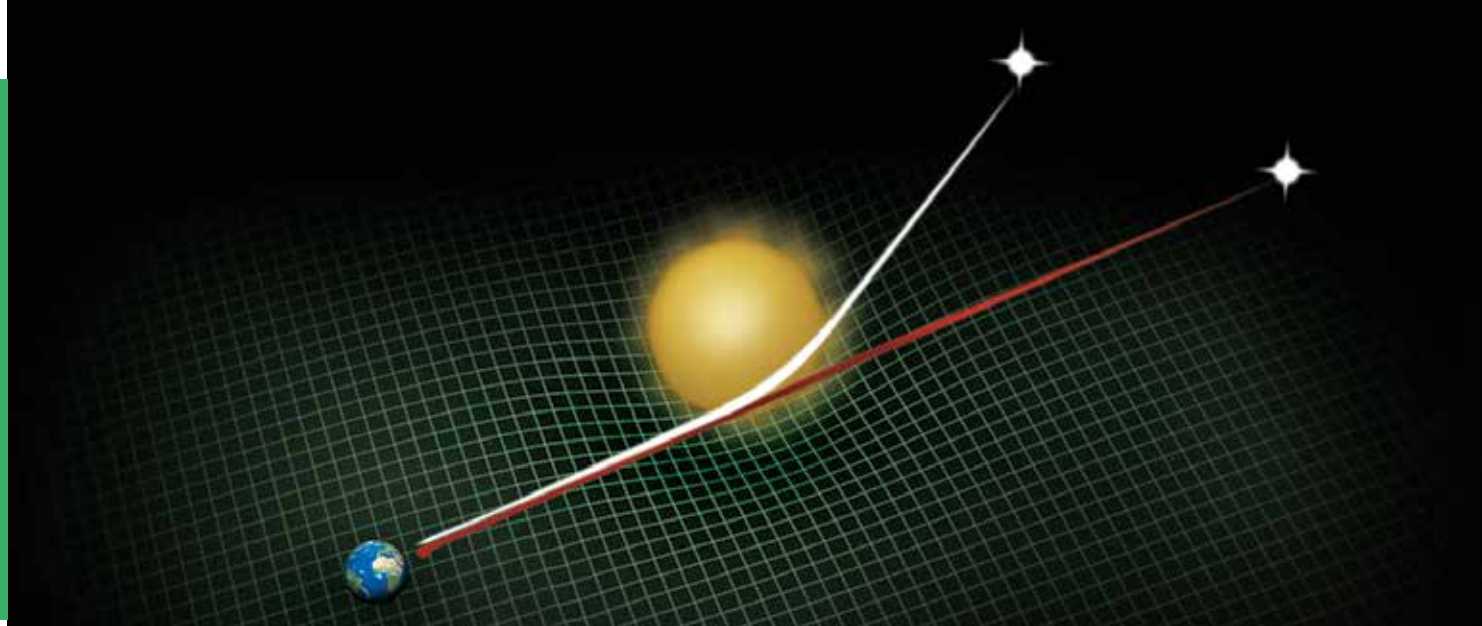


WHY DO EXPERIMENTS?

BHAS BAPAT

We are bequeathed a legacy of clever and painstaking experiments by the pioneers of modern science. In the age of information overload, it is prudent to consider why we need to dirty our hands doing experiments, instead of merely depending on processed information to push the frontiers of science.

Science is driven by human curiosity; curiosity to know why things happen the way they happen, or in other words, to understand how nature works. This curiosity gets channelised in many ways, two of which we can readily identify with. The first is to make careful observations of phenomena, identify factors affecting a particular effect or outcome, and then attempt to control the outcome by tweaking the influencing factors, thus establishing a cause–effect relationship. The other is to predict a cause–effect relationship by applying logic about how things should be without necessarily working out the ideas in practice. In the formal world of science, these two approaches are readily identified as experimental research and theoretical research respectively. However, contrary to common belief, these are not distinct streams, nor is one cleverer or purer than the other. Instead, they complement and supplement each other. An experiment (or a series of experiments), is no good if the inferences drawn do not help us build a more general or wider understanding of phenomena. Likewise, a theory is no good if it does not explain a set of observations or make correct predictions about things not yet observed. Very often, though not always, a theory is based on axioms or postulates that are a distillation of inferences based on observations. Humans are naturally trained to believe only what they are able to perceive with their five senses. A non-scientist is therefore likely to ask 'But, is it real?' for something that a trained scientist will accept as second nature, even if it can't be seen or perceived with the senses. A case in point is the microscopic world. We believe in atoms and sub-atomic particles, though nobody has really 'seen' them. This is so because we have been able to build an edifice of knowledge by making certain postulates,

