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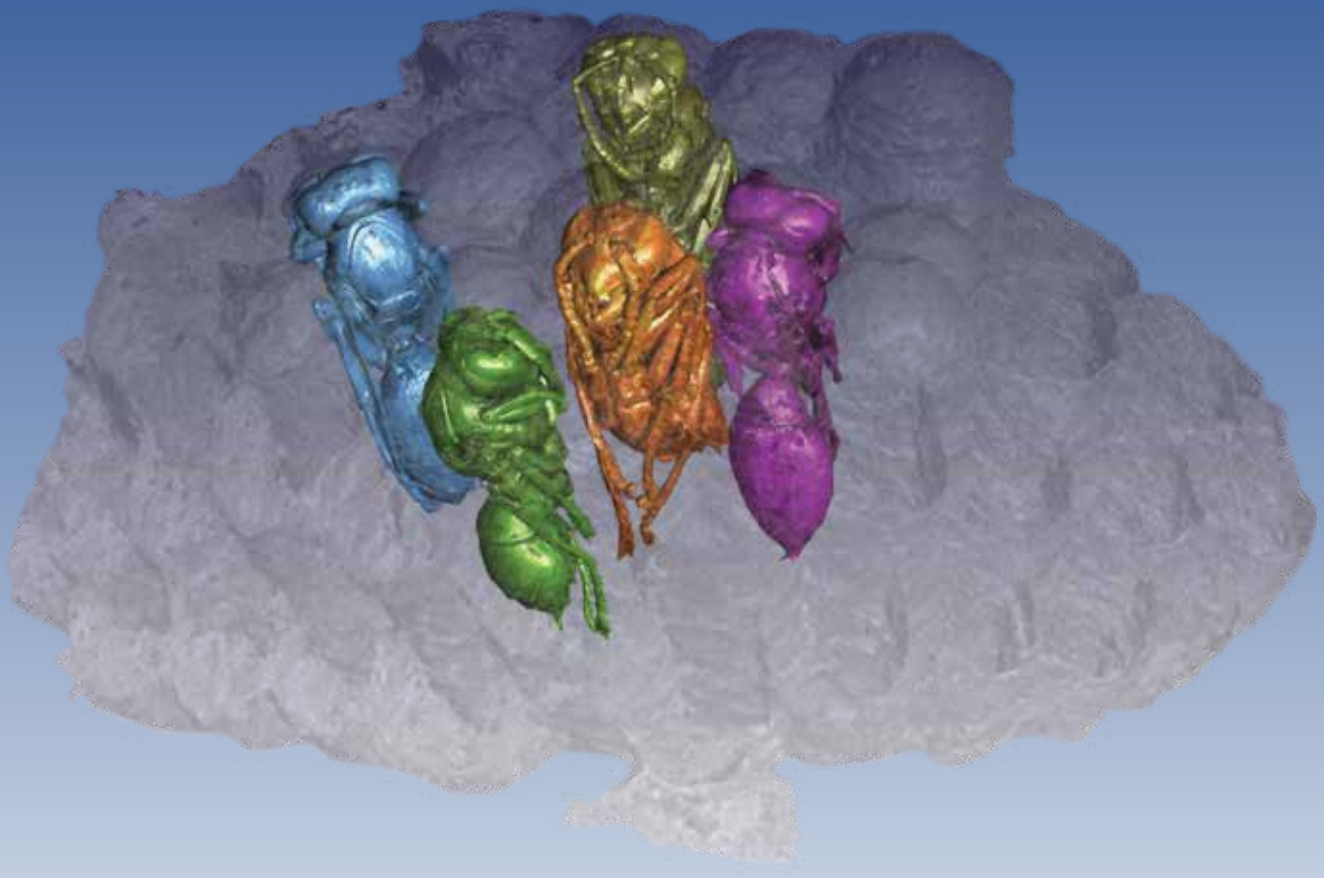
Micro-computed tomography

3D X-ray imaging



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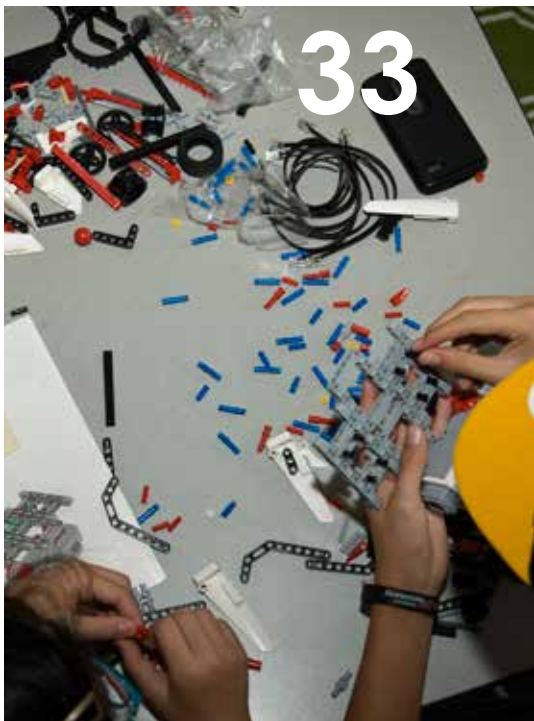

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The microCT – Nobel Laureates link

In 1979 Allan Cormack became the third South African to be awarded a Nobel Prize after Max Theiler, who received the Nobel Prize for Physiology or Medicine in 1951 for developing a yellow fever vaccine, and former ANC leader Albert Lutuli, who won the Nobel Peace Prize in 1960 for his non-violent resistance to the apartheid regime. Cormack was awarded the Physiology or Medicine prize jointly with Godfrey Hounsfield for the development of computer-assisted tomography (CAT), although they had come up with the idea quite separately in different parts of the world.

Cormack was a physicist who worked at the University of Cape Town before moving to the United States with his American wife in 1957 and taking up a professorship at Tufts University. Before leaving South Africa he had begun developing the theory behind CAT scans, and published this in the early 1960s in two scientific papers. He proposed that X-rays taken from different angles around a body or organ could be reconstructed into a three-dimensional representation by computer, but he never put the concept to the test, probably because the computers of the day were not up to the task.

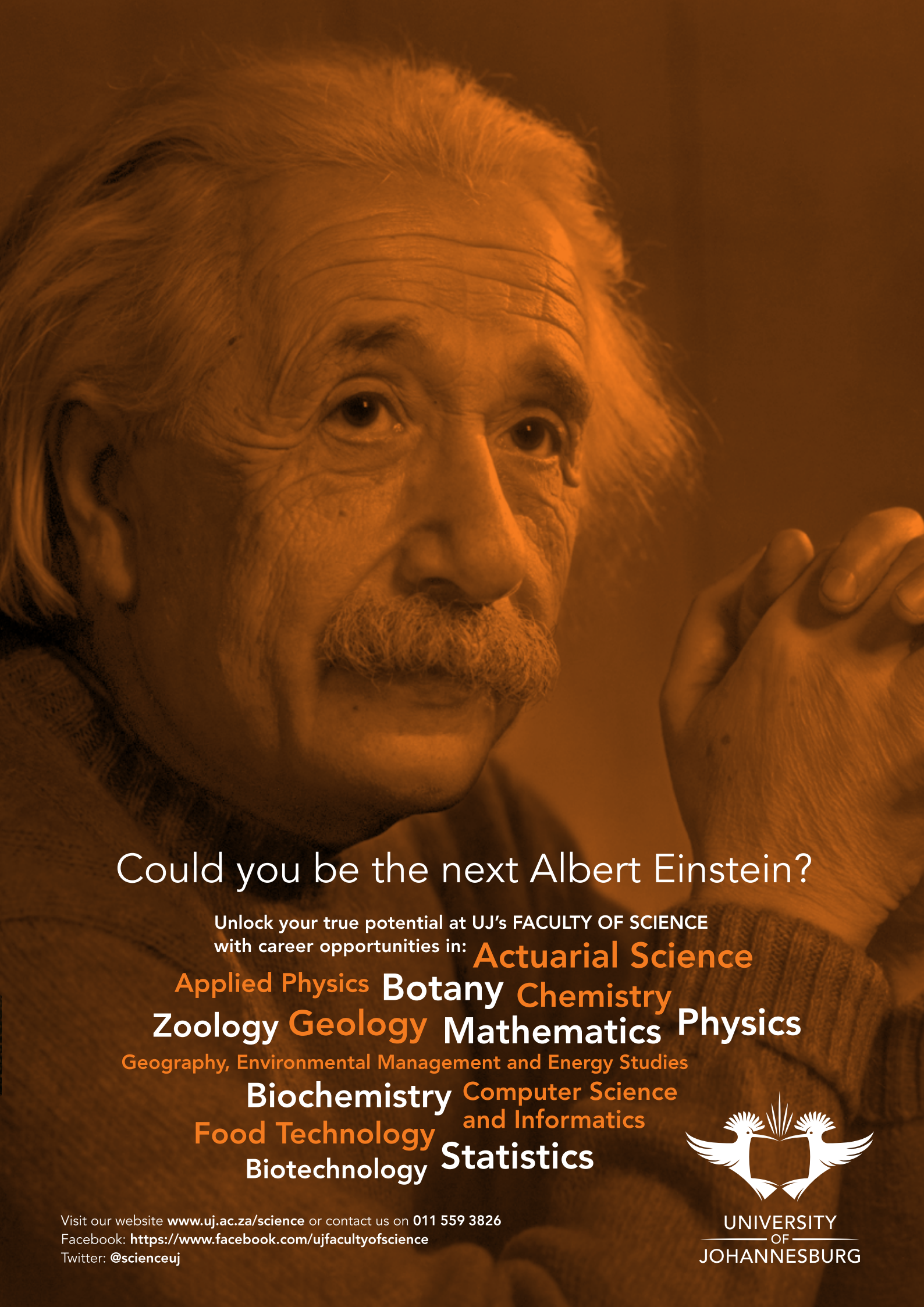
Hounsfield was an electrical engineer working at the Beatles' record label EMI (Electrical and Musical Instruments) in England. He was completely unaware of Cormack's work, but his experience with radar systems gave him the idea of reversing the process, and sending radiation beams into an object from all angles to obtain cross-sectional slices that could be reconstructed in 3D. He proposed X-rays as the form of radiation, and started working with a radiologist to develop a prototype machine. The 'EMI brain scanner' was installed in a hospital and used for its first patient – a woman with a brain tumour – on 1 October 1971. The process subsequently became known as computed tomography, computer-assisted tomography or computerised axial tomography, and 'CAT scans' soon became standard medical procedures.

Later, machines able to scan fine detail at massively increased resolution were developed for non-medical applications. The so-called micro-computed tomography is our theme for this issue of *Quest*, and we showcase a number of different applications of the technology.

Interestingly, the discovery of X-rays in 1895 by Wilhelm Röntgen was recognised with a Nobel Prize in 1901, the very first to be awarded for physics. This year's Lindau Nobel Laureate Meeting – a gathering of previous winners of the Nobel Prize and up to 600 young scientists selected from around the world – is dedicated to physics, and South Africa will be the 'host country' of the International Day. A larger than normal contingent of 20 young South Africans will be in attendance, and we trust they will benefit from the experience as much as the two Lindau alumni profiled elsewhere in this issue.

Sue Matthews
QUEST Editor

Our cover image, courtesy of Prof. Anton du Plessis of Stellenbosch University's CT Scanner Facility, shows five paper wasps in their hive. The artificial colour of the wasps, which had been dead for some months, was digitally applied to the image for visual appeal. More images and a 3D video can be viewed at: http://blogs.sun.ac.za/ctscanner/3d-imaging-of-a-wasp-hive/



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MicroCT

Our theme for this issue of Quest is micro-computed tomography, known as microCT or just µCT

What is microCT?

MicroCT is a 3D imaging technique utilising X-rays to see inside an object, slice by slice. MicroCT, also called microtomography or micro-computed tomography, is similar to hospital CT or 'CAT' scan imaging but on a small scale with greatly increased resolution. Samples can be imaged with pixel sizes as small as 100 nanometres and objects can be scanned as large as 200 millimetres in diameter.

MicroCT scanners capture a series of 2D planar X-ray images and reconstruct the data into 2D cross-sectional slices. These slices can be further processed into 3D models and even printed as 3D physical objects for analysis. With 2D X-ray systems you can see through an object, but with the power of 3D microCT systems you can see inside the object and reveal its internal features. It provides volumetric information about the microstructure, non-destructively.

How does a microCT scanner work?

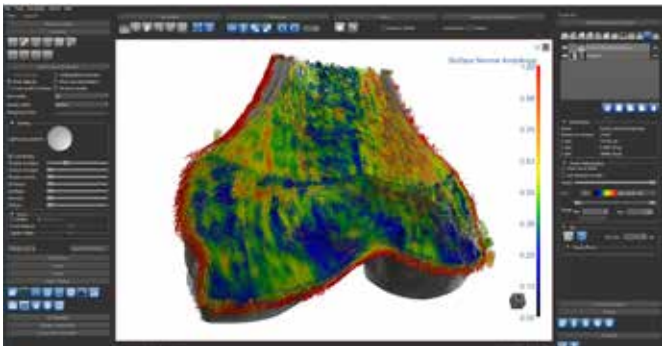
X-rays are generated in an X-ray source, transmitted through the sample, and recorded by the X-ray detector as a 2D projection image. The sample is then rotated a fraction of a degree on the rotational stage, and another X-ray projection image is taken. This step is repeated through a 180° turn (or sometimes 360°, depending on sample type). The series of X-ray projection images is then computed into cross-sectional images through the computational process called 'reconstruction'. These slices can be analysed, further processed into 3D models, made into movies, printed into 3D physical objects, etc.

What does non-destructive testing mean?

