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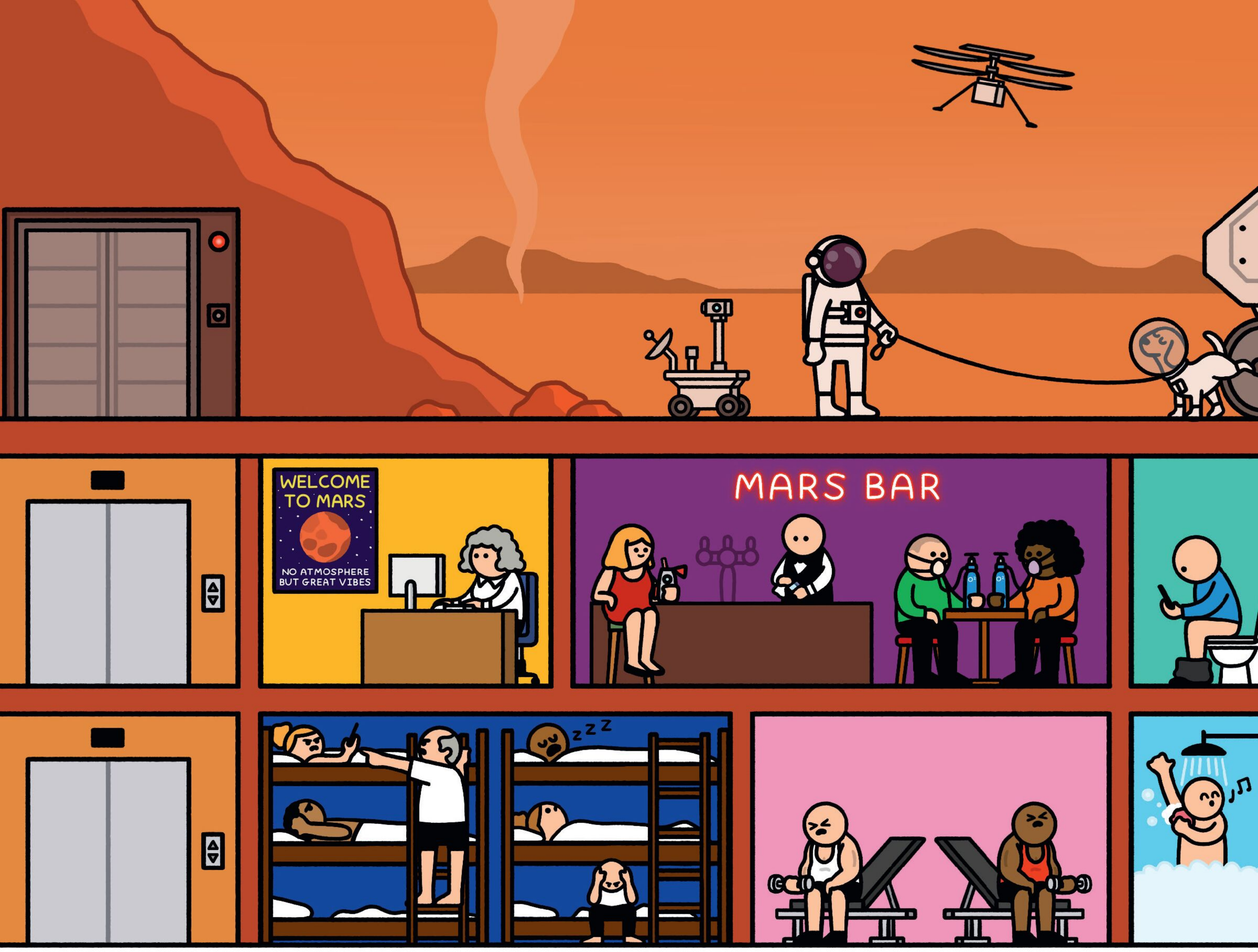


Life on Mars

You might have heard about plans to establish a self-sustaining city on Mars. But have we really thought it through, ask **Kelly** and **Zach Weinersmith**

EARTH isn't doing so great. Thanks to human-induced climate change, the seas are warming and rising, while the land – in many places – is alternately choked in drought or inundated with floods. As for us humans, we are engaged in warfare on multiple continents, far-right movements are ascendant across the world and, as of last month, "dude wipes" are available with a pumpkin spice scent in the United States.

Meanwhile, the escape hatch to space is creaking open. Elon Musk's company SpaceX has a growing fleet of cheap, reusable rockets. In October, the booster stage for its mega-rocket, Starship, was caught in the grip of a skyscraper-high tower as it descended back to Earth. It was an impressive feat. But Musk's goal with these vehicles is even more audacious: to start a self-sustaining million-person city on Mars in the next 30 years.