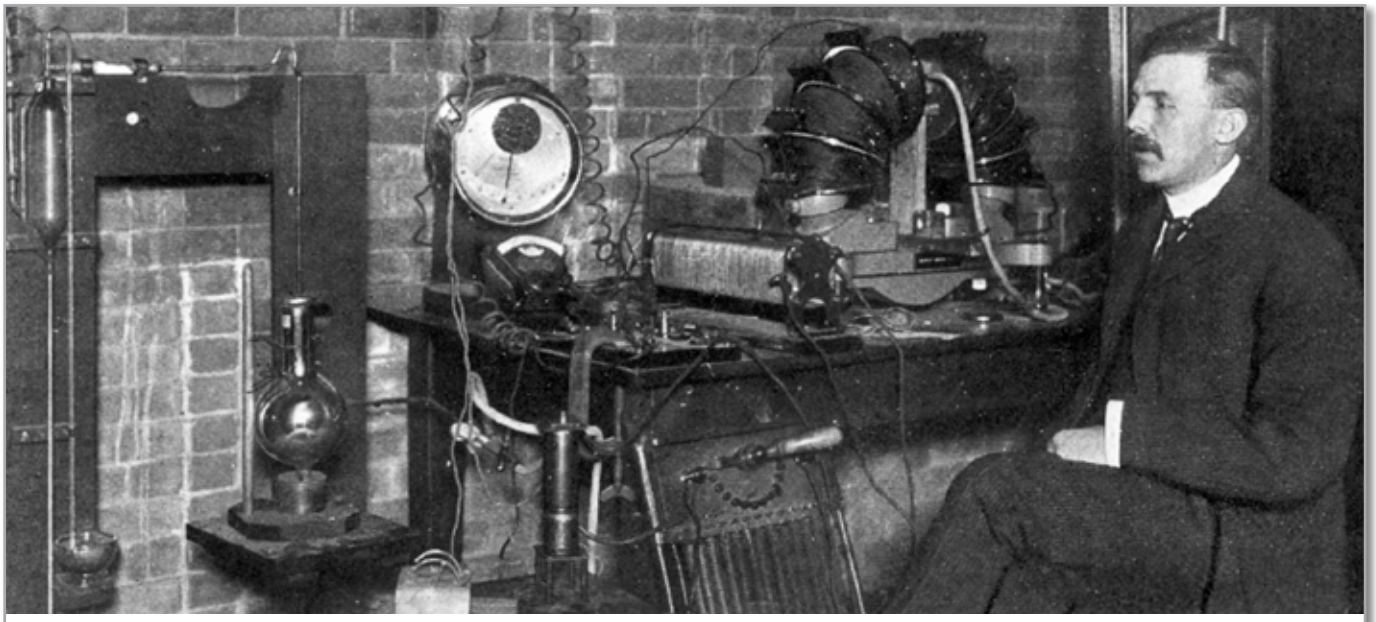