Non-destructive testing means that the sample or specimen being scanned isn't altered or destroyed during testing, or in the preparation for testing. This allows the sample to be preserved for historical record, tested again at a later date, used in another test or put into final production. Some other techniques require staining, cutting or coating of samples, which can affect the sample's structure, its ongoing usefulness, or its use in later studies. There are several techniques that allow samples to be imaged in their native states, including light microscopy, laser scanning, visible and other spectrum photography. MicroCT is one such technique where most of the samples studied are scanned in an unaltered state.

Indaba yethu kulesisqephu igxile kwi computer encane yokuthatha ezithombe emzimbeni, ibuye yaziwe ngokuthi I microCT noma µCT. Lona ngumshini okwazi ukukhipha izithombe zamathambo noma izicubu zomzimba, usebenzisa imisebe evela macala onke ento ayishuthayo ukuze kuphume izithombe ezi two-dimensional (2D), bese zihlanganiswa ukukhanda I three-dimensional (3D).

Translation by Zamantimande Kunene



Following microCT scanning, the image data can be processed for detailed analysis. *© Dragonfly ORS, Wikimedia*

What are the advantages of microCT scanning?

MicroCT provides high-resolution 3D imaging information that can't be obtained by any other non-destructive technology. It can be used to study the interior structure of both material and biological samples without having to cut the samples, preserving the samples or specimens for future studies. The quantitative information obtained from microCT scanning can only be obtained from 3D images, and 3D digital models created from microCT virtual slices allow scientists to measure any parameters for comparison in before-and-after studies.

These unique features of microCT scanning allow scientists to look at the morphology of a sample and study features such as porosity, structure / bone thickness, volume fraction, defect analysis, density, particle size, voids and fibre orientation. Researchers use microCT to study bone, teeth, tissue / organs, composite materials, medical devices, batteries, etc.

What is the difference between medical CT and microCT scans?

MicroCT scanning is X-ray imaging in 3D, using the same method as medical CT (or 'CAT') scans, but microCT is on a much smaller scale with greatly increased resolution. Scans from medical CT – introduced as a tool for medical imaging in the 1970s – are limited to a resolution of one millimetre, which provides sufficient detail for clinical use. For materials science and small animal imaging, much higher resolution was needed, so microCT scanning was introduced in the 1980s. MicroCT scanners can work at the level of one micrometre (or micron), which is a thousandth of a millimetre, and smaller.

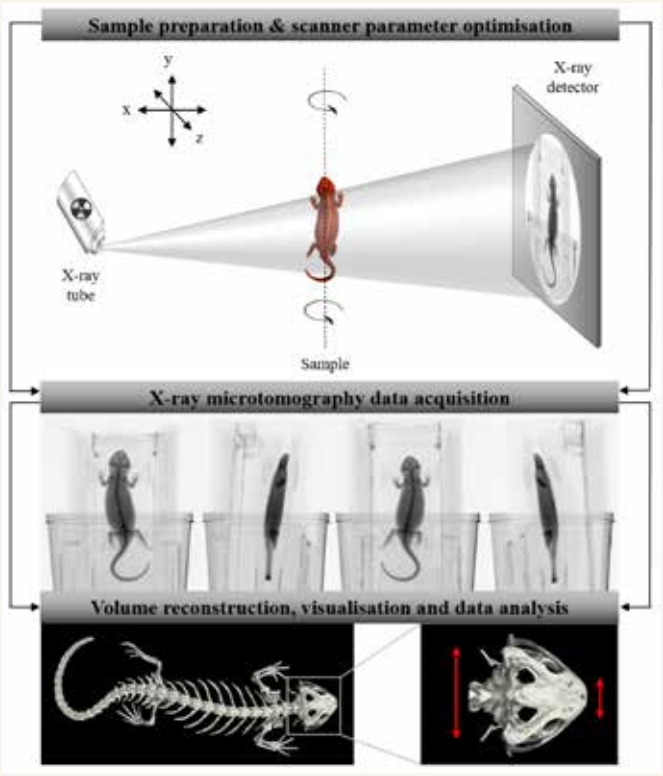
What is the difference between *in vivo* and *ex vivo* microCT scanning?

Simply put, *in vivo* (Latin for *within life*) is the scanning of live specimens and *ex vivo* (Latin for *out of living*) typically refers to things that used to be alive or samples excised from something that had been alive. For microCT, *in vivo* typically refers to systems that scan mice and rats and in some cases rabbits, while *ex vivo* systems typically handle the remainder of the applications.

With *in vivo* microCT instruments, since the animal remains alive, longitudinal studies can be performed to measure the effects of drug, diet, hormonal and other treatments on tumours; bone growth and quality; body mass and other applications on the same subject. This can reduce the number of animals needed for a study.

Ex vivo microCT instruments typically handle the remaining applications, which include end-point studies of specific regions of an animal that get excised (lungs, bone, tumours, implants, grafts, etc.), biomaterial studies, implants in large animals, materials studies, compression studies, and more. *Ex vivo* microCT instruments allow for higher spatial resolution, longer scan times (since dose to the sample isn't of concern), better signal to noise ratios, and therefore better images. *Ex vivo* systems have typically been used for most applications outside of a living animal.

The word tomography is derived from the Greek word 'tomos', meaning slice or section, and 'graphe' meaning drawing.



https://doi.org/10.1163/15685381-20181102

Above: Schematic of the microCT scanning and data-processing technique. *© Broekhoven and Du Plessis*

Below: This live armadillo lizard entered defensive mode, with typical tail-biting behaviour, prior to the cooling stage and maintained this 'pose' throughout the scanning period. The 3D-rendered image shows the arrangement of the bony plates, called osteoderms, embedded in the skin after digitally removing the scales. *© Broekhoven and Du Plessis*

https://doi.org/10.1111/2041-210X.12661

Close Encounters of the **3D** Kind

Live animals usually need to be anaesthetised, either via injection or inhalation, prior to microCT scanning to ensure they keep perfectly still during the process, because any movement would result in blurry images. Chris Broeckhoven and co-researchers at Stellenbosch University recently described a protocol to immobilise and restrain live reptiles and amphibians without administering anaesthetic. These 'cold blooded' animals – more correctly known as ectotherms – cannot produce internal heat to maintain their body temperature, so if they become cold they quickly enter a state of torpor (chill coma).

The researchers used live lizards as their example to explain the protocol. Each lizard was restrained between two taped-together Styrofoam blocks, and then placed in a holder with crushed ice in a way that ensured no part of the animal came into contact with ice or meltwater. This cooled the specimen to a chilly 8°C before scanning began. Experiments were conducted with various scan settings to determine the effect on radiation dose rate, image quality and scan time. Apart from some blurriness in images of the sides of the thorax due to the lizards' breathing, the results were comparable with microCT scans of dead lizards. After the scanning procedure, which took up to 16 minutes per individual, the lizards were monitored for a month in the laboratory, but no ill effects of the irradiation were apparent. The lizards were then released back into their natural habitat, and monitored for another three months using remote camera traps. Most of the lizards were recovered at the end of this period, and the researchers felt it likely that all the lizards were still alive at that point. But what an experience they had had – rather like the classic alien-abduction movie *Close Encounters of the Third Kind!*

Digital avatars new in taxonomers' toolkit

Helen Swingler explains how microCT can be used in taxonomy – the science of naming, describing and classifying organisms

Digital avatars – specimens captured via X-ray 3D micro-computed tomography (microCT) scanning technology – give taxonomers a new tool to 'dissect' and study rare or delicate specimens on their computer screens, without (or in addition to) museum or natural history collections and artists' replicas.

Marine taxonomer Dr Jannes Landschoff says although the tool will never fully replace physical specimens, it does allow scientists to download interactive, printable scans – or digital avatars – for 3D examination of specimens.

This is an important development for the description of new species, and will aid scientific collaboration as researchers can examine the digital sample of the same specimen at different places and times. Actual specimens, many rare and valuable, are difficult to ship around and can be examined by only one person at a time.

Marine biologists at the University of Cape Town and Stellenbosch University used this technology to scan seven hermit crab species. These include one undescribed species as well as two scans of rare species, one from a deep-sea habitat more than 500 metres below the surface. Three are species that are new to science and are described in Landschoff's PhD thesis.

A niche market

Landschoff is the lead author of a paper on the technology, featured in *GigaScience*, titled 'A micro X-ray computed tomography dataset of South African hermit crabs (Crustacea: Decapoda: Anomura: Paguroidea)'. His co-authors are his supervisor in the Department of Biological Sciences, Emeritus Professor Charles Griffiths, and Associate Professor Anton du Plessis of Stellenbosch University.

These specimens are held at the Iziko Museum in Cape Town and at the Smithsonian National Museum of Natural History in Washington, DC. But scientists, or even amateurs, who're also interested in having a look can now do so online. The 3D scans and 3D printer files are available from the GigaDB repository.

Until now, scientists have relied heavily on meticulously drawn illustrations of specimens and their sections. But this is not ideal, says Landschoff.

"Taxonomic biodiversity research is a niche market and a difficult field, and the new technology is important as there are several limitations to hand-drawing specimens, especially complex specimens such as hermit crabs."

"A great artist will produce marvellous illustrations. The main limitation, however, is the artist's skill and the time it takes to produce complicated drawings. When I draw complex structures, for example, of the crab's pincers, a single illustration can take me a week."

Hand-drawn illustrations are also subjective, he adds.

"On the one hand this is a good thing because the artist can highlight certain characteristics they think are

A 3D microCT image, or 'digital avatar' (left), of the hermit crab *Paragiopagurus atkinsonae* (right). The radiating patterns on the shell are colonial sea anemones, called zoanthids, living on the crab in a symbiotic relationship. Sand and organic material adheres to their mucous coat, building up to form a soft shell around the crab. In other families of hermit crabs, the shell of a dead sea snail is used as the crab's 'home'.

The male hermit crab, here shown without its soft 'shell' covering, has one enlarged pincer, or cheliped. It is not known whether this is used to fight off competing males during courtship, grasp the female for mating, or simply attract females that may be impressed by large pincers!

important. On the other hand, this might over-emphasise some things. So, it can result in mistakes. There is also the issue of reproducibility. Each scientific experiment should be reproducible."

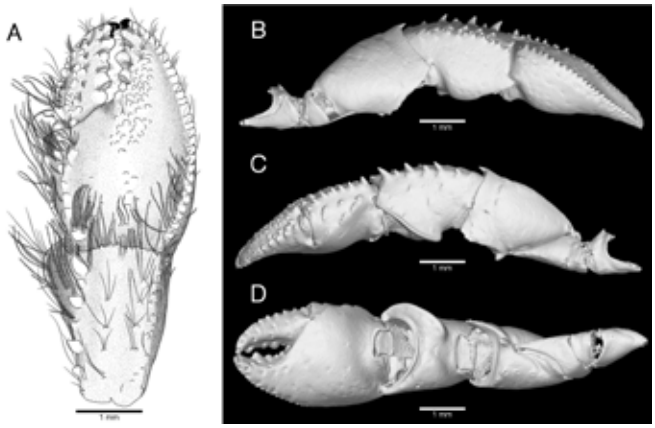
Machine-derived images are less vulnerable to bias.

Computing power

In an interview for the *GigaScience* blog, Landschoff says that the power and magnification of X-ray microCT also gives a precise picture of surface textures, which are often missing in photographs or manual drawings.

Ironically, hermit crabs are among the most challenging model organisms within Decapoda to use CT scanning on. Many are small, and half of their body – the pleon, which is encased by the scavenged sea shell it lives in – is soft.

"The pleon has many fine-scaled, soft tissue identification characteristics," he adds. "Because CT scanning is based on X-ray detection, these soft structures are difficult to detect. If hermit crabs can be scanned, other groups like Brachyura [normal crabs], which are entirely calcified, would be very visible for scanning."



Hand-drawing a hermit crab's claw could take as long as a week, while microCT scanning from all angles can be done in an hour or two, although the subsequent data processing and analysis is very time-consuming.

The new technology does need a lot of computing power and special software, which can make it expensive. While the scanning process is relatively quick and easy, the analysis of the 3D data is time-consuming, as is working on the scan data on the computer, cleaning unwanted scanning artefacts, cutting the specimens open virtually, and so on.

As Landschoff says, drawing is cheap and doesn't come with these challenges.

"I require only a pencil, eraser and paper."

A crab in hand

On the other hand, the CT images are very powerful, which makes this a useful tool for education and training. The scans provide a powerful connection to the real thing.

"When I can show a high-resolution rotation movie to an audience instead of a picture of a colourless specimen in a jar of alcohol, that's a huge advantage in making taxonomy more interesting in general," Landschoff explains. "I still believe that having a living specimen at hand is the most fascinating thing for students of biology."

With over 1 100 species and 120 genera of hermit crabs described to date, and with very many species undescribed on museum and laboratory shelves, this digital advance should broaden options and possibilities for greater coverage of specimens.

Helen Swingler is a senior writer at the University of Cape Town. Article republished from UCT News.

All images courtesy of Jannes Landschoff.
A short animation entitled '3D video microCT scans of new and rare hermit crab species' is available on the GigaScience Journal's YouTube channel.

Looking inside a brooding brittle star

Jannes Landschoff tells us how he used microCT to research reproduction of a marine invertebrate

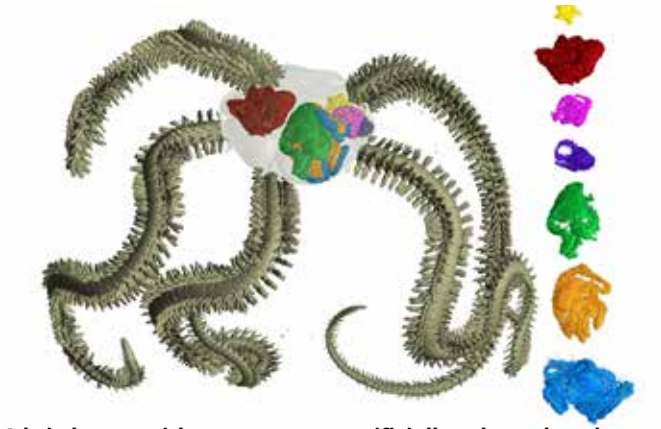
Brittle stars are echinoderms in the class Ophiuroidea. They consist of a central disc and five long, thin arms that can break quite easily – hence the name! Although not as well known as their cousins the starfishes (class Asteroidea), brittle stars are widespread in the marine environment, occurring from very shallow waters down to the deepest depths of the ocean. More than 2 200 species are recognised in the world, of which about 140 occur in South Africa.

