Writing Samples

Sedeer el-Showk

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FEATURES

FINAL RESTING PLACE

Finland is set to open the world's first permanent repository for high-level nuclear waste. How did it succeed when other countries stumbled?

By **Sedeer El-Showk**

After passing through a security gate, the van descends into a tunnel that burrows under the forests of Olkiluoto, an island off Finland's west coast. The wheels crunch on crushed stone as a gray, wet October day gives way to darkness. "Welcome to Onkalo," deadpans Antti Mustonen, a geologist here. Onkalo—"cavity" or "pit" in Finnish—will be the world's first permanent disposal site for high-level nuclear waste, and a triumph for Finland.

Safety lights guide the van down through switchback turns that lead to a cavernous chamber, its walls reinforced with spray-on concrete. In just a few years, spent reactor fuel rods, encased in giant copper casks as tall as giraffes, will arrive here via elevator before robotic vehicles take them to one of the dozens of dead-end disposal tunnels that will form an ant's nest in the bedrock. In a freshly excavated disposal tunnel, Mustonen explains over the roar of ventilator fans that the peculiar smell comes from rock dust mixed with a trace of explosives. It is muddy underfoot—not what you want to see in a place that shouldn't have leaks, but Mustonen says the water is only from the excavation effort.

In the blackness, bare bedrock glints in the meager light from the van. After 30 to 40 of the copper casks are buried in the tunnel floor, the holes will be plugged with bentonite, a water-absorbing clay. Each tunnel will be backfilled with more bentonite and sealed with concrete. The casks will then begin their long vigil. They must remain undisturbed for 100,000 years, even as the warming climate of coming centuries gives way to the next ice age. "It's final disposal," Mustonen says. "Right here, in stable Finnish bedrock, 430 meters belowground, 420 meters below sea level."

Although nuclear power is declining in many nations, Finland has embraced the carbon-free energy source, lobbying the European Union to label it as sustainable. Two of the country's four reactors are on Olkiluoto. After a new Olkiluoto reactor is connected to the grid later this year, nuclear power will account for more than 40% of Finland's electricity.

The emissions-free electricity comes with a downside: hot and highly radioactive spent uranium fuel rods. In Finland, the rods cool for decades in pools of water; other nations park them in concrete and steel "dry storage" casks. Either way, surface storage is vulnerable to accidents, leaks, or neglect during the thousands of years the waste remains dangerous, says Budhi Sagar, a nuclear expert formerly at the Southwest Research Institute. "It's not safe—some disaster will occur," he says, citing the groundwater contaminated by leaky waste tanks at the U.S. Department of Energy's (DOE's) Hanford Site in Washington state, where reactors produced plutonium for the first nuclear weapons.

Without a long-term solution, the waste is piling up. Finland had about 2300 tons of waste in 2019, and about 263,000 tons of spent fuel sit in interim storage facilities worldwide, a report this year from the International Atomic Energy Agency estimates. "In my view, that's an unacceptable legacy to leave to future generations," says Tom Isaacs, a strategic adviser for Canada's Nuclear Waste Management Organization (NWMO) and Southern California Edison. "We generated this electricity. We benefited from that."

Many experts view permanent deep repositories like Onkalo as the best solution, but getting community buy-in is often a deal breaker. Street protests have slowed down plans for a disposal site in France, and in 2009, after years of debate, then-President Barack Obama's administration gave up on plans to develop Nevada's Yucca Mountain as the U.S. national repository. "The U.S. approach didn't pay sufficient attention to community acceptance or engagement," says Isaacs, who was the lead adviser on a 2012 blue-ribbon report commissioned by DOE to chart a way forward. "The original approach led to conflict rather than cooperation."

Finland, however, has run into remarkably few problems with Onkalo, which the government approved as a site in 2000. It helped that the residents of Eurajoki, the town closest to Onkalo and the nearby reactors, were comfortable with nuclear power. "Almost everyone in Eurajoki has a friend or relative who has worked in the nuclear power plants, so they know how we operate," says Janne Mokka, CEO of Posiva, the nuclear waste company set up by two nuclear power utilities to develop and manage Onkalo.

But experts say the success of Onkalo also reflects unique cultural and political conditions in Finland: high trust in institutions, community engagement, a lack of state-level power centers, and a balance of power between industry and stakeholders. "If you tried to implement the same thing in a country with much lower levels of trust, it would probably fail," says Matti Kojo, a political science researcher at Tampere University in Finland.

"The Finns have been able to articulate a consistent message about what they're doing, why they believe this facility will be safe, and why it will be a major benefit to the well-being of certain communities," Isaacs says. In late December 2021, Posiva applied for a license to begin operations in 2024.

POSIVA BEGAN its search in the 1990s, with dozens of candidate sites, before narrowing the list to four with different geological characteristics. The final choice was

Spent uranium fuel rods will be sealed within thousands of tall, corrosion-resistant copper canisters.

About 100 nuclear waste disposal tunnels are being dug 430 meters underground at Onkalo.

PHOTOS: LEHTIKUVA/EMMI KORHONEN/VIA REUTERS; (OPPOSITE PAGE) TAPANI KARJANLAHTI/TVO

Spent fuel rods from Olkiluoto's nuclear power plants will cool off for several decades in interim storage pools before final burial at Onkalo.

between Olkiluoto and the area around the town of Loviisa, which houses the country's other nuclear power plants. In 1999, Posiva put forward the site that would become Onkalo.

The bedrock at Onkalo has been mostly stable for the past billion years, geologists say, although there is evidence of earthquakes during the past 10,000 years as massive glaciers retreated at the end of the last ice age and the bedrock rebounded. Posiva scientists don't expect significant earthquakes in the region until after the next ice age. Mustonen says Onkalo was purposefully situated between two parallel fault zones about 800 meters apart. If an earthquake were to occur, it would preferentially happen along those existing fault lines, he says. "They absorb the movement and nothing happens here in the area in between."

But earthquakes aren't the main threat. "The only way for things to move from the repository out to the surface and to impact people is to be carried by water," says Sarah Hirschorn, director of geoscience at NWMO. That means deep repositories are best situated in certain types of clay, salt, or hard crystalline rock, because they have small, disconnected pore spaces and are almost impermeable to water. At Onkalo, the nearly 2-billion-year-old bedrock is mostly gneiss, a hard rock formed at high temperatures and pressures.

Although decidedly nonporous, these rocks can still contain cracks, and Posiva had to map and avoid them as workers dug deeper. "It's these fractures which control the movement of water," says Neil Chapman, a geologist who has served as an independent consultant for Finland's nuclear regulator, the Radiation and Nuclear Safety Authority (STUK). If any significant fractures are discovered when drilling individual cask pits, he says, those holes won't be used.

If water were somehow able to seep into the repository, it would still have to get past the bentonite and copper to reach the spent fuel. "You're never relying on a single barrier," says Emily Stein, who researches deep geologic disposal at DOE's Sandia National Laboratories. "If one barrier fails, you have other barriers that can minimize or prevent radionuclide release."

After arriving at Onkalo, spent fuel will be unpacked in an encapsulation plant. In a stainless steel room surrounded by 1.3-meter-thick concrete walls, robots will vacuum away any water left on the fuel rods from their time in the storage pools, and seal them within a cast-iron canister nested inside a copper canister. Argon will be injected between the two canisters to provide an inert atmosphere, and the copper cask will be welded shut.