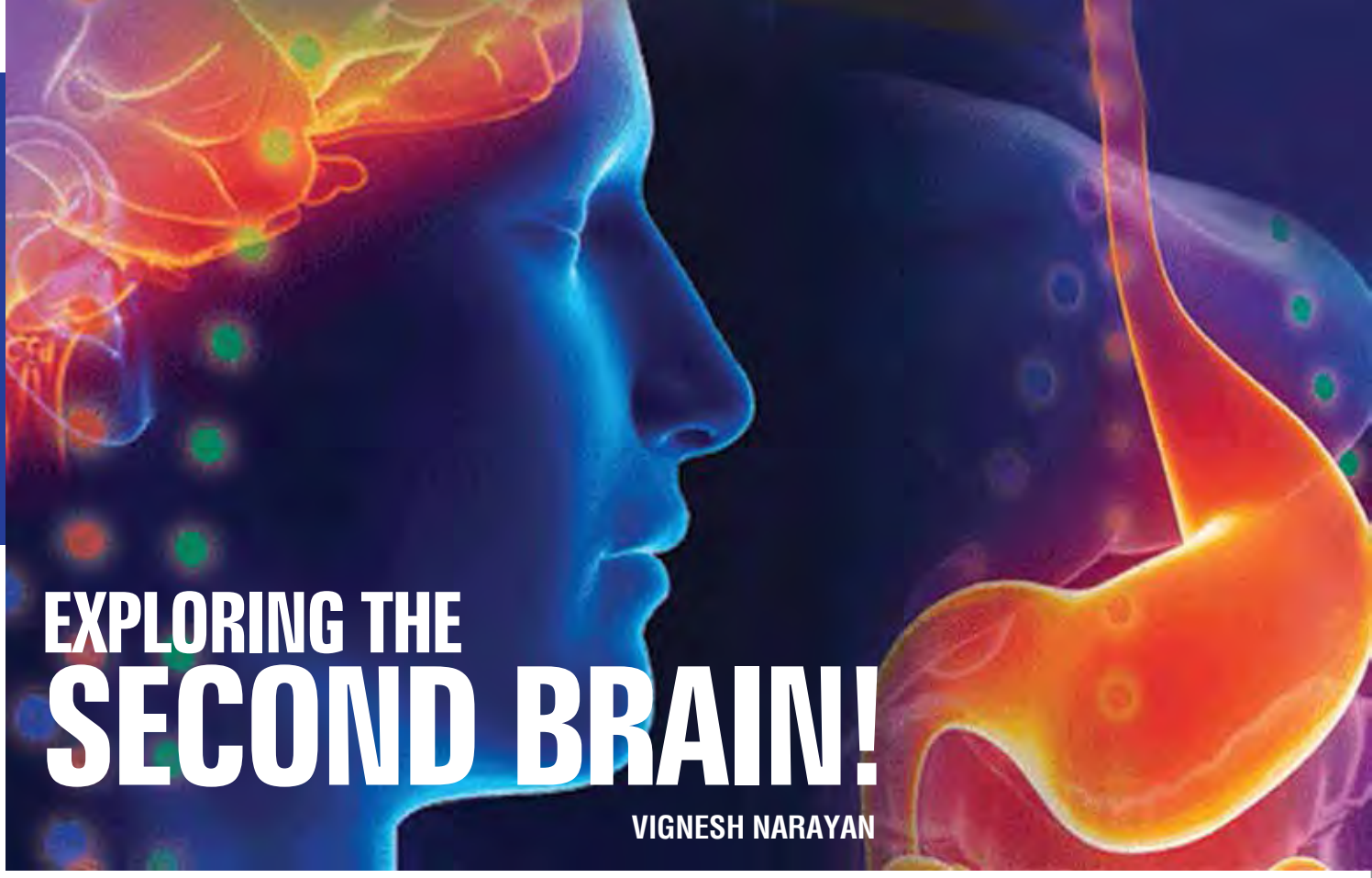


