient, but consider the risks in a world where evidence-faking algorithms proliferate.

We're facing a digital revolution, writes Daniela Piana in this article exploring the ethics of predictive justice. It's up to us to ensure that we are still ruled by the law rather than falling into the trap of making the rule of law equal to the rule of code.

Speaking of rules, in a world where legal processes are influenced by artificially intelligent judges and juries, these four principles could help guard against programmed AI bias.

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