Has anyone really thought this through? Well, yes, as it happens, albeit not Musk. We are a wife-and-husband research team – a biologist

STEVE NELSON

and cartoonist, respectively – and we have spent four years looking into how humans will become space settlers for our latest book, *A City on Mars*. We set out to write the essential guide to a glorious off-world future. What we learned, however, made us space settlement sceptics.

Here's the thing: Mars sucks. When you dig into what life would really look like on the Red Planet, in terms of the squishy details of human existence, it becomes hard to avoid an inconvenient conclusion – that moving to Mars to escape Earth would be like moving to a toxic waste dump because your neighbours aren't mowing their lawn often enough.

To rewind for a moment, we are space geeks. We love rocket launches and zero-gravity antics. We also hate being pessimistic, especially about an endeavour that so many of our fellow space enthusiasts think embodies the best of human nature. Unfortunately, the data led us in another direction.

Let's start with Mars as a destination. It certainly has its qualities: relative proximity to Earth, plentiful water, a day-length similar to our own, the chemical elements needed to support human life and temperatures that swing from a not-so-bad-by-space-standards -153°C (-243°F) to a positively comfortable 20°C (68°F) at certain locations. Plus, as the SpaceX website notes, perhaps in a nod to humanity's track record on climate change: "It is a little cold, but we can warm it up."

With all that said, Mars will remain worse than Earth even if the direst predictions of the consequences of climate change come to fruition. Take the air, for starters. The Martian atmosphere is mostly carbon dioxide, which, while popular among plants, is toxic to humans if breathed exclusively. To put it bluntly, if you step outside on Mars, you die.

Cosmic radiation is another problem. Thanks to Earth's dense atmosphere and the strong magnetic fields that surround it, the radiation criss-crossing its way through space is mostly screened out before reaching the delicate inhabitants on the surface. On Mars, which has no planet-wide magnetosphere and an atmosphere that is only 1 per cent as dense as Earth's, most of this radiation will make it to the surface.

Cosmic radiation is different to the radiation we typically experience on Earth, and the truth is that we have no idea how bad it is for us. Even astronauts living on space stations orbiting our planet are largely protected within Earth's magnetic field, which means we have very little relevant data on the effects of this radiation on humans, or on the other life we have sent into space. But a reasonable assumption held by almost everyone who has studied cosmic radiation is that constant exposure to elevated doses increases the risk of cancer.

All of which has knock-on effects for the question of where, or in what, we would live on Mars. Forget those illustrations of gleaming glass domes under which happy dinner-party guests drink wine and count the stars. That glass would let the radiation through. What we need is thick shielding. Indeed, most suspect ›

we will set up home inside long caves carved out by ancient lava flows, or else build shelters using onsite materials. That is, we will bury ourselves in Martian dirt.

Alas, this dirt, technically called regolith, is truly horrendous stuff. It may look like dust or sand, but without the gentle wear from wind and running water, regolith tends to be jagged and sharp. Breathing it repeatedly may cause scarring of the lungs similar to that seen in silicosis, a condition caused by breathing in silica dust from sources such as stonecutting or construction, leading to breathing problems and even death.

Toxic dust

Regolith also happens to be laced with nasty chemicals called perchlorates. At high doses, these cause thyroid problems by competing with the iodine ions your body needs to produce certain hormones. This probably isn't good, especially for developing fetuses and children. Experiments conducted on Earth have found that plants grown in soil containing perchlorates incorporate them into their tissues, which means that any water or regolith from Mars will have to be detoxified before use.

Optimistic space-settlement enthusiasts say that perchlorates can be turned into oxygen. But we lean towards a less optimistic take. The thing is, when people talk about space settlement, they are often weirdly generous to conditions they would never accept on Earth. Imagine you are planning to have kids and are looking to buy a homestead, for instance. How do you feel about a real estate agent saying: "It's a great location, but I should mention the surface contains high levels of chemicals that are dangerous for children. And those chemicals can get taken up by edible plants, so if I were you, I'd convert those perchlorates to oxygen before you put in the veggie patch."

Speaking of food, we still have a lot to learn about how to grow enough of it in space. A typical journey to Mars takes more than six months, and settlers would have no choice but to stay for at least a year at a time to ensure the two planets are close enough to each other for the return journey. We will need to be self-sufficient, and growing food on site will require not only agricultural facilities, but excellent recycling systems too, as part of something scientists call closed ecological systems. One thing worth knowing about closed ecological systems is that humans aren't very good at living in them.