Figure 1. Ernest Rutherford with his apparatus for studying radioactivity. An apparatus is merely a tool that puts out some numbers. It is the inferences drawn from the numbers that may have far-reaching implications in science, as they did in this case. They also brought Rutherford fame by way of a Nobel Prize. Source: Contributor unknown, published in 1939 in Rutherford: being the life and letters of the Rt. Hon. Lord Rutherford, O. M - http://wellcomeimages.org/indexplus/image/L0014629.html. Wikimedia Commons. License: CC-BY. URL: https://en.wikipedia.org/wiki/Ernest_Rutherford#/media/File:Ernest_Rutherford_1905.jpg.

which appear reasonable based on experimental observations, and then applying logic.

So, experiments serve three main purposes. First, obtaining information about phenomena that have not been understood before, which in turn assists the development of a theory pertaining to those phenomena and enhances our ability to make predictions. History of science throws up innumerable examples. The development of the concept of an atom and the particulate nature of matter and the associated concepts of heat and temperature are largely based on insightful analysis of chemical and physical reactions. The second purpose of experiments is to verify or reject the predictions of a theory. Some outstanding examples of this include the demonstration of the quantisation of angular momentum of atoms by Stern and Gerlach, and the measurement of the bending of light due to the sun's gravitational field by Eddington and his collaborators. In more recent times, the discovery of various particles in high energy particle collisions has confirmed the predictions of the Standard Model. A famous experiment that rejected a popular theory is the Michelson Morley experiment; it sounded the death knell for the all-pervading ether. The third purpose that experiments serve is paving the way for application of science for societal benefits. There are simply too many of them to list, but one outstanding example is the Haber process that enabled fixation of atmospheric nitrogen as ammonia which plants could use as a nutrient - a process that was the key to scaling up of agricultural production to meet the burgeoning population and associated food shortages. One field that has benefited enormously from relentless experimentation, in diverse streams of chemistry and physics, is medicine. Diagnostic tools such as biochemical analysis, ultrasonography, X-ray, NMR, minimal invasive interventions and therapies are a fall-out of a series of experiments, in domains where theory is far too complex and intractable, if not unknown. Many scientific discoveries have been serendipitous, and it is easy to see that the more you tinker, the more likely you are to hit something big.

Bhas Bapat is a physicist working at the Indian Institute of Science Education and Research Pune, and has interests in school science education. He can be contacted at bhas.bapat@gmail.com.



EXPLORING THE SECOND BRAIN!

VIGNESH NARAYAN

Join the author in an exciting narrative about the Gut, a small but amazing organ that does so many things that it is called the second brain. From digesting anything that is put in it to controlling feelings and emotions, the Gut is a Jack of all trades, and a master in every one of them.

"Located neither high nor low, soft at heart and smooth in flow, my job is serious, I'll let you know! I crush and grind and pump all day, filled with lakes that can eat iron nails. I can sense everything that comes my way, sometimes I quiver with joy, sometimes I groan in pain!"

You are here at last! I have been waiting for you today, to show you some of the wonders of your body, and my humble job here as a small but important organ. Before we begin, let us play a guessing game. If you can guess who I am, I'll never give you any trouble again, and as far as I am concerned, everything in your body will flow smoothly. Oops! Almost gave myself away. Well, without further ado, here is a tricky question for you – what has close to five hundred million (that is 5 followed by 8 zeros!) neurons (nerve cells), receives and sends electrical signals to muscles as well as other nerves, and produces more than 90% of the serotonin (a chemical that acts as a 'neurotransmitter'- which means that it helps transmit information across the body through neurons) and 50% of the dopamine (another neurotransmitter) found in the body?

I, my friend, am called the Gut. Located just below the stomach, I am the last part of the largest structure in the digestive system, called the 'gastro-intestinal tract'. This is not a very difficult word to understand. 'Gastro' refers to the stomach (from the Greek word gaster which means belly); 'intestinal' refers to the small and large intestines in the abdomen; and 'tract' just means a really large area, or, in this case, a really long tunnel. The digestive system is like an assembly line in a factory. The food you eat moves down this assembly line, along which there are different kinds of specialized cells and organs that pour different kinds of enzymes (proteins that perform certain biological reactions) that digest the food. Each section of your digestive system has a gate called a 'sphincter' (sfinkter) to allow food to enter a certain section of this factory and keep it there until it is digested partially or

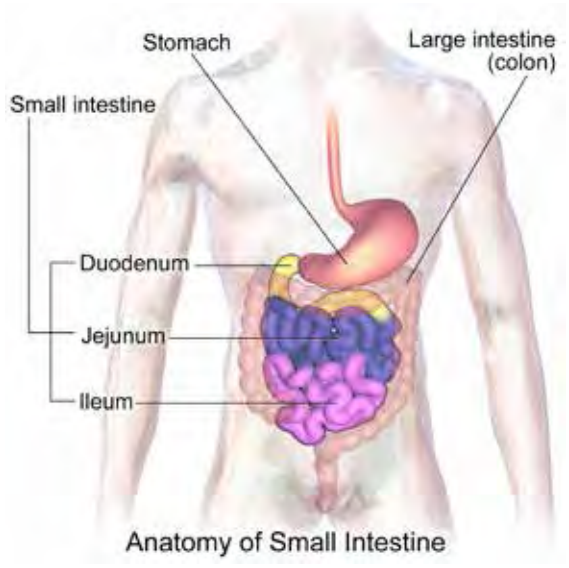


Figure 1. Anatomy of the small intestine. Source: Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010. ISSN 20018762. URL: https://en.wikipedia.org/wiki/File:Blausen_0817_SmallIntestine_Anatomy.png. License: CC-BY.

completely. Whenever it is my turn to digest food, the pyloric sphincter opens up - in gushes a mass of semi-digested food, ready for me to process.