Normally, brittle stars release their eggs and sperm into the water, where they are externally fertilised and then develop as tiny larvae in the plankton. This method is called broadcast spawning. However, about 5% of all brittle star species actively brood their young in specialised pouches called 'bursae'. This behaviour has long fascinated biologists. It is remarkable that an animal without a centralised brain, and with one opening to the stomach that serves both as the mouth and the anus, is capable of such a complex reproductive behaviour, similar to that of humans.

The young brittle stars stay inside the mother for an extended period, potentially up to a year. During this time they need to be nurtured and fed by the mother. Previously it was not entirely clear how the young brittle stars lie within the mother's bursae – to see them inside, biologists would have to cut the specimen open. This would destroy the brood pouch, changing the position and orientation of the young in the process.

MicroCT scanning has helped to visualise the internal brooding of brittle stars, as this non-invasive technique can produce *in situ* images of the young in their natural position. There are usually 10 brood pouches in a brooding brittle star. The serpent-skinned brittle star *Ophioderma wahlbergii,* which is common in the coastal waters of Cape Town, was found to brood up to 33 young at a time, and different developmental stages could be seen in different brood pouches.

It was also previously hypothesised that the young are fed by the mother secreting nutrients through the bursal body wall. This would mean that these animals are 'truly viviparous', giving birth to live young that were nourished and developed inside the parent's body. Some research suggests that bacterial activity at the surface of this body wall helps the young gain sufficient food. The young would therefore be expected to press their mouths against that surface, but this could never be verified.

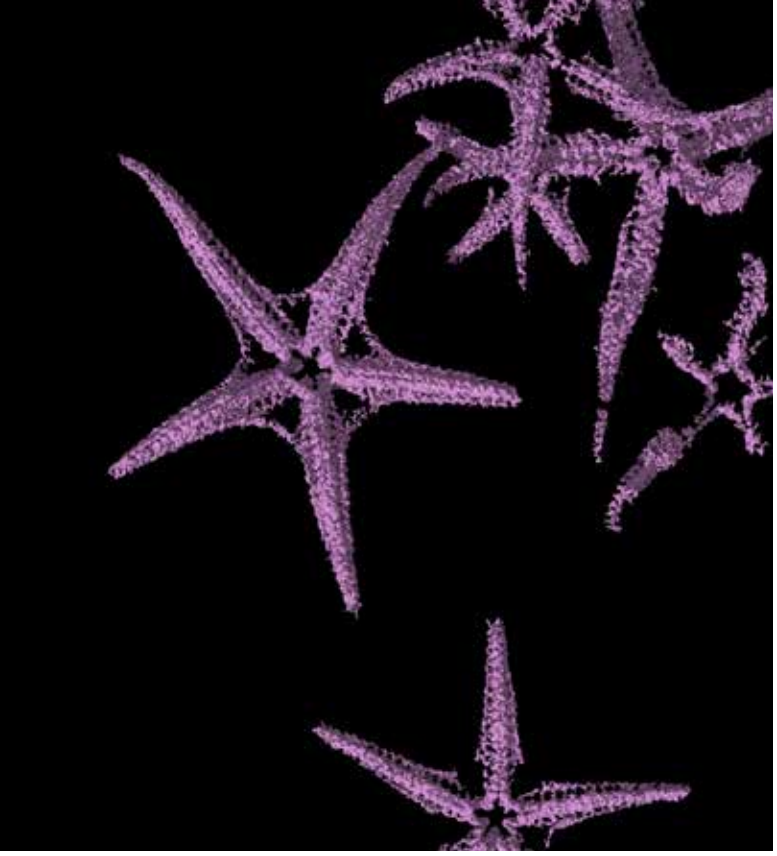


A brittle star with seven young, artificially coloured to show their size and position. © *Jannes Landschoff*

MicroCT scans have now shown that most young would indeed be positioned with their mouth against the wall, but not all. Especially when they occur with other siblings in the same brood pouch, they are often stacked on top of each other. The siblings inside may well fight for the best positions and compete for the available food sources. What remains unknown is how much the young actually move around inside. Perhaps by scanning living organisms, microCT imaging could help to solve this mystery in the future.

A two-minute video animation of microCT images of a brooding brittle star is available on YouTube. Search for Brittle Star [2014].

Young brittle stars poke their arms through their mother's bursal slits, getting a taste of the underwater world that awaits them. © *Jannes Landschoff*



Brittle stars in the Bokkeveld

The next time you travel along the N1 national road from Johannesburg to Cape Town, look around at the arid landscape before you descend the pass into the Hex River Valley. Consider the fact that you are 125 km from the nearest coastline, and some 950 m above present-day sea level – and then picture the marine brittle stars that were found here, as ancient fossils!

In the Devonian Period some 400 million years ago, when the land that is now the African continent was part of the giant supercontinent Gondwana, the southern Cape was underwater, part of a basin covered by the Agulhas Sea. It was during this time that the fine-grained sediments of the Bokkeveld Group were deposited on the seafloor, which was home to a thriving community of bottom-dwelling invertebrates.

The Bokkeveld Group was laid down on top of the Table Mountain Group, and was subsequently overlain by the Witteberg Group. These three groups make up the Cape Supergroup, which was later buckled and thrust up by tectonic activity to form the Cape Fold Belt mountains. The Bokkeveld is known to be rich in fossils, as the marine organisms of the time were better preserved in the fine sediments that ultimately hardened to mudstone and shale, compared to the coarser sandstones of the other two groups. Two of the oldest Bokkeveld layers, the Voorstehoek and deeper Gydo formations, have particularly well-preserved 'shelly' fossils such as trilobites (now extinct), brachiopods (lamp shells), bivalves (mussels and clams), gastropods (sea snails) and even echinoderms (including starfish, feather stars and brittle stars).

With this in mind, Mhairi Reid – then a BSc Honours student in the University of Cape Town's geology department – went on a fossil-finding road trip in 2014 with Honorary Research Associate Dr Wendy Taylor, an expert on echinoderm fossils. Mhairi was searching for a suitable subject for her Honours project, which she specifically wanted to do on fossils.

"We went out for a week, driving around and looking at outcrops, and we stumbled across it by pure chance," says Mhairi.

What they discovered, at a road-cutting next to the N1, was an entire bed of fossil brittle stars – or ophiuroids. The bed was lying about 120 cm below the surface of the 2 m high rocky embankment, which had a sedimentary profile representative of the Voorstehoek formation.

"It's quite rare to find echinoderms, just because they're so delicate," says Mhairi. "They need exceptional events to be preserved."

These events, known as obrution events, involve rapid burial or smothering by an underwater 'landslide' or a storm-induced current that sweeps sediment down a slope. Sedentary bottom-dwelling (benthic) invertebrates that cannot move fast enough to escape are particularly prone to being entombed in this way. Over time their soft tissues and eventually their calcareous shells – or ossicles in the case of echinoderms – dissolve away, but by then

The presence of the brittle star bed was given away by orange, star-shaped patterns on the surface of the rock, caused by oxidation of iron in the mould fossils.

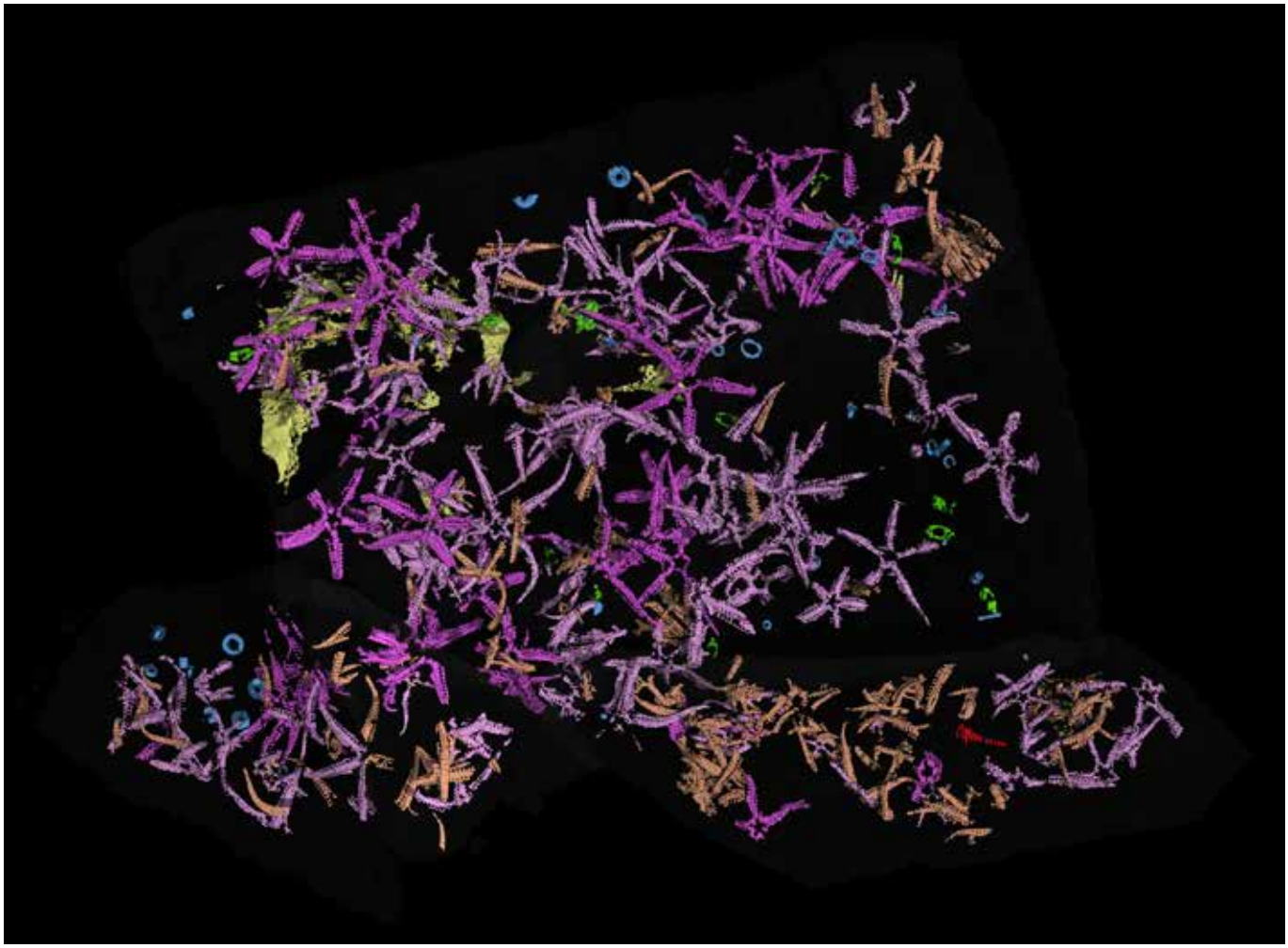
their bodies have left impressions in the rock. The fossil brittle stars were examples of these mould fossils, rather than a mummified version of the animal itself.

Initially, for Mhairi's Honours project, some rock samples containing the fossils were collected, but for her MSc project an entire section – about 2 m long, 1 m wide and 4 cm thick – was excavated using a pickaxe, flat brick chisel and geological hammer. The weathered nature of the rock meant that it was impossible to remove the section as a single slab though. It broke up into 55 pieces, which were carefully labelled and then put back together again in the laboratory to be photographed.

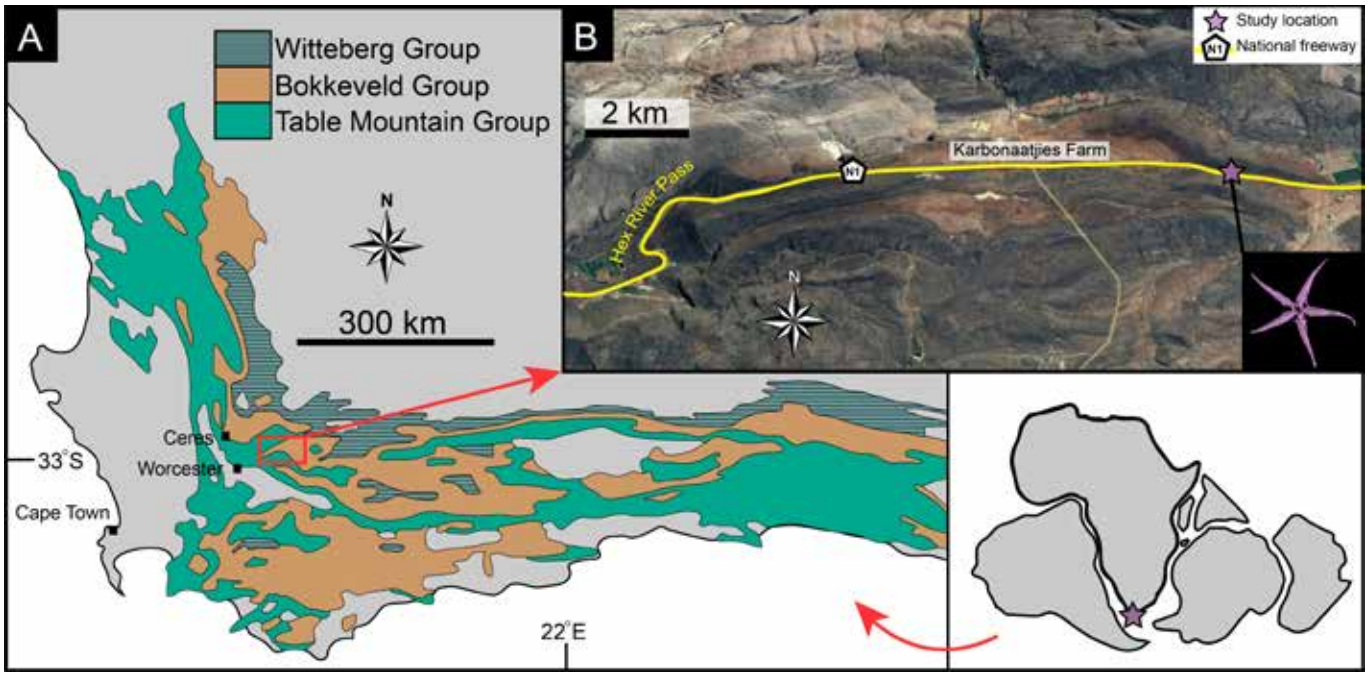
While photos were fine for capturing the fossils on the surface of the rock pieces, they were hopelessly inadequate for showing what lay inside, so the pieces were taken to Stellenbosch University's microCT facility for scanning. This allowed the internal contents of the rocks to be 'exposed' as cross-sectional images from all angles, without any risk of damaging the fossils. All the images were then digitally stitched together to create a virtual 3D model, which revealed that there were more than 700 brittle stars in the excavated section, along with trilobites, brachiopods, bivalves, gastropods and other echinoderms. The microCT images essentially represented a snapshot of a benthic marine community that lived together 400 million years ago.