The most famous habitat of this type is Biosphere 2, a facility in the Arizona desert that ran a two-year experiment in the 1990s to see if eight people could survive sealed off from the outside environment. The only external inputs were sunlight and power from the local grid. Things went OK. Nobody died. But they were certainly hungry. The crew did physical labour eight to 10 hours a day, five and a half days a week, and the women lost 10 per cent of their body weight while the men lost 18 per cent. Also, at one point the carbon dioxide levels in Biosphere 2 started to soar, causing the Biospherians intense headaches and malaise.

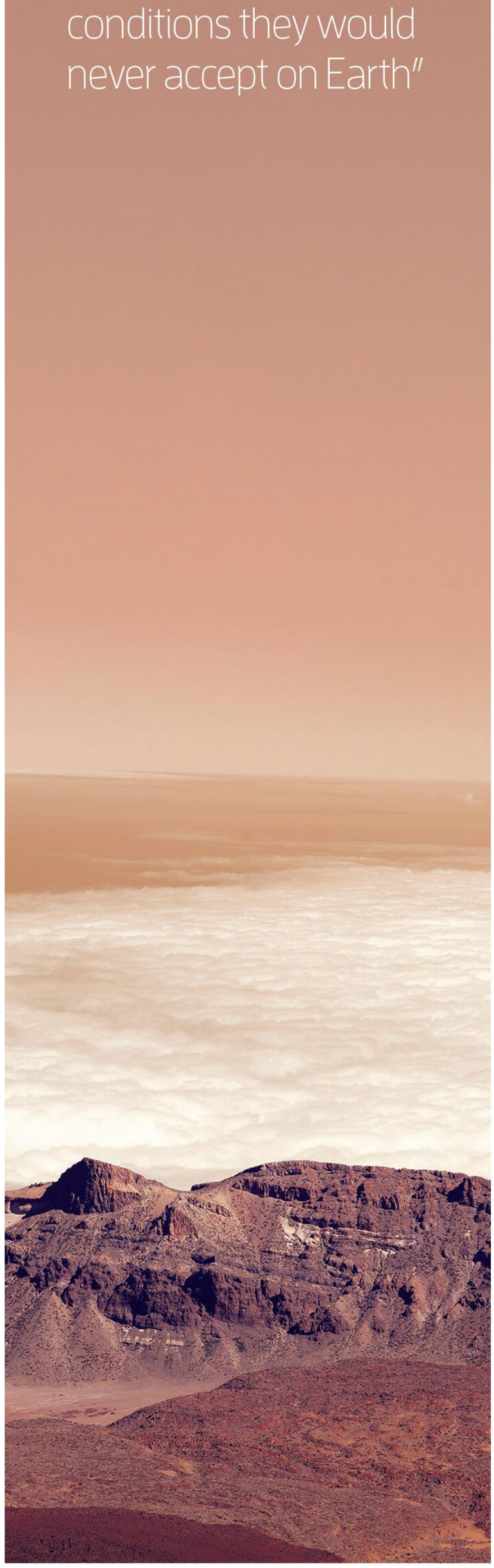
Few experiments of that kind have been done since, and none on the same scale. In China's Lunar PALACE (Permanent Astrobase Life-support Artificial Closed Ecosystem), the setting of a 105-day experiment in 2014, there weren't enough plants in the facility to soak up the carbon dioxide exhaled by the three men living there. Levels fluctuated wildly, which isn't an ideal description of the behaviour of a toxic gas in your living space. However, when two of the men were replaced with women, the carbon dioxide levels stabilised at a low level and air quality improved. Among various lessons that might be drawn here, the one screaming at us is that more data is needed before we try to scale from a handful of people to the million Musk would like to land on Mars.

Lunar PALACE did succeed in other areas. For example, they were able to recycle 100 per cent of their water. Water recycling in space is something we know about, as fluids like urine, sweat and exhaled breath are collected and recycled on the US side of the International Space Station. This recycling is why astronauts refer to water as "yesterday's coffee".

The Lunar PALACE also grew 78 per cent of the participants' food by mass, and made good use of a protein source often proposed for space settlements: insects. What's not to like? They reproduce quickly, don't take up a lot of space, eat food scraps, are high in protein and you never name one Wilbur and fall in love with it. Proposed protein sources include crickets, silkworms, mealworms, hawkmoths, drugstore beetles, termites and flies.