I am made up of two parts - the first of which is called the 'small' intestine because it is narrow and highly convoluted. The second part - called the large intestine, receives material from the small intestine, and helps remove the undigested waste from the body through an opening called the anus. Interestingly, while the large intestine is only about 4.5 feet long, the small intestine measures 19 feet in length! Although the small intestine is about three and a half times the average length of an entire human body, it is folded and packed so neatly that it looks smaller than even the large intestine. Let me tell you the reason behind this packing. The inner walls of the small intestines are not flat, but folded up into pleats, like the ends of a dhoti. Each of these pleats is covered with tiny projections called 'villi'. Each villi, in turn, is covered with cells, which have tiny hair-like structures covering its surface. In this way, about 5.8 metres of the small intestine has an absorptive surface of almost 250 square metres. That is 7 times the surface area of the small intestine if it were not folded up and slightly larger than a tennis court!

You may make the mistake of thinking that I am just a long pipe - after all, who wouldn't! However, there is more to me than meets the eye, my friend. My walls are made up of strong involuntary muscles (smooth thin muscles that cannot be controlled voluntarily, like the ones controlling your bladder which force you to run to the bathroom in the middle of class!), whose powerful motions push semi-digested and digested food through the entire canal. Like the rest of the digestive tract, lining my walls are millions of specialized cells that pour out digestive enzymes onto the food. Needless to say, by the time the food you eat reaches your anus, there is not a tiny speck of nutrition left, for I have absorbed all of it!

Let me give you an exact break-down of what happens as soon as food enters my walls. Once the stomach finishes with its job of breaking proteins into smaller units, I step in as the major organ of digestion, and the only part of your entire body that can absorb nutrients from the food and eject the waste material left behind. To digest the food from the stomach, I work along with your pancreas. The pancreas, as you know, is an organ that produces a huge variety of enzymes that are absolutely essential for your body. These pancreatic enzymes, enter my walls through small ducts or tubes, and break down peptides (short pieces

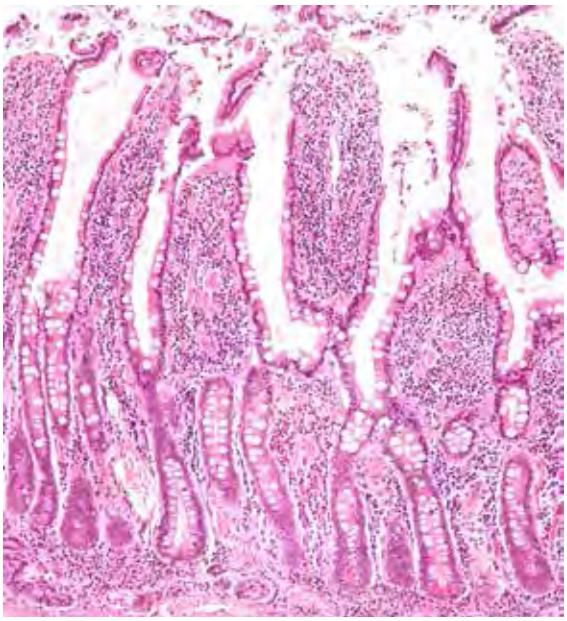


Figure 2. A micrograph of small intestinal mucosa showing intestinal villi. Source: Nephron, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Small_intestine_low_mag.jpg. License: CC-BY-SA.