What was even more special about the Karbonaatjies obrution bed, named after the local farm, is that more than half of the brittle star fossils were 'intact' – in other words, all five arms remained joined to the central disk. Brittle stars have arms that easily detach, which is an adaptation to escape predators. When grabbed by an arm, they can simply shed it and grow a new one later, but they also tend to fall apart quickly after death, as the soft tissue and ligaments attaching the arms to the disc soon decay. The number of intact specimens lend proof to the theory that the animals were buried alive.

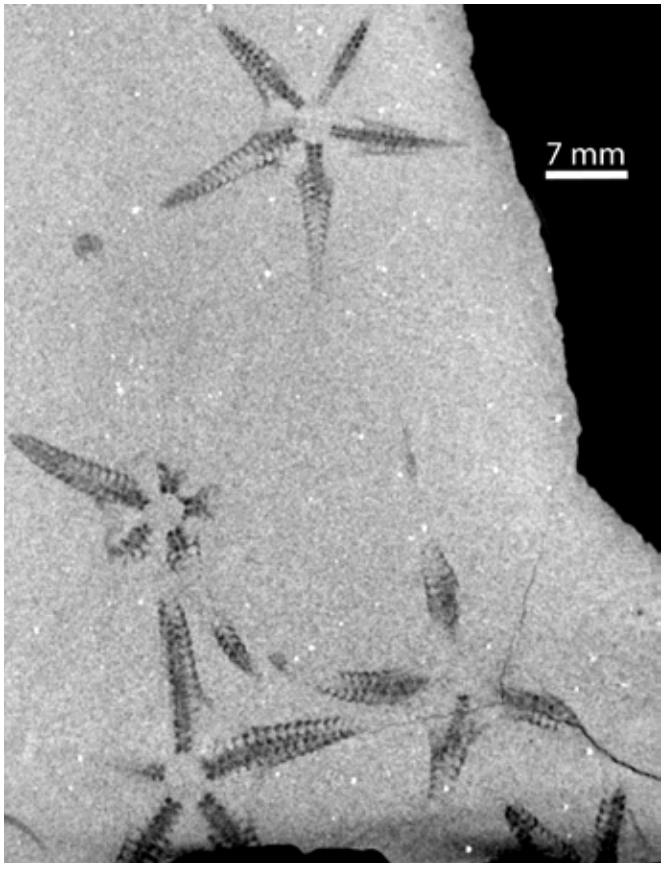
Mhairi also counted more than 600 detached arms in the microCT scans, and noted that many of the brittle stars were lying upside down. Since there are a number of records of mass amputation in modern-day brittle stars after storms and hurricanes, she interprets her observations as being consistent with a strong, storm-induced current that tumbled the ancient brittle stars over as they were covered in sediment. Some even had one or more arms raised, which is exactly the posture modern brittle stars adopt when crawling up out of a thin layer of sediment, but the ancient brittle stars were clearly buried too fast and too deep to escape. Their muddy grave was beyond the reach of scavenging or burrowing animals, which would either have eaten their remains or facilitated aerobic decomposition through bioturbation.



A virtual reconstruction of a portion of the fossil bed showing about 80 complete brittle stars (light pink = right side up, dark pink = upside down), as well as fragmented arms (pale orange) and parts of other animals.



A simplified geological map of the Cape Supergroup showing the fossil bed's location beside the N1 national road, near the Hex River Pass. The small inset depicts Africa's position within Gondwana.



A 2D microCT scan representing a cross-section of rock with brittle star fossils.

The fossil brittle stars were recognised as members of the Family Protasteridae, but were a genus and species new to science – although long extinct and only distantly related to modern-day brittle stars. Mhairi has recently co-authored a paper with British fossil echinoderm expert Dr Aaron Hunter, Dr Taylor and her MSc supervisor Dr Emese Bordy, formally describing the new species. She named it *Gamiroaster tempestatis*.

"For the genus name, it had to end in *'aster'* [Greek for star], but I wanted to name it something African, so I went with *'Gamiro'*, which is the Khoikhoi word for a star in the sky – although I had to take out the click syllable!" explains Mhairi. "The species name, *'tempestatis'*, refers to the storm that smothered the animals."

The fossil-bearing rocks have now been curated in the Iziko South African Museum, and it is hoped that the 3D microCT images will form part of a future display.

- Fossils are protected by the National Heritage Resources Act (*No. 25 of 1999*) and may not be destroyed, damaged, altered, excavated or removed from their original site, without a permit from the relevant heritage resources authority. The necessary permits were obtained in order to conduct this research.

Article by Sue Matthews, images courtesy of Mhairi Reid.
For more detail, and access to the 3D model of the fossil bed, refer to the open-access paper: Reid et al. (2019) in GigaScience, Vol. 8 (3). https://doi.org/10.1093/gigascience/giy156
A short animation entitled 'A 3D visualisation of a microCT dataset of fossil starfish in an ancient sea bed' is available on the GigaScience Journal's YouTube channel.

CURRICULUM CORNER

LIFE SCIENCES GRADE 10
Support systems in animals; Biodiversity and classification; History of life on Earth

GEOGRAPHY GRADE 10
Geomorphology

Little Foot's inner ear

MicroCT scans of the hominin fossil known as Little Foot shed light on how she lived and moved, more than three million years ago

The inner ear of hominin fossils has the potential to provide valuable information about how an individual moved, what its hearing capacities were, and how the evolution of the species relates to others.

Based on microCT scans performed at the Evolutionary Studies Institute at the University of the Witwatersrand, a Wits scientist and colleagues have been able to 'virtually extract' the inner ear of Little Foot, the *Australopithecus* fossil dated at 3.67 million years old. Dr Amélie Beaudet, Professor Ronald Clarke and their team published a description of the inner ear in the *Journal of Human Evolution* in January. They also compared it with 17 hominin specimens from Sterkfontein, Swartkrans and Makapansgat belonging to the genera *Australopithecus, Paranthropus* and *Homo* and dating between three and 1.8 million years ago, as well as with 10 chimpanzees and 10 modern humans.

Overall, Little Foot's inner ear has both ape-like and human-like features, because the inner ear canals and the cochlea provided different results. The semicircular canals in Little Foot's inner ear are different from both modern humans and from *Paranthropus* – a genus of extinct hominins that lived at the same time as the first humans. The *Paranthropus* canals have a very specific shape that is not shared with any of the fossil specimens.

"By contrast, we found that the Little Foot inner ear canals are close to those of chimpanzees," says Dr Beaudet, lead researcher of the study. "They differ from modern human inner ear canals in that modern humans' canals evolved for unique activities such as running."

The study also shows a large diversity in the shape of the inner ear canals among *Australopithecus* species, which could suggest a high degree of variation in locomotor behaviour in this group.

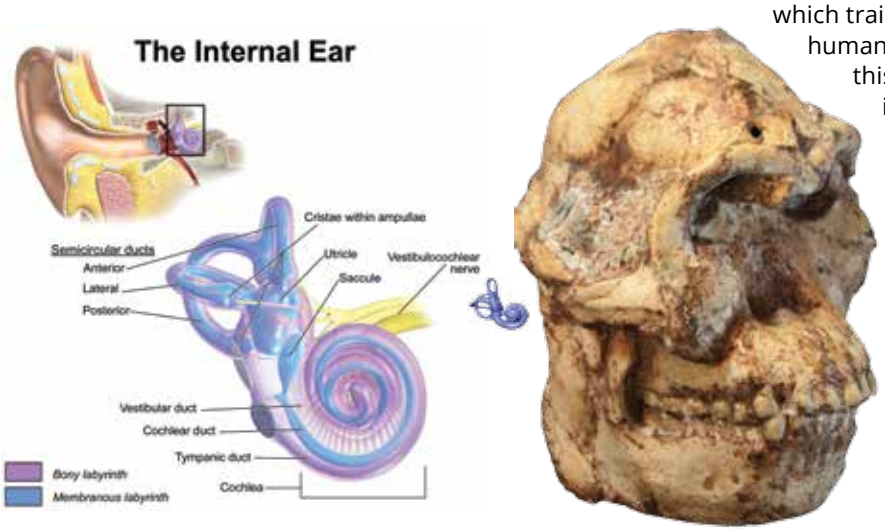
"Our analysis of the inner ear might be compatible with the hypothesis that Little Foot and the *Australopithecus* specimens in general were walking on two legs on the ground, but also spent some time in the trees," says Dr Beaudet. Little Foot's cochlea, though, is quite similar to other *Australopithecus* specimens in the study and to *Paranthropus*, but it differs with fossil *Homo* specimens. "This organ is related to sound perception and to ecological factors such as diet, habitat or communication, which means that Little Foot differed in this regard with early members of our own genus, implying some difference in behaviour," says Dr Beaudet.

The dimension and shape of the cochlea are related to the range of frequencies that can be detected by a species. The shape of the cochlea of fossil *Homo* specimens is compatible with an extended low-frequency hearing limit. This was not the case for *Australopithecus*, including Little Foot, nor for *Paranthropus*.

"At the moment, we are not yet sure what this means. It may be that the early *Homo* species had to extend their range of frequencies for adapting to a different environment or perhaps even to communicate to each other. We don't really know."

Of all the comparisons of Little Foot to other specimens, the greatest similarity in the overall inner ear pattern was with a specimen of similar age from the Jacovec Cavern in the Sterkfontein Caves.

"Having a reference point, such as comparing Little Foot to the Jacovec specimen, is important in detecting which traits are specific to us – humans – and whether humans evolved more distinct characteristics. With this finding we now would be able to know what is specific to *Homo* and *Paranthropus*, and when these features emerged in the fossil record," says Dr Beaudet.



Blausen Medical: Wikimedia

The semicircular canals (balance system) and cochlea (hearing organ) of Little Foot's inner ear differ from those of modern-day humans.

Issued by Wits University. Read about Little Foot's discovery in Quest Vol. 14 No. 1 (2018).

A longer article by Dr Amélie Beaudet was published online in January: https://theconversation.com/virtual-images-reveal-secrets-of-an-ancient-fossils-brain-and-inner-ear-108349

It includes a 36-second video animation of the virtual reconstruction of Little Foot's brain and inner ear, which can also be viewed at: https://vimeo.com/306999133

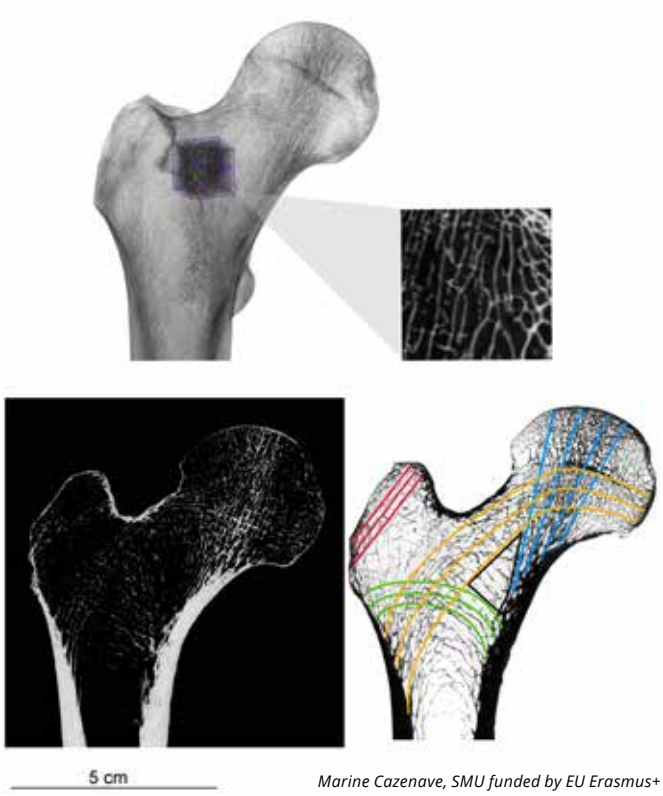
'Bakeng se Afrika'

Forensics 'For Africa'

MicroCT will play a central role in a new project to develop a digital repository of skeletal images for research and teaching purposes.

The three-year project, titled *Bakeng se Afrika* (For Africa), will be coordinated by the University of Pretoria's Forensic Anthropology Research Centre (FARC), but two other South African universities – Stellenbosch University and Sefako Makgatho Health Sciences University – as well as three European universities and the National Energy Corporation of South Africa (Necsa) will also be involved. The project has been made possible by a €1 million (R15.9 million) grant from the Erasmus+ Programme of the European Union.