Copper is slow to corrode, and by the time any groundwater does reach Onkalo's depths, chemical or microbial reactions would have consumed all of its dissolved oxygen, making it less reactive. But Peter Szakálos, a chemist at the KTH Royal Institute of Technology in Stockholm, has concerns. In a 2007 study, he and colleagues found signs that copper can corrode even in pure, oxygen-free water. When the metal is exposed to water, Szakálos and his colleagues found it releases a whiff of hydrogen gas. He suspects the water reacts with the copper to form a "distorted" copper oxide crystal along with free hydrogen, which is either released or absorbed into the copper. Szakálos says any absorbed hydrogen would make the copper brittle and prone to cracking, and bronze would have been a safer choice. "It's just a matter of time—between decades and centuries—before unalloyed copper canisters start to crack at Onkalo."

Posiva and SKB, Sweden's nuclear waste management company, say Szakálos's experimental conditions are not relevant for the planned repositories. Even so, SKB contracted Uppsala University and the University of Toronto to try to replicate the findings. The Uppsala tests did not find evidence of any reaction with pure water, whereas the Toronto group observed one but said it was too slow to matter. "Making a measurement that tells you nothing happened is impossible," says David Shoesmith of the University of Western Ontario, a corrosion chemist who has consulted for SKB. "Based on what's been published, the answer to this question is that minimal things will happen."

Those concerns nevertheless delayed plans for what would be the world's second deep repository, near the Swedish coastal town of Forsmark. In 2018, Sweden's Land and Environment Court called for SKB to provide more evidence that copper corrosion would not undermine long-term safety. SKB submitted additional documentation to the Swedish Radiation Safety Authority, and in January, the Swedish government approved the facility based on the regulator's assessment that the other barriers would keep the repository safe.

PHOTO: TAPANI KARJANLAHTI/LTVO

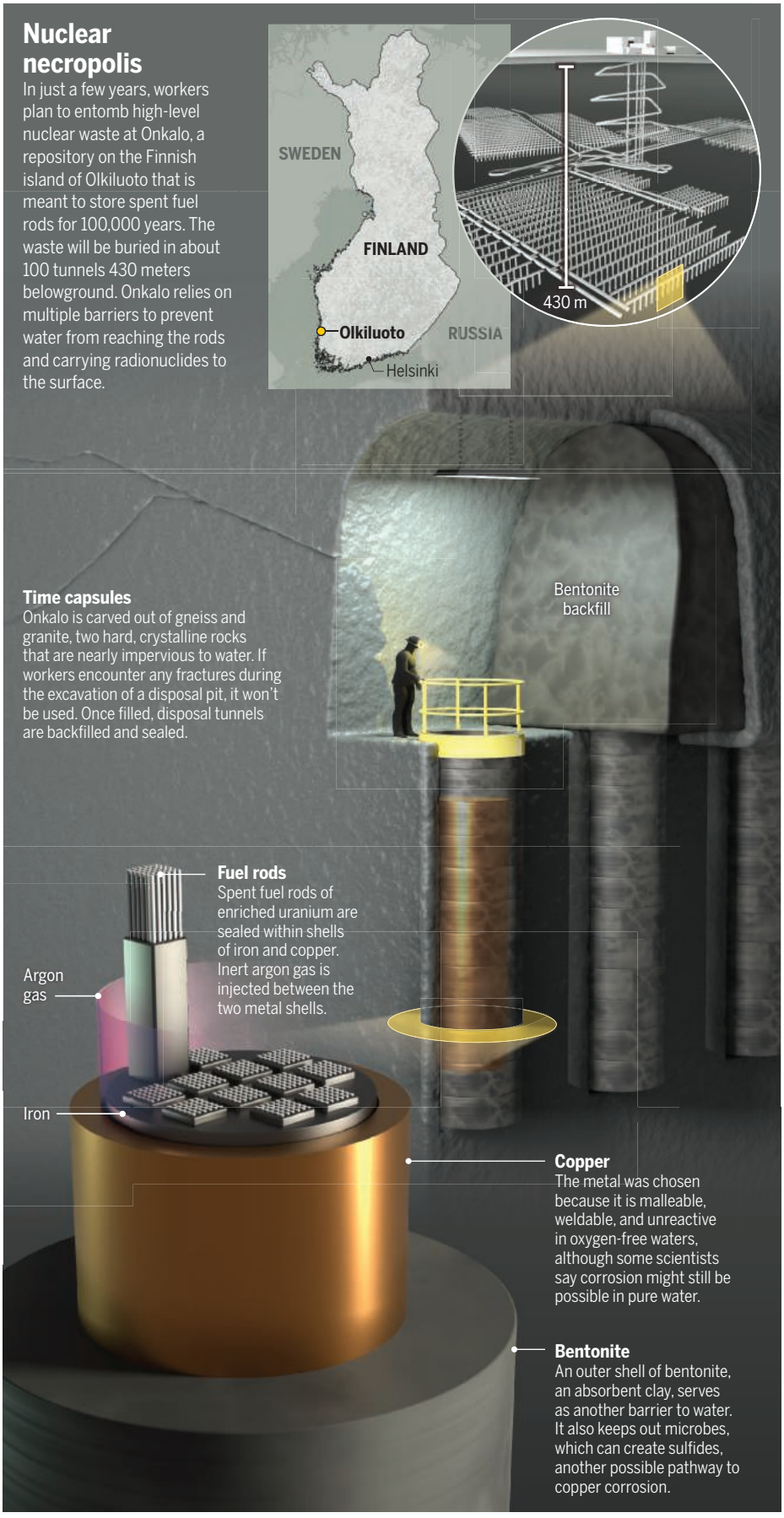
In addition to the casks themselves, the bentonite surrounding them will also prevent radionuclide escape, regulators say. The mineral not only keeps water away, but also prevents microbes from reaching the canister surface. Microbes can pose a threat, says Karsten Pedersen, CEO of Microbial Analytics Sweden, a company that researches their effect on deep repositories, because they can metabolize sulfates in groundwater and turn them into sulfides, which can slowly corrode copper. Posiva acknowledges that possibility, but the company's calculations suggest that even at elevated sulfide levels, the canisters would have a lifetime of more than 100,000 years.

Should all these barriers fail, escaping waste would face one last impediment: the decades it would take to migrate to the surface, with radioactivity levels dropping all the while. Sagar, who reviewed the long-term scenarios that were a part of STUK's overall safety assessment, says that even under worst-case assumptions the impact of leaking radionuclides would be minimal. For people living near the repository and drinking contaminated water from deep wells, the assessment found, the annual exposure would be well below the allowable limit set by STUK, which is about the same as the average background radiation exposure a person in Finland experiences today. "That's the point of a multibarrier system," Sagar says. "Even if some containers fail or a systematic construction error means they all have defects, the geology and other barriers are good enough that you're still within limits."

YET THE TRUE SECRET to Finland's success with Onkalo lies not so much in geology and engineering, but in the site selection process, the structure of government, and a culture of trust in institutions and expertise.

Finland's 1987 Nuclear Energy Act set up a nuclear waste management fund, financed by the nuclear operators, which incentivizes companies to develop waste disposal solutions. It also insulates the process from politics. Isaacs notes how this differs starkly from the situation in the United States, where DOE—which answers to the White House—runs the waste disposal program. "No matter how competent and well-intentioned people are, presidential and congressional elections are held regularly," he says. Important decisions can end up subject to political expedience, crippling a project that takes decades to build.

Another important difference, according to Isaacs, is the absence of strong state-level government in Finland. State governments, often far from disposal sites, see repositories more in terms of perceived



GRAPHIC: V. ALTOUNIAN/*SCIENCE*

Onkalo's encapsulation plant (white) sits atop an ant's nest of underground tunnels in this August 2021 photo. Olkiluoto's nuclear power plants can be seen in the distance.