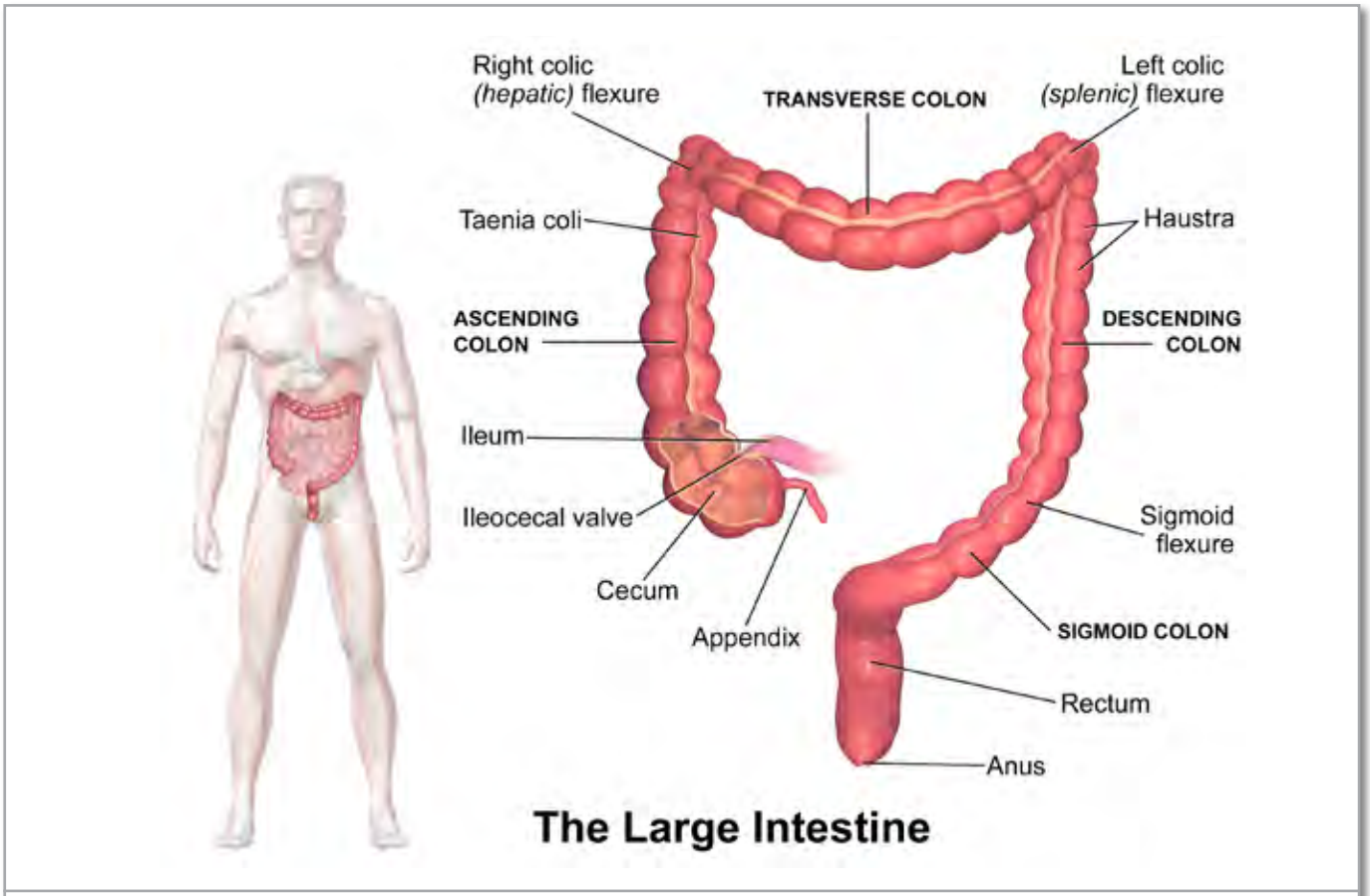


Figure 3. The large intestine. Source: Blausen.com staff. "Blausen gallery 2014". Wikiversity Journal of Medicine. DOI:10.15347/wjm/2014.010. ISSN 20018762. URL: https://en.wikipedia.org/wiki/File:Blausen_0604_LargeIntestine2.png. License: CC-BY.

of degraded proteins) and amino acids (smallest units that make up proteins), lipids (fatty foods), and some carbohydrates (commonly called sugars). Let us not forget one of the most important chemicals that enter my walls - bile. Produced by the bile duct, bile helps neutralize the horribly strong acid that the stomach uses to break proteins into smaller peptides. The pH of the stomach can go down to three, which is strong enough to digest razor blades!