A microCT facility was installed at Necsa in 2011, and has been used by researchers and postgraduate students to acquire a large quantity of three-dimensional data on human bones, especially skulls. This data is useful to other researchers – both nationally and internationally – from the anatomical science, bio-engineering and dentistry fields. Together with outputs from other methods, such as Lodox Statscans and CBCT scans, it will be made available in a digital archive. Strict ethical guidelines will apply, however, with research projects requiring ethical approval from institutional committees before access is granted to the repository.



Marine Cazenave, SMU funded by EU Erasmus+

Brandon Anderson, Flickr

What is Forensic Anthropology?

Forensic anthropology is the examination of human skeletal remains to assist law enforcement in identifying the deceased. A biological profile that includes sex, approximate age, height and ancestry can be created, based upon physical characteristics that have been determined from the study of human skeletal differences. The time since death can be estimated, while evidence of bone injuries, medical procedures and diseases can assist in identification, and sometimes even indicate the likely cause of death.

MicroCT meets ...

Forensic Files

MicroCT may also be used by forensic scientists in analysing evidence that might assist in prosecution. For example, toolmarks on bone can provide information about a victim's murder or subsequent dismemberment, with differences between blunt-force trauma and straight-edged or serrated blades clearly apparent.

Research studies have used microCT to analyse both gunshot residue in wounds and ballistic impacts on bone to estimate firing distance, as well as blood spatter on textiles. And detailed microCT imaging of the metamorphic development of blowfly larvae may ultimately help to refine estimates of post-mortem interval.

The limited availability of microCT – together with a lack of replicated scientific studies to determine the validity of such research findings – means that it is still an emerging technology in forensic science, but it promises to be a powerful tool in future investigations.

MicroCT for metal 3D printing

By Anton du Plessis. Images courtesy of the CT Scanner Facility, Stellenbosch University

Most people have heard of 3D printing by now, but not everyone knows it can be done with metals. It is actually possible to produce custom and complex designs, similar to plastic 3D print models, in solid metal. This is known as additive manufacturing, and while it is not something for your hobby room or garage, it has been introduced globally in many big companies and is starting to be used in real applications – for example, in Formula 1 racing cars and fighter jets!

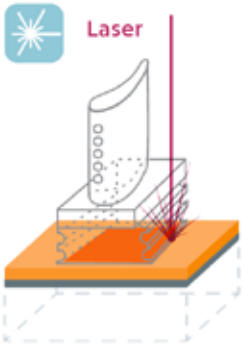
The process works by using a focussed high-power laser that is scanned across a surface to melt fine metal powder in a single layer, according to the 3D model. This is followed by lowering the solidified layer, and then adding the next layer of powder and melting this layer on top of the previous one and so on, until the entire model is created in solid metal, surrounded by powder. The part is removed from the powder and processed further to ensure it has acceptable mechanical properties.

Additive Manufacturing

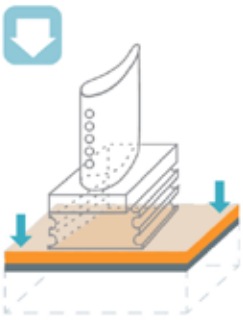
Turbine blades manufactured with 3D printing: The high performance gas turbine components are produced using Additive Manufacturing.

A digital production plan of the new turbine blades is created on a computer.

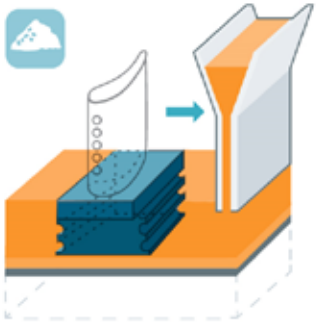
A thin layer of a powder of high performing superalloy is applied.



A fiber laser beam fuses the powder, thereby creating the first layer of the turbine blade.

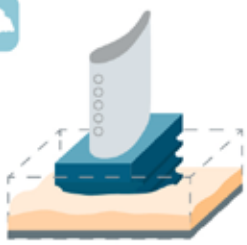


The platform lowers by a few micrometers, lowering the component being produced.

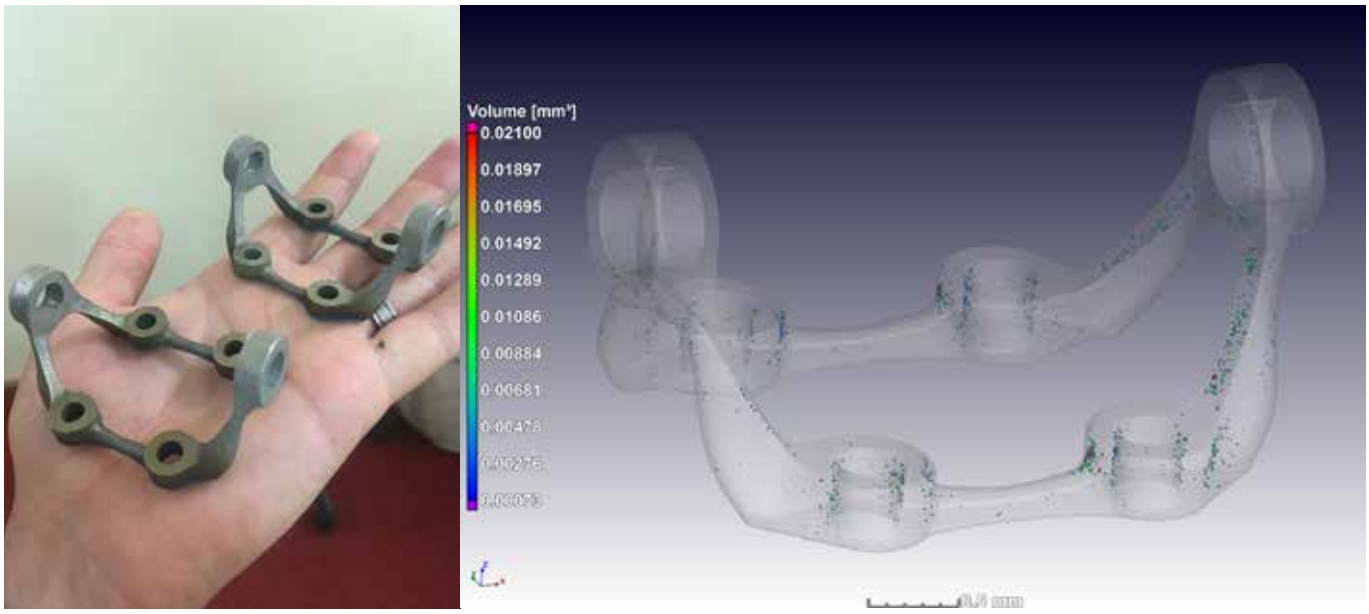


Layer by layer new coats of the polycristalline nickel superalloy are applied and fused.

The laser traces the outline of the digital production plan on every coat.



At the end a heat-resistant turbine blade emerges out of the powdered superalloy.

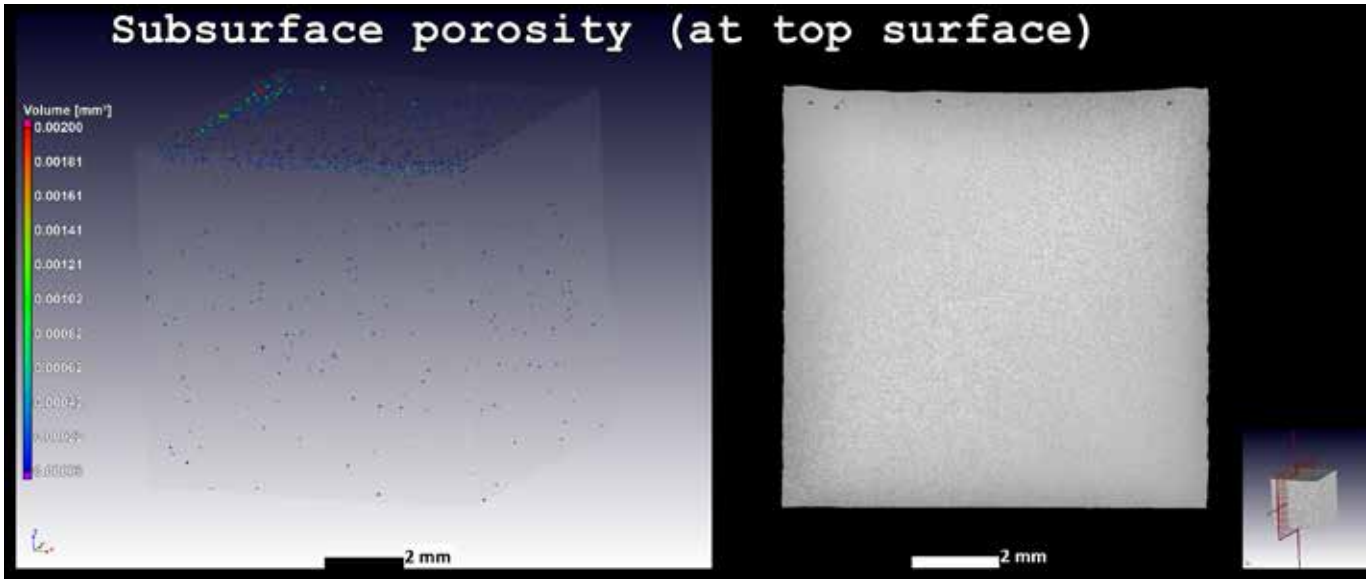


These titanium brackets were 'additively manufactured' using metal 3D printing and then tested using microCT. The small coloured dots represent porosity of different sizes. These are gas bubbles inside the metal that need to be minimised for optimal quality of the part.

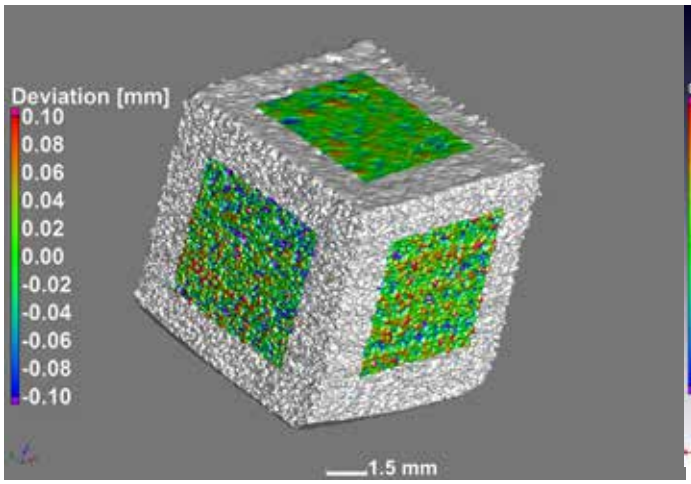
Obviously this is a complex process, with expensive equipment and powder, and many things that can go wrong. In traditional manufacturing, various well-known quality-control tools are used to ensure structural integrity and quality of the final parts. These include dimensional measurements, density measurements, surface-quality measurement, 2D X-ray inspection (digital radiography) and sometimes even 3D X-ray inspection (microCT). By contrast, additive manufacturing relies heavily on microCT, because many of the traditional quality-control tools are difficult to use for these parts. In additive manufacturing the parts are more intricate, so some areas are not accessible, and the internal pores, cracks and other flaws that can occur are smaller. The high-detail imaging capabilities of microCT make it very useful for checking these parts quickly for major flaws.

Besides final quality checks for parts, microCT is also very useful and cost-effective for optimising all the various parameters in the additive manufacturing system before starting to build the parts – in other words, fine-tuning the machine. It allows for easy checking of which parameters result in the minimum porosity and crack formation, with 3D images indicating what could be wrong in the process. During the laser melting of the powder particles, gas bubbles can form in the molten metal region under the laser spot, and then get trapped in the solid metal due to the rapid cooling as the laser spot moves. It can also happen that the laser moves too fast and does not melt enough metal powder, so layers on top of one another do not weld together sufficiently, and even have spaces called 'lack of fusion'. Obviously these two errors have different resulting 'pore shapes', which can be easily seen in microCT images.

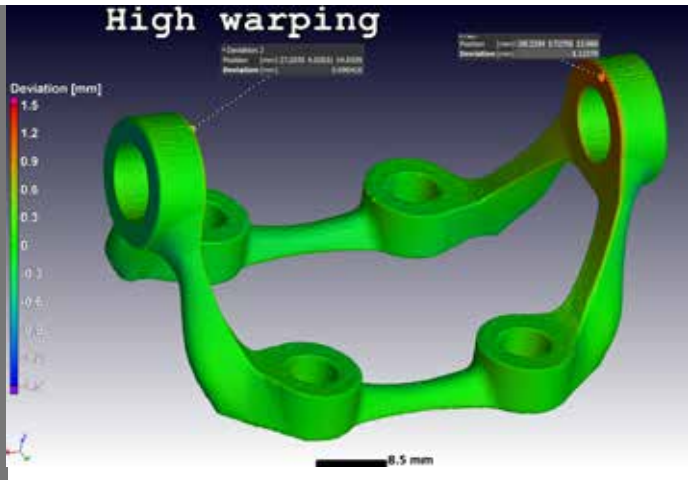
In general, no production method is perfect, and gas bubbles are also present in other traditional parts such as metal castings. In the case of additive manufacturing,



MicroCT of a 3D-printed titanium cube of 10 mm, shown in 3D with colour coding and in a virtual cross-section to visualise porosity. The pores, represented by black dots, occur mainly near the top surface.



Colour mapping of surface roughness of a 10 mm cube, showing side surfaces much rougher than the top surface.