PHOTO: TVO

costs rather than benefits, Isaacs says. Nevada officials—governors, senators, and others—have consistently opposed the development of the Yucca Mountain facility, blocking funding and throwing up other hurdles. More recently, state politicians in New Mexico have opposed a proposed temporary storage facility for nuclear waste in the state.

In Finland, without comparable power centers to play spoiler, Posiva and the national government could deal directly with communities like Eurajoki. Community acceptance was forged in the back and forth between Eurajoki and Posiva, Kojo says. "In the 1990s, the power companies knew that they really needed approval at the local level," he explains. Finnish law gave Eurajoki the right to veto disposal in the area. But Eurajoki officials were tempted by the tax revenue that would come from the third nuclear power plant if Posiva's parent company, TVO, decided to build it there. Posiva also funded the construction of a new senior center in town.

This approach—continual engagement with potential host communities—is rare in many other countries, including the United States. Even in Finland it is new. In the mid-1980s, Finland had a technical, top-down approach with no public participation that experts like Kojo and Isaacs call "decide-announce-defend." In 1986, TVO announced it would investigate the municipality of Ikaalinen as a final disposal site. However, local resistance, particularly in the wake of the catastrophic nuclear accident at Chernobyl in the former Soviet Union, foiled the plans. The company realized it would have to engage more and build local political support using an approach Kojo calls "mitigate-understand-mediate."

Once an agreement was reached, Eurajoki residents were largely willing to leave technical matters and safety questions to expert bodies. "In Finland, there is a very high level of trust in science and in the authorities," Kojo says. "If the national authority says the repository is safe, they don't need to worry about it." The process became a purely technocratic affair in the hands of Posiva and STUK.

Not everyone's concerns have been allayed. The Finnish Association for Nature Conservation (FANC) says it is worried about long-term ecotoxicity and bioaccumulation of the radioisotopes. It also cites concerns raised by retired geologist Matti Saarnisto, former director of research for the Geological Survey of Finland. In 2010, Saarnisto told Finland's national broadcaster that as the next ice age arrives, freezing soil and rock could create pressures that would damage the repository. In any case, Saarnisto argued, it is impossible to make predictions on the scale of 100,000 years.

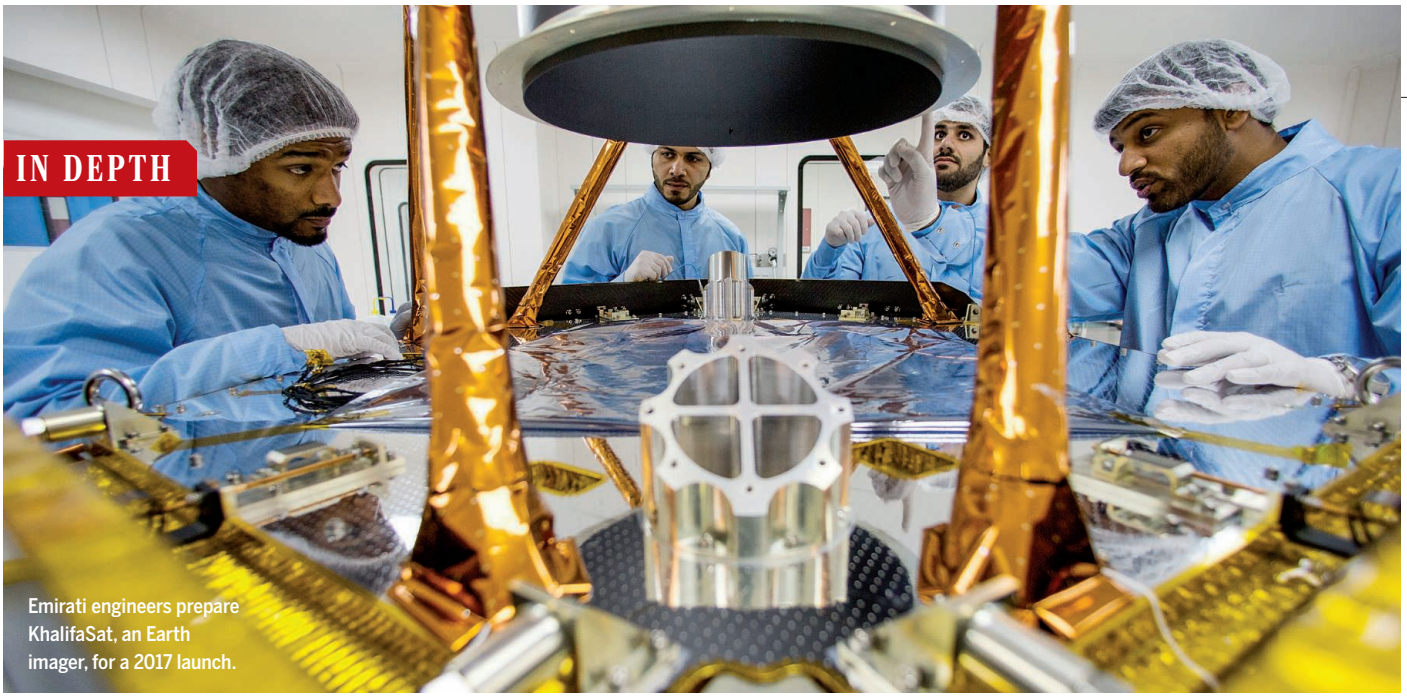
Jari Natunen, a scientist with FANC, says the relationship between industry and regulators in Finland is far too cozy—a form of "structural corruption." "The authorities are biased to think that the industry's position is correct and valuable, and the concerns of civil society are not," says Natunen, who is also a member of Nuclear Transparency Watch, an antinuclear advocacy organization.

Natunen adds that the Finnish media's coverage of Onkalo has been too compliant. By contrast, in the United States, France, and Sweden, safety concerns remain a central part of the public debate. A 2020 study by Kojo and his colleagues, for example, found that France's *Le Monde* newspaper played a more critical role in debates about repositories, acting as a watchdog that challenged authorities, whereas Finland's leading daily, the *Helsingin Sanomat*, generally took a more positive approach that reflected the framing and confidence of the government and industry.

If getting the operating license goes smoothly, Posiva is on track to begin to bury nuclear waste deep in the Finnish bedrock in 2024 or 2025. Excavation will continue over the next century as new disposal tunnels are added. When the repository is filled to capacity, sometime around 2120, the entrance tunnel will be sealed shut. The encapsulation plant and other surface structures will be demolished. Nothing above will remain, not even a warning sign. Deep below the dismantled site, 6500 tons of spent fuel rods will lie in their tombs, quiet but still warm from radioactive decay.

"What we are doing really has meaning and is really important," Mustonen says. "For me, this is the reasonable thing to do with nuclear waste, and we need to make it as good as possible. The sense of responsibility to the next generation doesn't keep me awake at night, but it's there. It just is." ■

Sedeer El-Showk is a science journalist in Helsinki who joined the communications team at Aalto University at the end of 2021. His reporting was carried out independently.



Emirati engineers prepare KhalifaSat, an Earth imager, for a 2017 launch.