Once the food passes through my first compartment, it enters the large intestine (which is actually much smaller) where I store the waste (left after the small intestine has finished with it!); and absorb water, ions (like potassium), as well as vitamins produced by bacteria that make their home here (I'll talk more about this later). By the time the food has reached the large intestine, I absorb most nutrients and 90% of the water, leaving behind a few electrolytes like sodium, magnesium, chloride and indigestible foods (mostly plant carbohydrates). As the food moves down towards the anus, most of the remaining water is

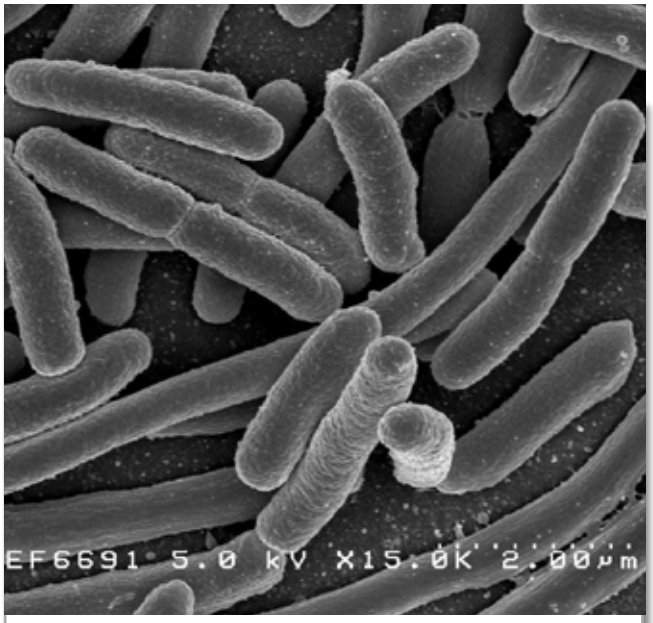


Figure 4. *Escherichia coli* is one of the many species of bacteria present in the human gut. Source: Rocky Mountain Laboratories, National Institutes of Health, United States Department of Health and Human Services. Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:EscherichiaColi_NIAID.jpg. License: Public Domain.

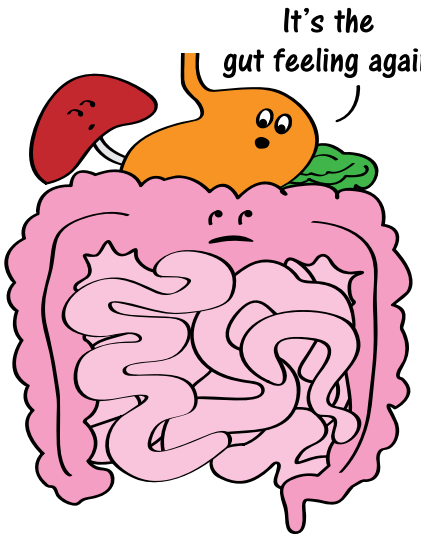


Figure 5. Have you ever had a 'gut feeling' about someone you have met?

removed, and the waste matter is mixed with mucous and bacteria (known as gut flora) and becomes faeces (also called stools). This way, the stools gradually become more solid as my strong muscles slowly push them along to their ultimate fate - the toilet!

Enough about these trifling things that everyone learns in school! Today, I'm going to let you in on secrets that scientists are only now figuring out. Did you know that for every human cell in your body, there are ten bacterial cells! That's right! Some people estimate that there are over 4×10^{13} bacterial cells (that is 4 followed by 13 zeroes!) in your body. Some of these bacteria live on your skin (especially where there is a lot of hair) and your urogenital tract, but over 90% of them, my friend, grow inside me. The entire population of bacteria living inside the human body is called the 'human microbiome', and the most important and dense microbiome in the human body is the 'gut microbiome'. Many people even go so far as to say that the gut microbiome is a forgotten organ, and I am inclined to think that they are absolutely right. The number of different species of bacteria inside me is more than twice the number of genes in a single human cell! That means that there are over 50,000 different species of bacteria, and all of them live on my inner surfaces.