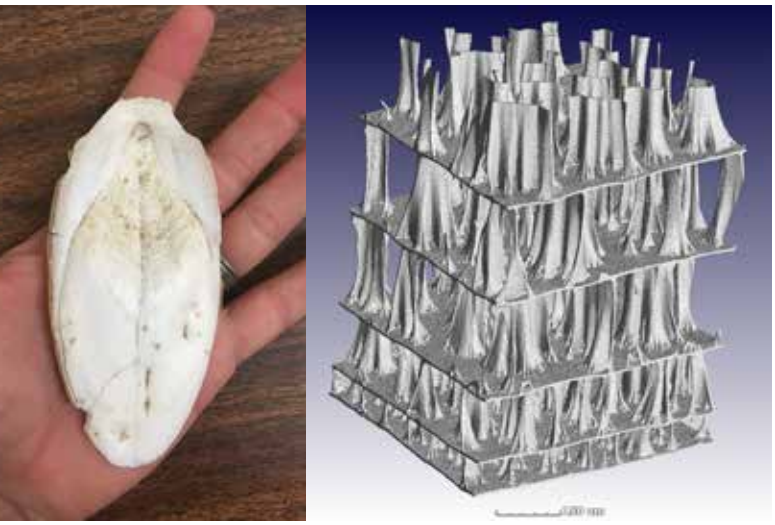


Colour coding shows deviation of up to 1.1 mm on the right side of the part compared to the CAD design file.

however, these flaws may be extremely small, while still affecting the properties of the bulk material. MicroCT is therefore crucial in helping to minimise this porosity by adjusting the laser power, scan speed, and other parameters of the additive manufacturing system. By fine-tuning the settings, highly dense parts can be produced with excellent properties.

Besides porosity, the surface quality varies from machine to machine, and even between vertical and horizontal sections on the parts. This can also be measured by microCT and can be used to assess requirements for post-processing, such as smoothing rough surfaces.

More importantly, microCT can be used to detect whether a part has been produced inaccurately compared to the design specification. The example shown here is a bracket that warped inwards by 1 mm on both sides. This happens during the layer-by-layer process if the heat input is not removed fast enough. Irregular thermal distribution results in stress in the material, which causes it to distort or warp and even crack in extreme cases. Although a 1 mm warping seems insignificant, it can be critical for a fighter jet!



The internal structure of a cuttlefish bone may be a design inspiration for additively manufactured lightweight materials.

In South Africa there are various facilities with metal 3D printers doing research into new processes and developing new applications, much of this R&D work being supported by the Department of Science and Technology through the Collaborative Programme in Additive Manufacturing (CPAM). These facilities are also making additive manufacturing available to local industry players that recognise the advantage of being able to produce extremely complex parts with exactly the shape needed for the application. These metal parts can have the same strength as a traditionally designed one, but with a fraction of the mass, which is very important for vehicle and airplane efficiency. MicroCT obviously assists in obtaining the best quality for such parts, but it can also help in designing them.

The parts are often visually impressive, with designs resembling natural structures, such as branch-like or spider-web connections. This is where microCT has another role to play – in the design of biomimetic parts.

Biomimicry is the practice of 'learning from nature' to design and produce materials, objects and systems. By allowing nature's designs to be visualised and analysed in full 3D, microCT can assist in the creation of engineering blueprints for new biomimicry applications, many of which could be implemented through additive manufacturing. The protective bony plates in reptiles or overlapping scales in fish, for example, might inspire the development of new kinds of body armour, from bullet-proof vests to shark-proof wetsuits!

- A thorough overview of microCT applications is available online in the open-access publication: Du Plessis *et al.* (2019) Advancing X-ray micro-computed tomography in Africa: Going far, together. *Scientific African* Vol. 3. https://doi.org/10.1016/j.sciaf.2019.e00061

Prof. Anton du Plessis is an Associate Professor in the Physics Department at Stellenbosch University and heads the university's CT scanner facility (http://blogs.sun.ac.za/duplessis/).
For more information, including a variety of microCT case studies, see: http://blogs.sun.ac.za/ctscanner/.

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Researcher: Jonathan Quanson
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Scarred Earth

Monitoring land degradation

The German-funded research project SALDi aims to develop new tools for assessing land degradation in South Africa so that the problem can be addressed

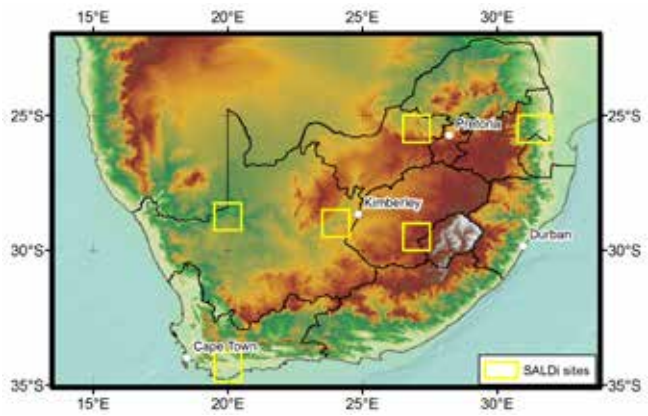
Large areas of South Africa have experienced a decline in soil productivity, reduced vegetation cover and increased soil erosion – sometimes evident as deep gullies that scar the landscape. But to what extent is this land degradation because of human impacts, such as overstocking cattle, clearing bush to plant crops or incorrectly channelling stormwater run-off from roads, rather than climate-induced changes, particularly due to periodic droughts?

A new German-South African collaboration aims to increase understanding of this conundrum in the long term by implementing novel tools for assessing land degradation. The three-year project – known as the South African Land Degradation Monitor, or simply SALDi – will build upon earlier research on the topic by a variety of local scientists. Much of this was collated by the Agricultural Research Council's Institute for Soil, Climate and Water (ARC-ISCW) in developing a Land Degradation Index, which takes into account soil erosion by water and wind, soil salinisation and acidification, hydro-climatic parameters, land cover and the loss of biodiversity.

The SALDi project can improve interpretation of such information and better assess the land degradation problem by taking advantage of the high-resolution Earth observation data that is now available from the European Sentinel satellites, as well as recent advances in modelling approaches.

"For instance, the USLE [Universal Soil Loss Equation] model that has been used in South Africa up to now works well for long-term averages, but not the kind of erosion damage that a farmer might see after one storm," explains project coordinator Dr Jussi Baade, from Germany's Friedrich Schiller University Jena. "So with the input of local partners we will adapt a physically based soil erosion model from Germany to apply in South Africa."

Six study sites, each covering an area of 100 km by 100 km, have been identified countrywide to represent a range of climatic conditions, geological substrates, vegetation cover and land-use practices. In addition, a modelling exercise will apply the WRF-Hydro (Weather Research and Forecasting Hydrological) Regional Earth System Model to the whole of southern Africa. The model essentially combines recorded precipitation data and predicted weather forecast data with a land surface model for a variety of uses, including flash flood prediction, river flow forecasts, seasonal water resource



The six SALDi study sites.

forecasts and land-atmosphere coupling studies. In this case, the model's output will be used as input data for soil erosion modelling.

By the end of the project, it is anticipated that an automated observation system to monitor aspects such as soil moisture, vegetation cover and potential land degradation will have been developed. This would be a freely accessible, online system allowing anyone – from school learners to farmers to local and international scientists – to zoom into a map, down to a resolution of 10–30 m, and view information derived from bi-weekly satellite data.

A kick-off meeting for the project was held in Pretoria at ARC-ISCW in March, attended by collaborating scientists, other potential partners and representatives of stakeholder government agencies. After the meeting, the research team headed out on their first fieldwork campaign. One of the first stops was the Welbedacht Dam, which was built in the early 1970s as part of Bloemfontein's water supply but has silted up to such a degree that it now has only a fraction of its original storage capacity.

The visiting German scientists were joined here by Dr Jay Le Roux, a soil erosion scientist from the University of the Free State, and his PhD student Mrs Marike Stander, who will be conducting research on erodible soils in the dam's catchment.

"We are collaborating to learn and assist each other where possible," says Dr Le Roux, who had suggested this as a SALDi site based on previous research he had done in the area. "Networking with the SALDi team will assist our development of the required capacities in terms of sediment measurement and mapping techniques. We also plan to apply for funding from the SPACES DAAD scholarship programme 'Capacity Building / Development'."

If successful, this would allow Mrs Stander to spend time at a German university as an exchange student, increasing her exposure to cutting-edge erosion science.

On a future field trip, Dr Baade intends surveying about 15 dams in three of the SALDi study sites to compare the siltation estimates with those of Rooseboom, published in a Water Research Commission report in the early 1990s. These surveys will be done from a boat, using an echosounder and GPS, to calculate the volume of accumulated sediment in the dam and hence the reduction in storage capacity.

"We're really looking forward to seeing whether siltation rates went up or down, because in certain areas where there are good soil conservation measures in place you could maybe expect that siltation in reservoirs has decreased," says Dr Baade. "This would be useful for showing farmers that they can do things to maintain their water storage capacity, because when that is lost they will be worse off in a drought."

Another component of the fieldwork is the surveying of erosion gullies, and this work began during the recent trip. Dr Baade explains that a South African company was contracted to do drone-based surveys, providing data used to construct highly detailed digital terrain models.

"At the end of the project we'll fly these areas again to see how things have changed," he says. "We're doing that mainly in the national parks because – given that they are directly protected by park management – it's basically just the rainfall or run-off signal that creates the dynamics of the gullies. In certain areas they are not a sign of land degradation, but we want to learn how they evolve naturally."

The project's kick-off meeting was held at the Agricultural Research Council's Institute for Soil, Climate and Water in Pretoria in March.

Some erosion gullies in the study sites have been surveyed using drones, and the resulting digital terrain models will allow changes to be monitored over time.

A moisture probe network consisting of eight sensors attached to a central unit has been installed at each site so that satellite-derived soil moisture data can be validated.

During the recent field campaign, a moisture probe network was also installed in each of the six study sites so that the soil moisture data derived from Sentinel-1 radar imagery can be validated. Each network consists of eight sensors placed in a 20 x 20 m area and attached to a central unit. Since these need to be protected from vandalism or theft, and the data downloaded every three months, they have been installed either in national parks or on the property of willing landowners. More specifically, one is at the Kruger National Park's sampling station near Lower Sabie, where there are a number of other monitoring instruments, another in Mokala National Park and a third in Augrabies National Park, while the others are on private farms near Pilanesberg, Ladybrand and Elim near Cape Agulhas.

This equipment will remain on site after the completion of the project, so that it can continue to be of use to South African scientists, together with all the processors, algorithms and models developed during the project. The German research team hope that the project outputs will ultimately assist in improving land degradation management in South Africa, but they point out that the scientific exchange with local scientists is also of benefit in addressing research questions they are working on in their own country.

Some of the relationships supporting such exchange go back many years, and there is an especially long history of cooperation with SANParks scientists. For example, Dr Baade did a reconnaissance survey of 15 reservoirs in the Kruger National Park a decade ago to establish whether their siltation could be used to assess spatial variation of soil loss. He has published a number of papers on this and related land management research in the park in the intervening years.

"One might be wondering why a land degradation monitoring project is being conducted inside a national park," says SANParks abiotic scientist, Tercia Strydom. "Well, there are two main reasons. Firstly, fully functional soils inside our parks will act as reference points for

degraded sites outside our parks for comparison purposes for the countrywide project. And secondly, with greater relevance for SANParks, many of our parks include previously utilised land that was incorporated into our parks in order to increase the area under conservation. Often, this recently acquired land has a history of farming and therefore has some degree of degradation. Since soils are critical in supporting a range of ecosystem processes, it is of utmost importance that degraded soils are rehabilitated and restored."

"SANParks invests a lot of time, money and effort into various types of rehabilitation techniques aimed at restoring some newly acquired land into fully functioning ecosystems. It is for this reason that this SALDi project will be very useful for park management – it will help monitor land degradation and evaluate whether our rehabilitation and restoration programmes are working."

Article by Sue Matthews; images courtesy of the SALDi project team.

The project is funded by the German Federal Ministry of Education (BMBF) and forms part of the programme known as SPACES, an acronym for Science Partnerships for the Assessment of Complex Earth System Processes. The SPACES programme has its roots in the 2012/2013 German-South African Year of Science, which had the theme 'Strengthen research partnerships for innovation and sustainable development'. Climate research was one of seven subject areas identified for collaboration, with the main priority being to investigate the causes and consequences of climate change. The SPACES programme was subsequently developed to implement scientific cooperation projects in the broader southern Africa region. The four projects that were funded in the first phase, starting in July 2013, have been completed, and in July 2018 the second phase began, with nine projects funded – among them the SALDi project.

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ZACube-2

Despite its tiny size, South Africa's latest nanosatellite can play a big part in protecting the marine environment

South Africa's second nanosatellite, ZACube-2, blasted into space aboard a Russian Soyuz rocket in late December. It was part of a payload that included 25 CubeSats, which are satellites made up of 10 cm cubes weighing up to about 1.5 kg each. These small units (1U CubeSat) can be stacked on top of one another or side by side to build larger systems. ZACube-2 is a 3U CubeSat, just 30 cm long and weighing about 4 kg. It carries an automatic identification system (AIS) for monitoring the movement of ships along the South African coastline, as well as an imaging sensor operating in the near-infrared range for detecting veld fires.

The satellite is still in the commissioning stage, but the first AIS data has been successfully 'ingested' into the Department of Environmental Affairs' vessel tracking tool, which is one of a number of decision-support tools in its new National Oceans and Coastal Information Management System (OCIMS). The department initiated the development of OCIMS with the Department of Science and Technology (DST), and in mid-2015 appointed the CSIR to facilitate its implementation. It forms part of the Marine Protection Services and Ocean Governance workstream of Operation Phakisa: Ocean Economy, a government programme that aims to accelerate delivery of National Development Plan priorities by unlocking the economic potential of South Africa's oceans.

But why the need to track shipping activity? Ashley Naidoo, the department's Chief Director: Oceans and Coastal Research, explains that the original motivation was to be able to observe vessel traffic and behaviour in offshore marine protected areas (MPAs). The process of identifying suitable areas for offshore MPAs began in October 2006, when a multi-organisational team of experts coordinated by the South African National Biodiversity Institute (SANBI) embarked on a five-year project that culminated in the identification of 10 offshore areas warranting protection.