In Lunar PALACE they used mealworms, which after a bit of seasoning were actually rated quite favourably by the crew. However, data of this sort can't always be trusted – participants in experiments like this are

"Would-be space settlers are weirdly generous towards conditions they would never accept on Earth"



SIMONAS ŠILEIKA/ALAMY

The Biosphere 2 research facility in Oracle, Arizona

BUDDY MAYS/GETTY IMAGES

often hoping that they will be picked by their respective government to become actual astronauts, so it is possible they were just trying to highlight what exceedingly good sports they are.

By contrast, the Biospherians weren't good sports – and the disagreements highlight some of the social and psychological challenges that a Mars colony would present. Tensions between crew members became so high that two crew members actually spat on a third. This was in a 12,000-square-metre facility, which is likely to be quite roomy compared with an early space outpost.

Between the carbon dioxide headaches, caloric deprivation and drive-by spittings, it is no surprise that some Biospherians reached out to mental health professionals. Unfortunately for Martian settlers, the vast distance between Earth and Mars means communication delays of between 4 and 24 minutes each way. So, while the inhabitants of Biosphere-2 could have real-time calls with family, friends and mental health specialists to help them get through their ordeal, on Mars you would be on your own.

Gravity shortfall

And let's not forget the physical health issues settlers will face, which could be significant even when inside an underground bunker, protected from cosmic radiation and regolith. Astronauts in stations orbiting Earth are in constant freefall, effectively experiencing zero gravity. Despite hours of exercise most days, astronauts on the International Space Station lose 1 per cent of the bone density in their hips per month. Muscles experience similar degradation. Low gravity also appears to contribute to deteriorating vision, for reasons that aren't entirely clear, but which may have to do with the extra pressure on your brain and eyes when gravity isn't around to drag the fluids down.

While we know freefall is predictably disastrous for the human physique, we don't know the long-term effects of Martian gravity, which is about 40 per cent of Earth's. Maybe that will be enough to stave off bone, muscle and vision loss. Or maybe some combination of 40 per cent gravity alongside extra exercise and medications will do the trick. But after a long day of subsistence farming, dodging coordinated saliva strikes from crewmates and tucking into a lunch of mealworm tacos washed down with recycled urine, who really wants to jump on the exercise bike? Besides, what if 40 per cent gravity is bad for the human body, and no amount of exercise can make up for the gravity shortfall?

More concerning for the would-be settler is the fact that all the human data we have comes from adults who were in space for a year and a half at a time or less. A self-sustaining human settlement needs to be able to make more humans. That means conception, pregnancy, birth and developing into a mature human ready to repeat the above process. We know almost nothing about whether any of this can be done off-world. As far as we know, no human has ever had sex in space, let alone become pregnant. The research on reproduction in non-human animals in space has been scant, and it has been done mostly on space stations – which, as you now know, experience less radiation and gravity than you would get on Mars.

The biological research needed to adequately assess how dangerous pregnancy, labour and child development will be on Mars will take years to acquire, which Musk's plans for settling Mars don't seem to take into account. In our experience of this discussion with settlement enthusiasts, Musk isn't alone in this oversight. For example, we have had people argue with us that women give birth on Earth in dangerous situations and without medical interventions all the time, with the implication that it would be fine on Mars. Setting aside that many of those women die from lack of care, "We already fail to provide sufficient maternal care to all the women on Earth" isn't a great justification for doing the same on other planets.

Now, at this point, you are almost certainly thinking that we would politely but firmly decline any invitation to Mars. You would be wrong. Well, kind of. Because although we wouldn't go personally, we do want to see humanity settle the Red Planet.

The task for those of us who grew up watching too much *Star Trek* and *Doctor Who*, and who sometimes look up on a clear night and say to ourselves "ah, to hell with realism", is to figure out the path forwards.

It is a slow one, for sure. It sits on a mountain of hard-to-get data about human minds and bodies in an environment we didn't evolve for. It also involves sensible plans for how to deal with space law, international relations and societal organisation in a scenario where breathable air is rationed, something we address at length in our book. But as space tech advances and the needed experiments become more plausible, the question of how to responsibly expand beyond this planet becomes an important one.

To be clear, we don't think humanity will be saved by leaving Earth. Solving our problems here, now, is more important than a short-term rush elsewhere. Even so, we do believe that there should be no tension between those who want to go to space for humanity and those who want to focus on Earth for humanity. If we fail to deal with terrestrial problems, such as global warming and the threat of nuclear war, there will be no second chance. But when, one day, there is a city on Mars, it will be a product not only of great technology but also, we hope, great wisdom. ▮

Kelly Weinersmith is a biologist at Rice University in Houston, Texas. Zach Weinersmith is a cartoonist. They are the authors of *Soonish* and *A City on Mars*, which won the 2024 Royal Society Trivedi Science Book Prize