What are they doing there, you ask? Well, I keep them because they make for wonderful factories! Bacteria are the most marvellous machines that nature has created; they can live on almost anything, and produce

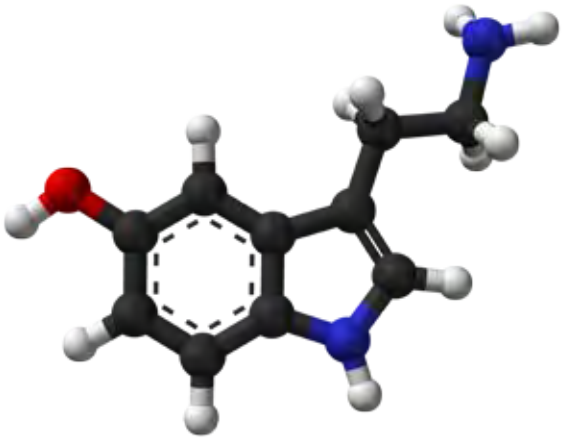


Figure 6. Ball-and-stick model of the serotonin molecule, C10H12N2O. Source: Ben Mills, Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Serotonin-Spartan-HF-based-on-xtal-3D-balls-web.png. License: Public Domain.

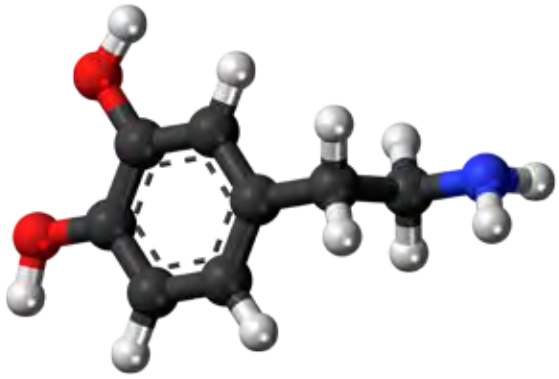


Figure 7. Ball-and-stick model of a molecule of dopamine - a neurotransmitter that affects the brain's reward and pleasure centers. Source: Jynto (talk), Wikimedia Commons. URL: https://en.wikipedia.org/wiki/File:Dopamine_3D_ball.png. License: Public Domain.

and secrete some very interesting compounds. My microbiome produces enzymes that digest food which I would find very difficult to break down myself. In addition, they produce important vitamins like vitamin B and vitamin K, without which your body will be subject to many horrible diseases. Recent research has positively proved that tampering with my microbiota in **any** way – be it removing the diversity (number of different types), or the numbers (population size), can cause obesity, anxiety disorders, depression and even autism! But I must add a note of caution. Sometimes, the bacteria that colonize me can be harmful - specific species of bacteria can cause cancer if they start dividing inside me.

If you still haven't realized that there is more to me than meets the eye, prepare to be completely astonished! I, your gut, a narrow tube running from your stomach to your buttocks, am your second brain. Have you ever had a 'gut feeling' about someone you have met? A 'gut instinct' that your guess in a difficult quiz question is correct? A sinking feeling in your stomach when you feel that something bad is going to happen? If you think that your brain makes most of your split-second decisions, think again. I am connected to your brain via the 'enteric' (meaning inside) nervous system, and am a whole brain hidden inside your body cavity! There are hundreds of millions of neurons connecting my walls to your brain. My neural networks are so sophisticated that I can work and think without any control from your brain. This enteric nervous system of mine not only ensures that the food is digested and ejected at a certain time and speed, but also dictates how you feel. I make and secrete a very important molecule called serotonin. Serotonin is a neurotransmitter (a chemical used by the brain, remember?) that controls your mood, appetite, sleep, memory and learning; and, regulates your temperature, social behaviour and libido. Serotonin is also important in the functioning of other organ systems like the cardiovascular system, the muscular system and some parts of the endocrine system. I could go on and on about the importance of serotonin! The more scientists discover the uses of serotonin, the more they realize that I run the body, not the brain. Simply because I produce 90% of all the serotonin your body needs; not to mention 50% of your dopamine, without which parts of your brain cannot talk to other parts!

The next time you feel sleepy, or cannot think clearly after eating, don't blame your brain. This is just me and the trillions of bacteria that I grow trying to take charge! Butterflies in your stomach? Feeling excessively happy? Me again! Now that you know this, I'm sure you will be more careful with what you put in your stomach. Remember to eat good quality food, at the right time and in the right quantities. All this talk has made me hungry - I think you should go get some pizza!

Vignesh Narayan is a Ph.D. student in molecular biology at the Indian Institute of Science, Bangalore. He is passionate about research and popular science writing. His area of expertise is in biology, with a special focus on molecular biology and microbiology of diseases. You can reach him at vigneshnarayan313@gmail.com