PHOTO: SPACE TECHNOLOGIES LABORATORIES, MBRSC

PLANETARY SCIENCE

Small Gulf nation aims for big splash on Mars

UAE mission to Red Planet in 2020 would probe mysteries of martian atmosphere

By **Sedeer El-Showk**

In the mid-1970s, Sheikh Zayed, the founder of the United Arab Emirates (UAE), was preoccupied with such earthly matters as building his young nation when a series of meetings at his palace with several Apollo astronauts turned his gaze to the heavens. "From that time, His Highness became interested in space," says Mohammed Al Ahbabi, director general of the UAE Space Agency in Abu Dhabi. Zayed's fascination stirred him to establish programs that have dispatched numerous Emirati students abroad for training and stints at NASA and other U.S. facilities.

Zayed died in 2004, but the seed he planted 4 decades ago is about to blossom into a startlingly ambitious project: a science mission to Mars. In July 2020, the oil-rich nation aims to launch a spacecraft called Hope that will orbit the Red Planet and probe its atmosphere from top to bottom, beaming back "the first holistic view of the entire dynamics of the lower atmosphere of Mars," says Sarah Amiri, Hope's science lead. The mission team, some 120 young Emirati scientists, is now gearing up for a critical design review. (The space agency has not released the mission's budget, though it notes that the UAE has spent $5.4 billion so far on its space program.)

Bethany Ehlmann, a planetary geologist at NASA's Jet Propulsion Laboratory and the California Institute of Technology in Pasadena who isn't involved in the mission, says it promises "data we've not had for Mars before." She hopes the UAE Mars probe will inspire others to undertake more such "smaller, nimbler missions that complement the big ones and really help us build up a picture of our neighboring planet."

To be launched on a Japanese rocket, Hope derives its novelty largely from an unusual orbit that will enable it to cover the entire planet. Five of the six spacecraft now reconnoitering Mars loop around the planet in a polar or near-polar orbit, which limits them to viewing any point on Mars just twice each martian day. Hope will follow a lower inclination orbit that will allow the spacecraft to monitor the atmosphere at various latitudes throughout the day and across seasons, thus offering researchers a global view of how the atmosphere evolves, says Amiri, who trained as a computer scientist before rising through the ranks of the Mohammed Bin Rashid Space Centre (MBRSC) in Dubai, UAE, which is running the mission.

Hope's second goal is to probe how the martian atmosphere bleeds off into space, a phenomenon that, over billions of years, has left the planet bone dry and inhospitable. In 2015, NASA's MAVEN mission showed that the solar wind helps erode the martian atmosphere. Hope will probe the link between processes in the lower atmosphere, which contains most of the martian atmosphere's water vapor, and the escape of hydrogen and oxygen from the upper atmosphere. "When something wiggles at the bottom of the atmosphere, how does that make other things, different things, wiggle at the top of the atmosphere? No previous mission has been able to tackle that question," says David Brain, an atmospheric physicist at the University of Colorado in Boulder who is helping design Hope's instruments, a high-resolution camera and infrared and ultraviolet spectrometers.

If all goes as planned, Hope will spend 7 months en route to Mars and send back data for analysis in time for the UAE's 50th anniversary on 2 December 2021. But planners acknowledge that the mission is something of a gamble considering the UAE's limited experience in space. MBRSC operates two DubaiSat Earth-imaging satellites, built with South Korea; an MBRSC team is going solo on a third imaging satellite called KhalifaSat, which is slated for a late 2017 launch from Japan aboard a Mitsubishi rocket.

Already, though, one payoff is clear: The mission is nurturing a new generation of Emirati planetary scientists preparing to work on Mars data, says Hope mission head Omran Sharaf, an electrical engineer who previously worked on the DubaiSat satellites. More broadly, Sharaf and others hope that Hope will entice the Gulf's next generation to embrace science as countries in the region begin contemplating postpetroleum economies. "This mission should serve as a catalyst for change," he says. "A first step." ■

Sedeer El-Showk is a science journalist based in Morocco and Finland.

Published by AAAS

PALAEOANTHROPOLOGY

Lessons from our cousins

Studies of Neanderthal brain development could provide insights into the evolution and inner workings of the human brain.

BY SEDEER EL-SHOWK

In petri dishes at the University of California, San Diego, unassuming white clumps of cells grow into miniature replicas of the developing brain. They are brain organoids — simplified models of the brain consisting of hundreds of thousands to several million cells. Although tiny compared with even the fetal brain, and lacking blood vessels and certain cell types, brain organoids created from human cells have already proved valuable. For instance, during the 2015 outbreak of Zika virus in Brazil, researchers used brain organoids to help to show that the virus caused microcephaly[1], a smaller than normal head size. But the organoids growing in Alysson Muotri's laboratory are different from those that have come before. In his quest to understand the brain's evolution, Muotri engineered brain organoids to carry a variant of a gene that is found in our closest extinct kin — Neanderthals.

Since the publication of the draft Neanderthal genome[2] in 2010, researchers have known that Neanderthals interbred with anatomically modern humans. "Ten years ago, I was teaching that there was little or no inbreeding, and now we know that it was quite frequent," says Philipp Gunz, a paleoanthropologist at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany. Scientists can now track Neanderthal gene variants in modern humans and, in combination with the analysis of preserved remains, pinpoint genes and developmental processes that have changed in humans since the two species diverged. The effect of these genetic changes can be tested in brain organoids such as those in Muotri's lab. As close relatives, Neanderthals offer an unequalled opportunity to uncover how modern humans probably evolved.

THE SHAPE OF THINGS TO COME

Researchers cannot study the brains of Neanderthals directly — the species is thought to have been extinct for around 40,000 years, and soft tissue doesn't fossilize well. But from preserved skulls, scientists have been able to infer that adult Neanderthals had brains of a similar volume to those of modern humans, but with a more elongated, less globular shape. Finding out when this anatomical difference becomes apparent during brain development could provide a clue as to which aspects of brain development are unique to humans. "We're trying to find out what evolved last," says Gunz. "What is the most recent innovation in our brain?"

To determine the stage in development at which the brains of modern humans and Neanderthals begin to diverge, Gunz and his team used a technique that he established as a postgraduate student to analyse digitally rendered casts of the interior of the skull, or braincase, of newborn, infant and adult Neanderthals, as well as those of modern humans of European ancestry, created from computed tomography scans. Because neuron formation in the brain is largely complete by birth, knowing the age from which skull shape begins to differ in the two species should reveal whether the globular shape of modern human brains is mainly the result of prenatal neurogenesis or changes in networking and connectivity that occur predominantly after birth.

Anatomically modern humans can be distinguished from Neanderthals (left) by their less elongated, globular skull (right).

PHILIPP GUNZ (CC BY-NC-ND 4.0)

His analysis suggested that the braincase of newborn Neanderthals is similar in shape to that of newborn babies[3]. "That tells us that most of the differences in brain shape developed after birth," says Gunz. He and his team propose that this postnatal growth pattern, which he calls globularization, is unique to the brain development of modern humans and was the most recent feature to evolve.

But earlier analyses tell a different story. Marcia Ponce de León, a paleoanthropologist at the University of Zurich in Switzerland, says that biases in the reconstruction methods used by Gunz make unfamiliar structures, such as newborn Neanderthal skulls, more likely to resemble known ones, such as modern-human skulls. Using an alternative method, she and her team found differences between newborn Neanderthal and modern human skulls[4], and therefore suggest that the globular shape of the modern-human brain is already present at birth.

Ponce de León suggests that the postnatal changes described by Gunz as globularization occur in all great apes except chimpanzees.

This raises questions about the validity of the chimpanzee brain as a model, as well as which elements of brain development are unique to modern humans. "Many features of the human brain and its development have deep evolutionary roots and are shared with Neanderthals," says Ponce de León. "Humans are not as exceptional as they perceive themselves to be."