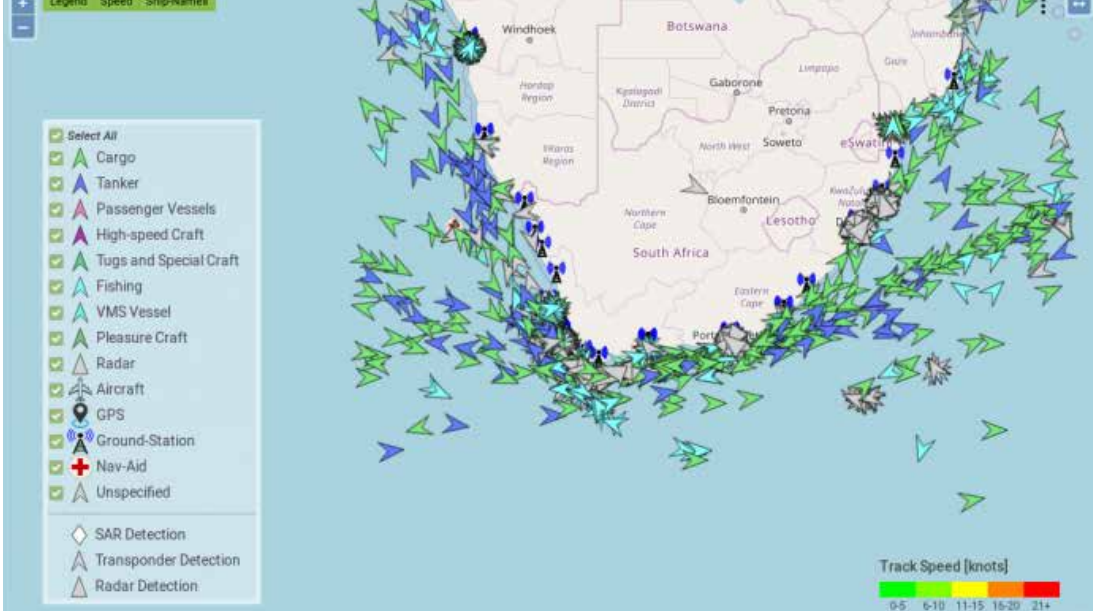
Prof. Robert van Zyl, Director of the French South African Institute of Technology (F'SATI) at the Cape Peninsula University of Technology (CPUT), with Minister of Science and Technology, Mmamoloko Kubayi-Ngubane, at the ZACube-2 send-off function in April 2018.

Subsequently, an MPA technical team set up as part of Operation Phakisa proposed a network of 22 new MPAs, some of which extend existing MPAs further out to sea, while others are entirely offshore. In October 2018 Cabinet approved 20 of these, and they were officially proclaimed when gazetted on 23 May 2019. Of course, all vessels are allowed passage through the ocean, but in MPAs there may be some restrictions on activities, such as prohibition of certain types of fishing, or dumping of waste at sea.

"The vessel tracking tool within OCIMS not only allows us to monitor vessel traffic in offshore MPAs," says Naidoo. "If an oil slick occurs somewhere around the South African coastline, the tool could also help us identify which ships were recently in that area, and predict where further slicks might be found."

Since the beginning of 2005, it has been a requirement in terms of the International Convention for the Safety of Life at Sea (SOLAS) for all vessels of over 300 gross tonnage on international voyages, cargo ships over 500 gross tonnage and all passenger ships regardless of size to be fitted with AIS transponders. These include a Global Positioning System (GPS) receiver and a VHF transmitter, automatically sending information on the ship's name, type, flag, position, course and speed to coastal authorities as well as other vessels in the area. Smaller vessels, including most fishing boats, often just have a 'receive only' AIS installation, so that they can see large ships approaching and move out of their way if necessary.

Traditionally, the data is received at AIS base stations along the coast, and there are a number of websites and online applications that make the information freely available. The LiveMap on MarineTraffic.com, for example, allows any member of the public to search for a particular vessel and track its movements, or zoom into an area around a port to see which ships are lying at anchor, approaching or departing. Since there is a concern that this information is a safety and security risk, ships are permitted to switch off their AIS transmissions in areas where maritime piracy is a problem. There is also a loss of signal when a ship moves 'out of range' of the coastal base stations, but this is where satellite-based AIS receivers come into their own. Typically, websites have a paywall requiring subscription for the satellite-based



The Integrated Vessel Tracking Tool in the National Oceans and Coastal Information Management System (OCIMS) allows the movement of ships and smaller vessels in South African waters to be monitored.

AIS tracking service, which allows fleet managers to keep an eye on their ships as they move around the world's oceans.

"What the ZACube-2 satellite AIS represents – together with OCIMS – is a complete South African solution, from the time the signal leaves the ship, to the CubeSat, to integration into OCIMS," says Naidoo. "In other words, we have the potential for a full communication loop, with South African technologies and human capability, and when we work together with other existing international capability, it makes for a very robust, locally driven integrated vessel tracking tool."

Of course, South African fishing vessels that remain in our Exclusive Economic Zone (EEZ) are not required under SOLAS to fit AIS transponders, but the national fisheries regulations – enforced by the Department of Agriculture, Forestry and Fisheries (DAFF) – require that they be fitted with Vessel Monitoring Systems (VMS). Of more concern is that foreign vessels have on occasion been caught fishing illegally in South African waters, sometimes after having turned off their AIS transponders.

One option of addressing this is to add monitoring via satellite-based synthetic aperture radar (SAR), which – unlike imaging sensors operating in the visible or infrared range – is largely unaffected by cloud cover and weather conditions, and allows day and night surveillance. This data is currently available from international partners, but the freely available low-resolution imagery is of limited use, while the high-resolution imagery is too expensive for ongoing monitoring of a vast area that includes the 200 nautical mile EEZ around the Prince Edward Islands. The possibility exists, however, that future South African nanosatellites might carry a SAR platform, making this monitoring method a viable proposition.

ZACube-2 was developed by CPUT-F'SATI postgraduate students.

Indeed, ZACube-2 is mainly considered a demonstrator for technology that will ultimately be used in a constellation of nine nanosatellites to be developed for the country's Marine Domain Awareness satellite programme (MDASat). In February the DST announced that it would invest R27 million in MDASat over the next three years, and that three new satellites would be ready for launch in 2020.

Like ZACube-2 and its predecessor ZACube-1, which was launched in 2013 for space weather research, these three satellites will be built at the Cape Peninsula University of Technology (CPUT), largely by postgraduate students based at the French South Africa Institute of Technology (F'SATI). CubeSat is used as a training tool within the Master's Degree in Engineering Science introduced by CPUT-F'SATI in 2009, which is exactly how the developers of the CubeSat standard intended for it to be used. It originated in 1999 as a collaborative effort between researchers at California Polytechnic State University (Cal-Poly) and Stanford University in the United States to facilitate access to space for university students, and has since been adopted by hundreds of organisations worldwide.

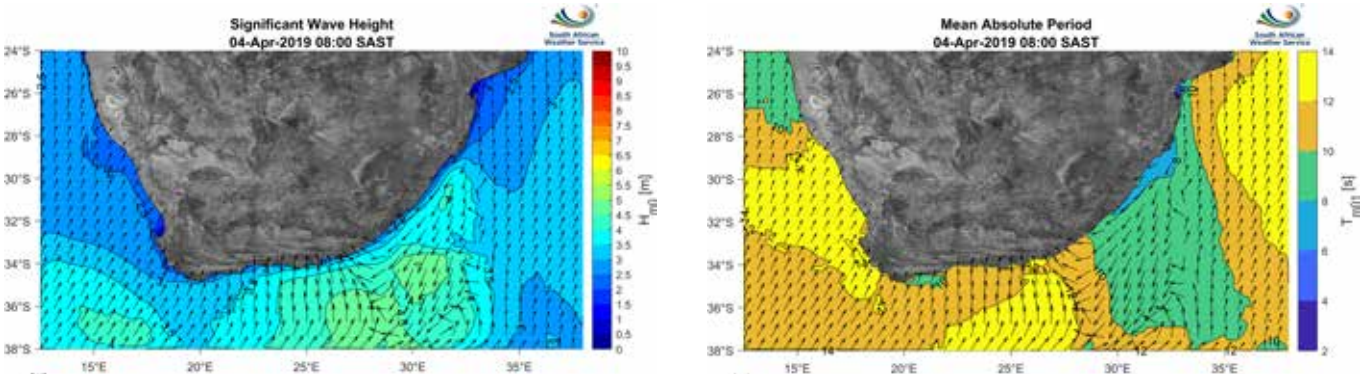
While it is already possible for the CPUT-F'SATI students to stay on after the Master's degree to do a PhD, they may also have the option soon of a Co-tutelle Doctorate Programme. This was one of the points of discussion when CPUT-F'SATI hosted a delegation from the University Paris Est Créteil (UPEC) at the end of February.

"Students registered in this programme will have two supervisors, one belonging to CPUT and the other belonging to the French partner university," explained Scientific Director of F'SATI, Prof. François Rocaries. "At the end of their work the student will have two doctoral degrees, one from CPUT and the other from the university partner."

Consideration is also being given to establishing a joint Master's qualification in the field of Space Technologies.

Marine forecasting

The Marine Unit of the South African Weather Service forecasts sea conditions for ocean users



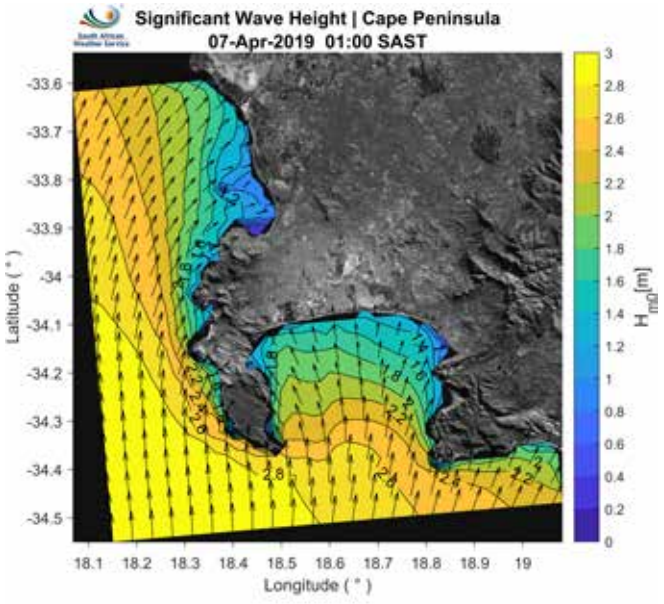
The wave forecast page on the SAWS Marine Portal has maps showing a regional overview of expected wave conditions. Viewers can press 'play' for an animation of changing conditions over the forthcoming three days. High-resolution wave forecast maps are provided for eight areas around the coast (below).

At the end of January, the South African Weather Service (SAWS) announced that it had 'gone live' with the country's first locally developed, operational wave-forecasting system. This provides state-of-the-art forecasts for key ocean wave parameters – such as significant wave height, period and direction – free of charge to the South African public. It has been designed with a multitude of users in mind, from surfers and paddlers to small-scale fishermen, from the coastal tourism community to offshore industry.

The new forecasting product is the culmination of extensive research and development by the SAWS Marine Unit's scientists, their aim being to design and implement a wave-forecasting system that is fit for purpose for South Africa's unique oceanographic context. To do this, they focussed on addressing key shortcomings of the global models that users have relied upon until now.

"Global models are adequate for painting a general picture of the open-ocean swell," said Marc de Vos, a researcher in the Marine Unit. "However, inherent technical limitations mean that they cannot accurately describe the wave conditions nearer the coastline, where the vast majority of wave-dependent activity takes place. This is why we have radically raised our model's resolution, as well as the quality of the data which we use to drive it – so that we can actually paint a true picture of the way waves are moving around our coastline in high detail. The model itself is also well suited to both open-ocean and nearshore waves."

The system consists of a regional Simulating Waves Nearshore (SWAN) model with a horizontal resolution of approximately 6 km (1/16th of a geographical degree). In key areas around the coastline, additional models are run with resolutions of about 2 km (1/48th of a geographical degree). For expert and commercial users, resolutions



from 250 m down to 10 m are available for specific areas of interest, to guide operations that are critically dependent on wave conditions.

The wave forecast page on the SAWS Marine Portal shows three-day forecasts as animated maps of Significant Wave Height and Mean Wave Period for the entire South African region. Links to high-resolution (zoomed-in) maps and time-series graphs are provided for Lüderitz, Saldanha, Cape Peninsula, Mossel Bay, Port Elizabeth, East London, Durban and Richards Bay. Since wave period remains constant as waves move into shallower water, the maps better represent a user's experience of the local sea state in nearshore areas than the time-series graphs, which show peak wave period (highest period) as well as wave height and direction.

US Coastguard

Apart from the new wave forecasts, the SAWS Marine Portal also contains the following:

Forecasts

Wind

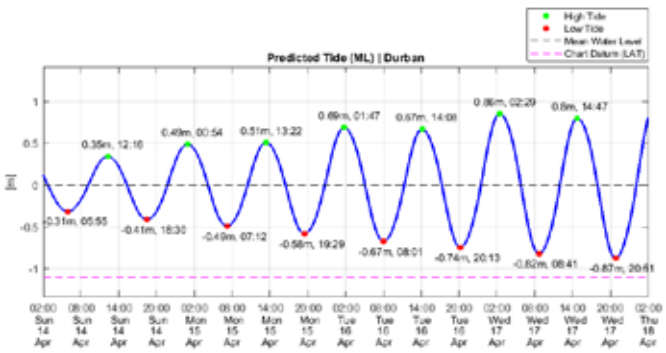
Distant wind systems generate ocean swells, while local winds are a major determinant of sea state, causing a 'flat' or 'choppy' surface depending on wind direction. In some areas, wind drives upwelling, which in turn affects sea surface temperature.