THE CROSS OF CHANGES

Regardless of when the differences develop, the distinct braincases of adult modern humans and Neanderthals offer a tool with which to tease out genes involved in brain development. By combining data on these anatomical differences with information from Neanderthal genetic fragments that are scattered throughout the genomes of people of non-African descent, researchers can find brain-related genes that changed after the two species diverged and therefore distinguish modern humans from Neanderthals. "Studying the effects of Neanderthal gene variants in modern people is a powerful model system," explains Chet Sherwood, an anthropologist working on evolutionary neuroscience at the George Washington University in Washington DC. "Our genetic background and overall biology resembles them more than other possible models."

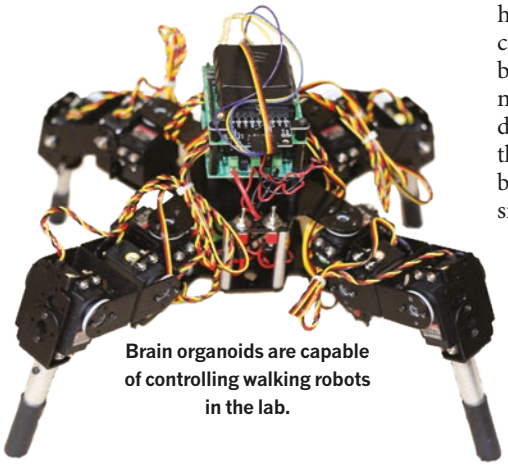
The trick is to identify Neanderthal gene fragments that correlate with a difference in anatomy, such as braincase shape. This reveals genes that influence the trait. Gunz started by studying magnetic resonance images of the brains of modern Europeans, which vary in their globularity. "It's a very subtle shift: nothing you would notice," he says. "There's nobody alive today that has a brain as elongated as a Neanderthal's." Next, Gunz created a score to quantify the globularity of each scanned brain. He then identified gene variants that differed with the score, which revealed brain-related genes that would probably have differed between Neanderthals and modern humans.

The technique led Gunz and his team to two genes in mice, one known to affect neurogenesis in the putamen and another that influences myelination in the cerebellum — both regions of the brain involved in movement. Neither gene had previously been linked to brain evolution. The differences between the modern human and Neanderthal versions of these genes are likely to alter their expression. Of course, these genes are just part of the picture — Gunz stresses that they probably play only a small part in brain development. "We're not trying to argue that these are the two genes that turn you into a modern human," he says. Researchers in the United States are also using the Neanderthal heritage of Europeans to investigate the modern-human brain. They tested whether the overall amount of Neanderthal DNA that a person carries is correlated to their skull shape[5], and found not only that it was, but also that it is correlated to the morphology of both the brain's visual cortex and the intraparietal sulcus — a brain region with roles in visual attention and motor coordination.

Gunz and his colleagues are working to replicate their findings in a larger data set from the UK Biobank repository, which might also enable them to identify other interesting genes. Long-term, the challenge is to discover the precise function of such genes and the effects of their Neanderthal variants. "This is the exciting start of a new research avenue, or probably several avenues heading off in multiple directions," Gunz says.

THE GHOST IN THE BRAIN

The genes that Gunz uncovered act too late in brain development to be studied in brain organoids, which recapitulate only the early stages. But, equipped with the gene-editing tool CRISPR–Cas9 and a copy of the Neanderthal genome, researchers are using brain organoids to study other genes that changed during the evolution of modern humans. The strategy is akin to intentionally substituting an ingredient in a recipe: the outcome of adding a Neanderthal variant of a gene to an otherwise modern-human recipe can teach us about the contribution of the original gene.



MUOTRI LAB/UC SAN DIEGO

Brain organoids are capable of controlling walking robots in the lab.

Muotri is using this approach to study a gene involved in RNA splicing that is strongly expressed by neurons and has been associated with neuropsychiatric conditions such as schizophrenia. He wants to understand the evolution of the 'social brain', which is thought to enable people to function in large societies. Comparing modern-human brains with those of a species that led a contrasting life could provide clues, and "there is plenty of evidence suggesting that Neanderthals might have had different life styles and social interactions," Muotri says. In the absence of living Neanderthals, his lab has used genome editing to create 'Neanderoids' — brain organoids containing Neanderthal versions of certain genes.

His team has uncovered intriguing differences, although so far have only presented them at conferences. Brain organoids are typically smooth spheres, but Neanderoids "have a popcorn shape", Muotri says. They have also noted changes in cell proliferation and migration, the formation of neural connections and downstream gene expression, as well as in RNA splicing. This reveals not only the pathways that are influenced by the edited gene, but also how the Neanderthal and modern-human versions differ in their effects.

Muotri is imbuing Neanderoids with other genes to further probe the evolutionary changes that set apart modern-human and Neanderthal brains, and similar work is being done elsewhere, such as in Svante Pääbo's lab at the Max Planck Institute for Evolutionary Anthropology, which sequenced the draft Neanderthal genome. Alex Pollen, a neurobiologist at the University of California, San Francisco, who works with chimpanzee brain organoids, supports such efforts. "We can now begin to ask these questions about human origins from a genetic and developmental perspective," he says, because these organoids offer a more faithful environment in which to test modern-human-specific genetic changes than do animal models.

Muotri says that his brain organoids and Neanderoids show a level of activity similar to that observed in the brains of developing humans. He thinks that it might be possible create devices that can provide feedback to the brain organoids that will help to refine their neural networks, similar to what happens during human neurodevelopment. To test the theory, his team is using electrodes to record the brain organoids' activity, and then sending the signal to small robots through a wireless link.

Already, the robots are able to walk in response to brain-organoid signalling. The team's next goal is to enable the brain organoids to receive input from the robots, which they aim to accomplish by the end of 2019. Muotri hopes the brain organoids will then be able to learn and adapt to their environment, "allowing us to test the impact of the Neanderthal variants on a physiologically relevant network". He thinks that his approach will eventually help to reveal crucial steps in the evolution of the modern-human brain, as well as some of the trade-offs required. "This strategy could not only illuminate how specific DNA alterations led to a highly sophisticated human social mind, but also shed light on the origins and causes of mental illness," he says.

From model brains to population-wide genomic analyses, researchers are taking advantage of clues from Neanderthals and their ancient crosses with anatomically modern humans. "To shed new light on the biological mechanisms underlying recent evolutionary changes to early brain development in our own lineage," Gunz says, "we turn to our closest extinct relatives, the Neanderthals." ■

Sedeer el-Showk *is a science writer based in Finland and Morocco.*

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NEWS

A broken healthcare system: the legacy of Syria's conflict

Published online 24 November 2014

Syrians and their neighbours are paying a hefty price for the collapse of Syria's healthcare system; with infectious diseases spreading and crossing borders, as a side effect to conflict.

Sedeer El-Showk

As Syria's three-year conflict continues, the country's healthcare crisis means that the risk of infectious diseases becoming an epidemic is at its highest, according to a study published in *PLOS Pathogens*.

The study[1] describes the crisis as "a public health emergency of global concern" – with vaccine-preventable diseases not only reappearing in Syria but being spread to other countries with the outpouring of refugees.

The militarisation of healthcare caused many to suspect the neutrality of health professionals
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Polio has re-emerged in Syria because vaccination rates have fallen dramatically due to the ongoing conflict. In neighbouring Iraq, also wracked by war, a polio case was confirmed in northern Baghdad this March, the first in 14 years. In response to these outbreaks, the WHO, UNICEF, and ministries of health in seven countries launched the largest vaccination campaign in the region's history, aiming to reach more than 25 million children. Despite the campaign's success, hundreds of thousands of children remain unvaccinated, and the spread of polio throughout the region and beyond is still a realistic possibility, according to the WHO.

In Lebanon, which hosts some of the largest refugee camps for Syrians, the incidence of measles has surged among Lebanese nationals due to deficiencies in the immunization programme.

Leishmaniasis, which has been endemic in regions of Syria for decades, is now also found in refugee populations in Lebanon and Jordan. According to the *PLOS Pathogens* study, its sand fly vector may have been transported into Lebanon along with the refugees, raising concerns that the disease might spread to the general population.

Path to recovery

"Recovery on a national level will need a tremendous international and political push, both for getting funding and resources and for allocating them intelligently," says Souha Kanj of the American University of Beirut, one of the authors of the study.

In the long term, the deterioration of the healthcare system presents a daunting prospect. "The longer a war takes, the more the institutions which you take for granted are destroyed or don't function properly anymore," says Egbert Sondorp, senior lecturer in conflict and health at the London School of Hygiene and Tropical Medicine.

"Lack of trust is another issue. Winning back trust is very hard." He compares it to the Balkan conflicts, where some hospitals favoured one ethnic group over another, leading people to lose faith in doctors and the medical system as a whole.

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According to a study in *The Lancet* this year, many hospitals in Syria give priority to treating fighters, reducing access to healthcare for civilians. The military and anti-government forces have also threatened and targeted doctors, forcing them to choose between helping patients or saving their own lives. Healthcare professionals have fled Syria and Iraq, leaving a vacuum of competent personnel in both countries.

As a result of the militarisation of healthcare, many citizens have lost confidence in the proficiency and neutrality of health professionals.

“If you have a good peace agreement and there's a legitimate government and some external resources coming in, then you can definitely repair, but it usually takes much longer than people think,” says Sondorp. “Don't expect magic solutions. It takes time to restore systems and to restore trust. You need to put in a prolonged effort if you want to assist.”

doi:10.1038/nmiddleeast.2014.271

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Nature Middle East EISSN: 2042-6046

In its search for a solution to the worsening water crisis, the Jordanian government is reaching out to women to help conserve water and change how it is used.

Fixing Water Shortages at Home

Writer: Sedeer el-Showk

Chronic water shortage

"All problems in the home, whether electricity, water, or other issues, are the woman's responsibility to deal with," says Reem Ahmed, a housewife and mother. "The woman is the pillar of the home and we want to know how to fix any problems that may arise."

Reem Ahmed is one of 26 women who signed up to the women's plumbing course in the Hakama district of Irbid, Jordan's second city. The students hope to find work and improve their family's life, but the organizers of the course have a more ambitious goal. Sponsored by he German Federal Ministry of Economic Cooperation and Development (BMZ), the class is part of a larger effort to address Jordan's chronic water shortage.

While many of its neighbors struggle with political instability or military conflict, Jordan finds itself facing an ongoing crisis of a different kind. A vast expanse of desert, the Hashemite Kingdom is among the poorest and least secure countries in the world in terms of water. According to the UN's Food and Agriculture Organization (FAO), each resident of Jordan gets an average of only 128 cubic meters of fresh water per year – roughly one-twentieth of the volume of an Olympic swimming pool. By comparison, the average European has access to nearly 9,000 cubic meters per year.

Faced with a chronic water shortage exacerbated by the influx of refugees from Palestine, Syria and Iraq, the Jordanian government has turned to international donors for aid. Governmental and non-governmental organizations fund

and support a variety of projects to help cope with the lack of water, from improving the supply network to training in water conservation practices. "We have reached the level where people can't reduce their consumption any further," says Adnan al-Zoubi, the spokesman of the Ministry of Water and Irrigation. "Our philosophy now is to teach them how to make do with the small amount of water they get each week."

With the help of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the German development agency, the ministry plans to communicate its message to the Jordanian people through eight 'multipliers' that are key sectors in society which can help spread the message. In addition to university students, religious leaders, farmers and journalists, the program, which is being implemented on behalf of the Federal Ministry of Economic Cooperation and Development, enlists women, a decision which may turn out to have consequences beyond merely changing habits of water use.

Teacher Iman al-Abadi helps a student on the women's plumbing course in Irbid as she practices using a pipe cutter. **Source:** Sedeer el-Showk.

Agents of change

Traditional family structures in Jordan put women at the heart of the household. Housewives are the end users and key decision-makers in domestic water issues. "Women are at the center of whatever issues there are regarding household water. Management, use, control – it's all done by women," says Ruby Assad, a GIZ consultant working on the project. They also raise and educate the next generation, making them a uniquely powerful motor for changing society's relationship with water.

In 2007, the ministry launched the Water Wise Women's initiative in an effort to involve women as agents of change in water issues. The goal was to train a network of

women in water awareness, water-saving techniques and improved hygiene. The women would then teach others, raising awareness and improving water use behavior in their communities. Since its inception, the network has grown to include nearly 200 women spread across Jordan, and continues to expand. "We need women to learn everything about water inside the home and to train other women, too," says al-Zoubi.

I feel younger. And self-confident – that's probably the biggest change. I'm really self-confident now. I feel like I'm contributing to society.

- Iman al-Abadi, teacher of the women's plumbing course

Trouble at home

Al-Zoubi also encourages housewives to reduce the amount of water lost to leakage – a major problem in this water-poor country. The Yarmouk Water Company, which supplies water to four governorates in the north of Jordan, claims that, on average, nearly half of the water it produces in Irbid is lost to leakage, although this includes leaks in the delivery infrastructure and households as well as illegal connections. According to Joumana al-Ayad of Miyahuna, another water company operating in the area of Greater Amman, at least 25% of customer billing complaints result from undetected water leaks in household plumbing.

In many cases, water leaks are not dealt with promptly. Conservative values prohibit women from interacting with men without a male family member present; since plumbers are traditionally men, housewives are forced to wait for a male relative to deal with the leak. During her work on the Water Wise Women's initiative, Assad estimated that 80% of the households she surveyed suffered sustained leaks because of this problem, leading to additional water losses. GIZ therefore approached Jordan's Vocational Training Corporation (VTC) to establish a plumbing training course for women, which would enable them to solve problems in their own home and to work as professional plumbers.

The proposal initially met with some misgivings; VTC was concerned that people might not accept the new idea and raised practical issues, such as male plumbers teaching female students. To allay these concerns, GIZ invited Brigitte Schlichting, a plumber from Berlin, to teach a pilot course. "Bit by bit, VTC got interested," says Assad, and eventually the project went ahead.

"We were surprised by how well people accepted the idea and by the demand for the course," says Ahmad al-Shatnawi, director of the VTC institute in Hakama, where the plumbing course is now taught. "We've had to refuse many women who wanted to join and put them on a waiting list in case the course is organized again."

Studying solutions

Alaa Abulheija did not know what to expect from the course after her father signed her up. "When I first came, I thought 'What am I doing here?'" she says. "But the teachers encouraged me, and I've enjoyed the course a lot. We do everything ourselves now. I go to the neighbor's house and fix their taps and repair their water leaks."

During the course, the women learn basic household plumbing, from fixing leaks to installing a sink. The classroom is divided into a lecture area and a workshop where the students can apply what they have learned. A cluttered tool bench

stands against one wall, and the workshop is dotted with toilets and sinks the students have mounted or are practicing on. "It's a hands-on course," says al-Shatnawi. "The students have to repeat the basics until they reach a point where they can work by themselves."

The students call out answers and ask questions. During the practical sessions, the women, all wearing a hijab or niqab, eagerly await their turn – in this case, to cut and ream a pipe. The room is filled with their discussions, punctuated by applause each time a student finishes a task. When the class breaks for coffee, several of the women want to tell "Miss Ruby" about their latest project, while others chat among themselves or review together over a short length of pipe.

The students are already applying the acquired skills during the first month. Abulheija has already repaired the plumbing in her family's home and fixed their neighbor's water leaks. The students also learn about water conservation, which Abulheija says has changed how she uses water in the house: "I'm doing things I didn't know how to do before. Now, I have strength and willpower, and I'm comfortable talking to people."

Reem Ahmed shares the feeling that the course has changed her life: "It's completely different now," she says. "The teachers showed us that it isn't wrong for a woman to take a risk and work in this profession." She tells stories about how she has used what she's learned and is eager to apply for support to start her own business, an opportunity announced at the end of the day's course. Asked whether she would like her daughters to take a similar course, she immediately replied, "Absolutely, there's nothing wrong with it!"

Pioneering progress

Two graduates from the pilot program teach the course with Schlichting. Tahani al-Shati remembers their unusual reception when they first started working as plumbers: "There were people who would ask us to come and fix things just because they wanted to know if we could really do it – and they would pay us!" Since then, people have grown accustomed to the idea of women plumbers, a change al-Shati is proud to have helped bring about.

Iman al-Abadi, the other teacher, is a confident woman with a soft voice. "Everyone prefers to work with women," she says. Rather than using her husband as an imperfect go-between with a male plumber, "the housewife can show us exactly where the problem is and tell us about it directly. She knows more about the problem because she's more involved." Both are founding members of the women's plumbing cooperative established last year to keep the women plumbers safe and to increase customer confidence. The cooperative is lobbying for VTC to arrange an advanced plumbing course for women. "The master plumber degree is more advanced and gives you more options," says al-Abadi. "I hope

Teachers Tahani al-Shati (left) and Iman al-Abadi (right) are both founding members of the women's plumbing cooperative that was established last year in Irbid. **Source:** Sedeer el-Showk.

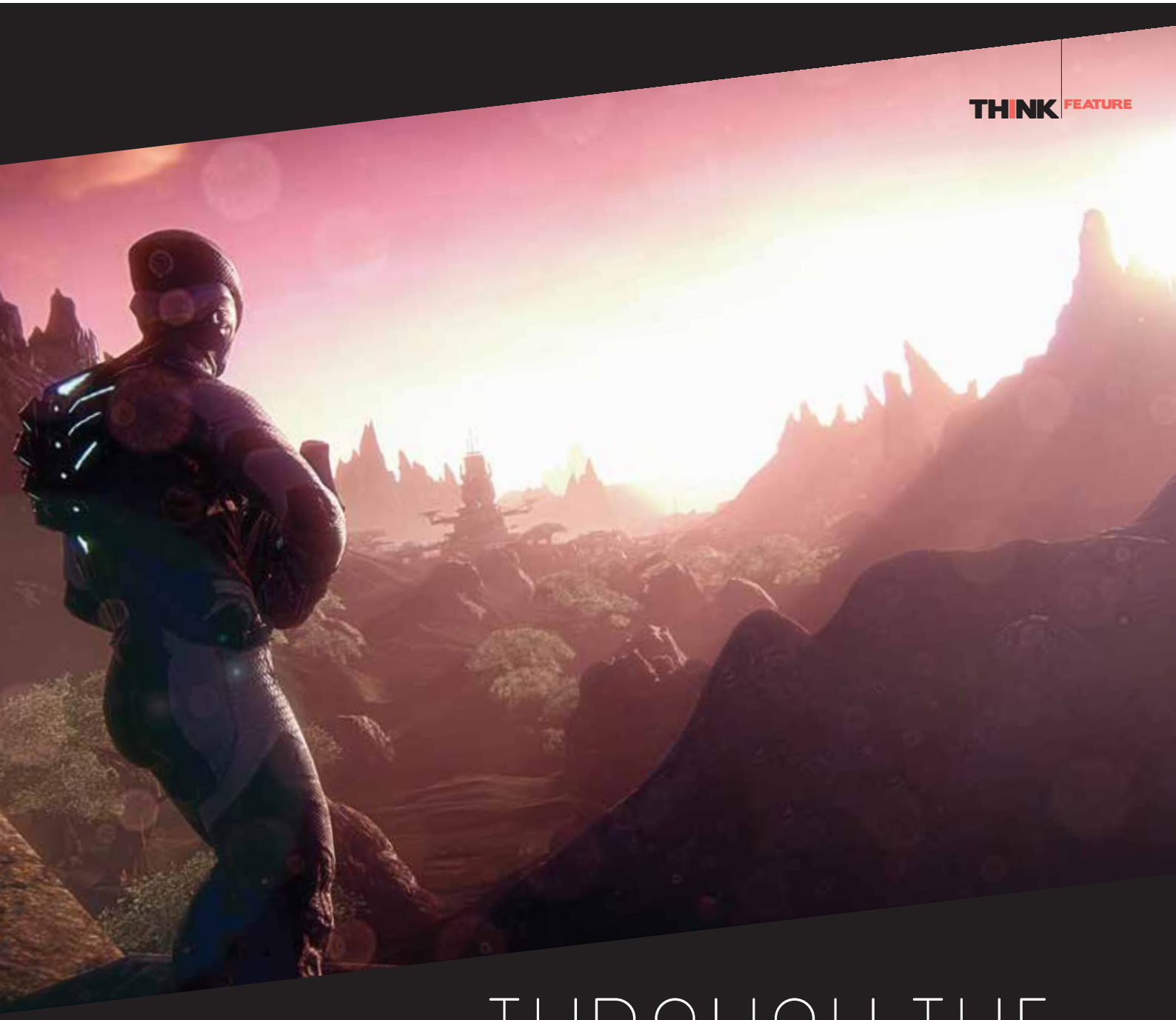
they'll consider our suggestion and arrange an advanced course in the coming months."

In the meantime, the cooperative is pursuing plans to buy equipment for cleaning water tanks – a project which will increase their income and benefit customers. "We want to buy three machines, one for Irbid, one for Kafrein and one for Amman," says al-Shati. "And we want to train these women [the students] to use it. We want them to benefit from it."

The women's plumbing course focuses on direct, tangible results, but its bottom-up approach may lead to broader, longer-lasting changes. By turning obstacles into opportunities, the program has created a space for these women to transform their community, their lives and themselves. "I feel younger," says al-Abadi. "And self-confident – that's probably the biggest change. I'm really self-confident now. I feel like I'm contributing to society."

We do everything ourselves now. I go to the neighbor's house and fix their taps and repair their water leaks.

– Alaa Abulheija, student



THROUGH THE LOOKING GLASS

What's your favourite game? *Pacman*? *Doom*? *World of Warcraft*? Most of us have spent hours immersed in video games, many still do. **Prof. Gordon Calleja** studies why and how we get so involved in games. Science writer **Sedeer El-Showk** found out about Calleja's latest book and game that are developing worldwide fame

Sedeer El-Showk

A screenshot from *Will Love Tear Us Apart*

Gordon Calleja has a dream job: he studies video games. It may sound like frivolous fun, but his work is serious research. He examines how people perceive the world around them and interact with it. His research blends aspects of philosophy, neuropsychology, and literary theory with futuristic concepts like cybernetics and post-humanism; his papers are peppered with references to Wittgenstein and Borges alongside quotes from avid gamers. In his book *In-Game: From Immersion to Incorporation*, published last year by MIT Press, Professor Calleja tackles the question of how we experience games – how the barrier created by the screen and the controls dissolves into a sense of really being there. 'Ultimately,' he says, 'studying presence in games is asking how we are conscious here in the physical world.'

A revolution in gaming

Professor Calleja didn't start out in game studies — a field which didn't even exist in his youth. As a student at the University of Malta (UoM), he studied literary theory and media communications before finding work as a teacher and auditor. Still, his involvement with games and game design dates back to his earliest years. 'My dad used to set me up with hex paper, some dice, and a bunch of figurines,' he recalls. 'It was his idea of babysitting.' The young Calleja grew up playing and designing games, and even won the New Zealand Blood Bowl (tabletop game) championship as a teenager. Despite this strong start, games became a smaller part of his life as an adult, giving way to work and other commitments.

Video games underwent a major transformation during Professor Calleja's hiatus. The proliferation of broadband led to the development and growth of Massively Multiplayer Online Games (MMOGs) like World of Warcraft and Second Life, persistent online virtual worlds populated by people from across the globe. Through their avatar, players of MMOGs interact with one another and with the virtual world, exploring, completing quests, and even getting married. 'I got a bit glassy-eyed with amazement at the realisation that there were other people actually connected to the same world,' said Professor Calleja, describing his first experience in an MMOG. He became fascinated with understanding how players relate to these game worlds. As he learned more about the subject, he realised that there were significant gaps in our understanding which he could address thanks to his background. He switched his Ph.D. to game studies, launching a research career that has led to him heading ITU Copenhagen's Center for Computer Game Research at the age of 31. Five years later, he became director of the Institute of Digital Games at the UoM.

Bringing in a new perspective

One of the problems Calleja faced was the description of how players become involved in a game's virtual world. Despite the question's importance, researchers had been using terms like 'presence' and 'immersion' without a precise definition, leading to confusion. Calleja described how the same terms were being used for two different experiences: a sense of absorption and of being present in another place. Language from older me-

"When intention and action flow seamlessly from each other in a rich virtual environment, the line between player and avatar fades away and the world of the game becomes real"

dia was being used to describe games, a new kind of medium. Unlike films or books, games offer a sense of agency by acknowledging the existence of the player in the virtual world and responding to their actions. While it's perfectly possible to be deeply absorbed by a book or film, only the agency and feedback loops afforded by games can deliver the sense of inhabiting another world.

Professor Calleja took a new approach to the question. Rather than getting bogged down in vague terminological issues of presence/immersion, he stepped back to analyse the experience of playing a game, breaking it down into six different aspects of involvement. The player involvement mode, which he developed in his doctoral thesis and wrote about in *In-Game*, was received extremely well by the research community. It provides a general framework for understanding how games can make players feel as though they've been transported to a different world, offering a solid foundation for future research in the field.

The model describes six aspects of involvement: mastery of the control system, an awareness of space, planning and achieving goals, following and creating a storyline, feeling emotions in response to the story and our actions, and sharing an experience and space with others. Unlike other media, games bring these aspects together to give us the sensation of inhabiting a different world. Each aspect can engage us on the micro-scale of moment-to-moment involvement while playing a game or on the macro-scale of involvement between sessions, when players might make plans, revise strategies, or reflect on their experiences. Calleja also points out that the six aspects aren't independent, but are experienced together and in relation to each other; he likens them to stacked transparencies.

According to Professor Calleja, when the different aspects of involvement act in concert, our attention slips away from them and we stop being conscious of the game itself. When intention and action flow seamlessly from each other in a rich virtual environment, the line between player and avatar fades away and the world of the game becomes real. Professor Calleja uses the word 'incorporation' as a metaphor for the twin dynamic at work: internalising the environment and controls of the game while becoming embodied (made corporal) within that environment.

The sense of embodiment and the reality of games is clear in the language players use to describe their experience. In his interviews Professor Calleja found that they consistently say 'I' instead of 'my character' and recount »

A screenshot from *PlanetSide*

A screenshot from *Will Love Tear Us Apart*

events as though they were real. 'I just stopped, and stared at it. I worked my way around it as much as I could to see if from all angles and ended up on a rise a little above it, just watching it. I don't remember the time of day, but it might have been [around] sunset and I swore, I could practically feel the breeze on my face and hear the wildlife.'

In many ways, we experience virtual worlds the same way we interact with this one: through our senses. 'How we're aware of physical reality and virtual worlds is not different at all,' said Professor Calleja. 'I don't see any difference between the real and the virtual whatsoever aside from the physicality and haptic feedback of one. Whether you can give the right feedback to the brain is [just] a technological question.'

A different kind of game

Having designed games and game systems ever since his father used to entertain him with dice and figurines, Professor Calleja finally decided to try his hand at making a video game. Unsurprisingly, his goal was something that hadn't been done before: making a game based on a song. *Will Love Tear Us Apart* is a free browser-based game (review pg. 57) based on Joy Division's cult hit *Love Will Tear Us Apart*; the game consists of three stages, one for each verse of the song. It's a unique game which takes advantage of our expectations in order to explore the challenges and emotions of a troubled relationship. I asked Professor Calleja about his goals in adapting the song. 'I wanted to design a game that was true to the essence of the song,' he said, 'not just to the story or the atmosphere.'

Will Love Tear Us Apart focuses on emotional responses at the expense of other aspects of involvement; it lacks the spatial involvement and other aspects that create a strong sense of incorporation in games like *World of Warcraft* or Planetside. Calleja's design breaks with one of the traditional goals of games; rather than trying to entertain players, *Will Love Tear Us Apart* aims to provoke a response from them. The resulting experience feels different from traditional games — it's more like an emotional journey than a game.

> "'Humans have always been story-tellers and created worlds, but now we can inhabit each other's imagined worlds and create things together"

'I wanted to turn it around and look at how games control us,' said Professor Calleja. Games are loaded with a range of implicit assumptions, from the effects of our actions to the idea of 'winning'; Calleja skillfuly subverts these in order to create emotional impact. 'It was very hard to get the difficulty just right; we had to tweak it a lot,' he said. 'You have to believe you could have succeeded in order to feel cheated. You have to feel like you had a chance. Hopefully the player will reflect about that experience afterwards.'

Can we expect to see more games from Professor Calleja? 'Definitely,' he replied instantly. Assuming there's enough funding, he'd like to explore the range of possibilities for games inspired by songs or poems, as well as a follow up on a few other ideas. Given his record to date, it will be exciting to see what the future brings.

Understanding a changing world

For the moment, Professor Calleja is turning his attention to understanding how players construct and relate to the narratives of games. Traditional media convey a designed, structured narrative to the reader or viewer, but games bring an additional layer to this as players create their own stories individually and together. 'All of a sudden you have elements of the theatrical as our actions become part of the narrative,' observed Calleja. Narrative theory, which has been based on an analysis of traditional media, will have to be updated to take these aspects into account.

Professor Calleja spoke eloquently about the importance of researching games and virtual worlds. 'Virtual worlds are here to stay,' he said. 'Humans have always been story-tellers and created worlds, but now we can inhabit each other's imagined worlds and create things together. I think it's important to critically examine this and understand how it happens, so we can better understand ourselves and our experiences.' As we march into a future where the virtual and physical overlap ever more heavily, the science of games may prove essential in understanding the world around us, a world we both inhabit and create.

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