Storm surge

Storm surge, caused by a combination of strong onshore winds and low atmospheric pressure, results in abnormal volumes of water accumulating against the coastline. It manifests as a raised sea level that can last for several hours, leading to significant coastal flooding.

Tides

Tide time-series plots, produced from the newly developed SAWS Tidal Model, are available for 39 sites around the coast. These depict the rising and falling of the tides, resulting from the gravitational force of the sun and moon on the ocean as the earth rotates. The time and height above or below mean water level for high and low tide, respectively, are clearly shown.



Observations

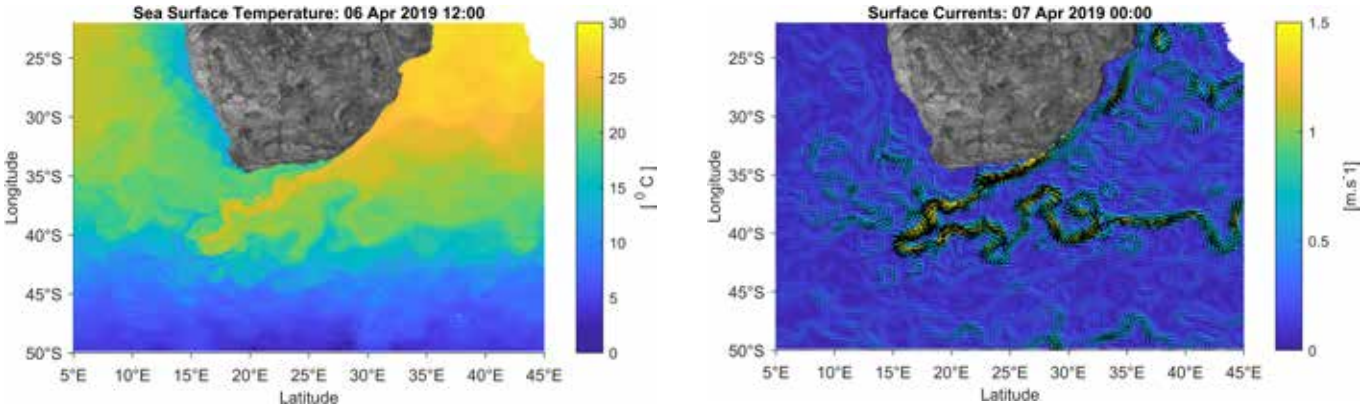
Regional sea surface temperature

Sea surface temperature (SST) is a measure of the heat content of the ocean's surface layer. It plays an important role in marine ecology, as well as ocean–atmosphere interaction. For example, a cold ocean along the west coast of South Africa inhibits convection, suppressing rainfall and keeping the adjacent landmass relatively dry, while the warm Agulhas Current along the east coast transfers heat energy to the overlying atmosphere, causing air to rise and condense, and resulting in rainfall that supports lush coastal vegetation.

The depiction of SST on the SAWS Marine Portal is a fusion of *in situ* and satellite data, processed by the Operational Sea Surface Temperature and Ice Analysis (OSTIA) project run by the UK Met Office, and made available courtesy of the EU Copernicus Marine Service.

SOLAS forecasts

These forecasts, available for both coastal areas and the 'high seas', are a requirement of the International Convention on the Safety Of Life At Sea (SOLAS), the first version of which was adopted in 1914 in response to the *Titanic* disaster. The forecasts are broadcast for shipping purposes, and include information on wind, visibility and sea state, as well as alerts such as warnings of poor visibility due to fog, special weather advisories, or abnormal wave conditions.



The Agulhas Current flowing down the east coast can be clearly seen in these maps generated from satellite data for sea surface temperature and sea surface height. These products are made available to SAWS by the European Copernicus Marine Service.

Regional sea surface heights

Sea surface height (or absolute dynamic topography) is a useful measure of the level of the sea surface in relation to a reference level. It provides a useful proxy for the strength of surface currents. Along the east coast of South Africa, for example, a considerable elevation is normally evident due to the strong, south-westward flowing Agulhas Current. The depiction on the SAWS Marine Portal represents a fusion of altimetry data from various satellites, made available by the EU Copernicus Marine Service.

Regional surface currents

The Agulhas Current can be clearly seen on the depiction of regional surface currents, using data made available by the EU Copernicus Marine Service. Surface currents are derived by applying theoretical formulae to absolute dynamic topography (or sea surface height) data, which are collected by satellite altimeters.

Coastal sea surface temperature

Dedicated volunteers around the coast record sea temperature with thermometers at the same time and place each day, and submit this to SAWS on a weekly basis. Many organisms in coastal waters are adapted to thrive in a specific range of water temperatures, so this long-term SST dataset is important for monitoring ecosystem health and assessing how coastal ecosystems might be responding to climate change.

Regional sea level anomalies

Sea level anomalies are deviations from the ocean surface's mean level – in other words, areas of higher or lower sea level relative to a long-term average. These anomalies are useful proxies for eddies that transport heat energy, salt and nutrients around the ocean. Many marine species depend on these eddies, while mariners can use the fast-flowing water around them to save travel time and fuel. Sea level anomalies are derived by subtracting a long-term mean sea surface height from the absolute dynamic topography (or current sea surface height) data, which are collected by satellite altimeters. The data is made available by the EU Copernicus Marine Service.

Drifting buoys

Each year, the SAWS marine research team deploys 30 to 40 drifting weather buoys, which get carried along by the ocean's surface currents. Their GPS transmitters, SST sensors and air pressure sensors allow real-time insight into key marine meteorological parameters. The data gets incorporated into global weather forecasts to enhance their accuracy, making them a critical element in ensuring navigation safety. The buoys are provided to SAWS annually by the US National Oceanic and Atmospheric Administration (NOAA) to use as part of the Global Drifter Programme.

Ships

The SAWS Marine Research Unit maintains instrumentation on various research vessels, allowing data collection from areas that are otherwise difficult to reach, such as the Southern Ocean. Personnel are also deployed onboard to conduct routine synoptic surface observations, noting many details about the weather at their given location. Apart from being important for refining weather forecast models and monitoring climate change, this data is often of great value to other researchers working on biological, chemical or physical subjects that may be influenced by local meteorological parameters.

Visit the SAWS Marine Portal for animated forecasts, observations and other information: http://marine.weathersa.co.za/index.html

CURRICULUM CORNER

GEOGRAPHY GRADE 10
The atmosphere; Water resources

GEOGRAPHY GRADE 11
The atmosphere

PHYSICAL SCIENCES GRADE 10
Waves; Chemical systems: hydrosphere

INFORMATION TECHNOLOGY GRADES 10-12
Solution development

The SAWS Marine Unit explains the process behind marine forecasting

Geography lessons teach us that the ocean plays a very important role in how the atmosphere forms and functions, while the atmosphere – through strong winds, rain and snow – in turn affects how the ocean behaves. This relationship and its direct implications can be very difficult to understand, and only through very large and dynamic (i.e. ever-changing and constantly updating) models can we begin to do so.

The motion in the atmosphere and oceans is governed by the laws of physics and thermodynamics. The language we use to describe these laws is mathematics. This concept of describing the movement of energy and matter in the oceans and atmosphere mathematically is called modelling, and we can obtain a 'numerical prediction' of what the winds, waves and tides are going to be in future by plugging in known values and getting computers to solve these complicated equations. Forecasting involves using these data together with actual data collected in the field, coupled with local knowledge and experience, to predict the weather for the next seven to 10 days.

To build a forecast model, we divide the area we are interested in into blocks, called grid cells. We then ask the computer to solve a list of equations we learnt about each of those grid cells, given some starting values. If the time for our starting values is T1, we solve the equations to get the conditions at T2. We then plug in the values from T2 to get values for T3 and so on, in each grid cell.

All kinds of considerations go into determining how the air (or water) will move, how big the waves will be or what direction they will travel in, according to these predetermined laws of physics. Some of these change constantly, and others do not. For wave forecasts, for example, we need to give the computer information about the sea floor, which generally changes quite slowly. We also know that wind generates waves, so we will need to feed in some wind data (generated by its own forecast model), and this will need to be updated regularly.

Validation of these models is then with 'real' data, or data observed from well-calibrated, strategically placed observation platforms. For atmospheric data, we need weather stations collecting wind speed and direction, air temperature and humidity, all inputted hourly into the South African Weather Service (SAWS) databases, which in turn are used to update the models and calibrate the hindcast model.

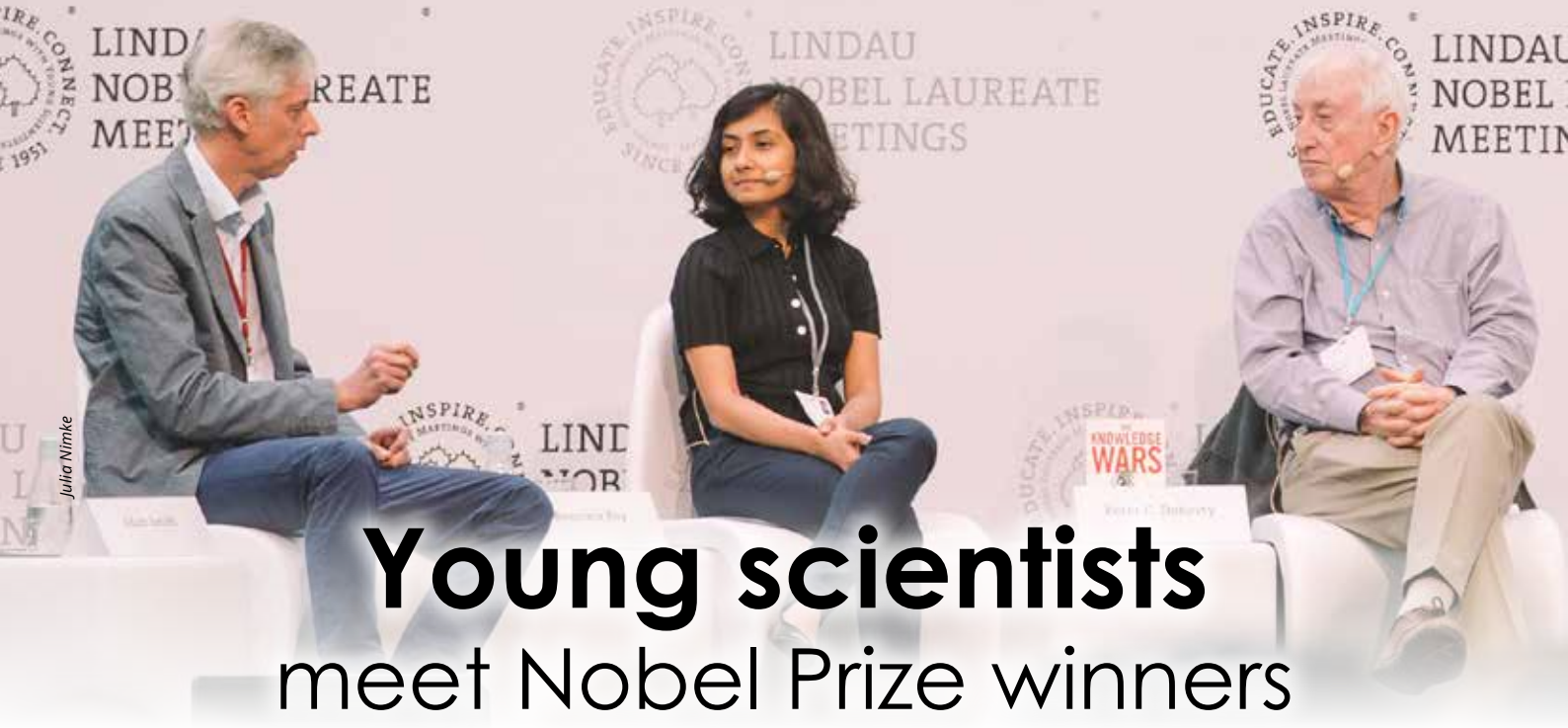
For the oceanographic data, this can be a little more complicated as some observation platforms are delayed time (i.e. their data can only be downloaded and used once they have been retrieved from the ocean), while others that are near-real time (satellite drifters and Argo floats) are not yet fully integrated into forecast models, but are used for validation of hindcast coupled-climate models.

The storm surge, wave and tidal models that have recently been developed by the SAWS Marine Unit are constantly being validated by data collected at sea and from coastal observation stations to ensure accuracy. These models are used to inform forecast offices and warn shipping agencies, disaster managers and any ocean users of potential threats. The primary objective is the safety of life, with the safety of infrastructure being a secondary concern.

Given that sea levels are expected to rise due to climate change and increased ocean warming, the risks storm surges and destructive waves pose in the future will only increase. Society needs to be prepared for this, and the necessary mitigation efforts made, to ensure we are resilient and can adapt with the change. Accurate data and reliable forecasting, as well as good environmental and municipal management, can help reduce the impacts of devastating coastal inundation.

The SAWS Marine Unit draws upon its diverse but complementary skillsets to ensure a continuous, accurate and useful marine service for the South African public. It looks forward to interacting with the academic and coastal engineering sectors, various government agencies, shipping industry stakeholders and other ocean users around our coastline.

For more information, please contact the Marine Coordinator: tamaryn.morris@weathersa.co.za.



Julia Nimke

Young scientists meet Nobel Prize winners

For six days each year, the small German town of Lindau – situated on an island at the edge of Lake Constance, or Bodensee – hosts the annual Lindau Nobel Laureate Meeting, when promising young scientists get to rub shoulders with previous winners of the Nobel Prize, known as Nobel Laureates.

The meetings aim to foster exchange among scientists of different generations, cultures and disciplines, and they focus alternately on the three natural science Nobel Prize disciplines – physiology and medicine, physics and chemistry – with an interdisciplinary meeting covering all three every five years.

The 2019 event – known by its Twitter hashtag #LINO19 – will be the 69th Lindau Nobel Laureate Meeting and will be dedicated to physics, the key topics being cosmology, laser physics and gravitational waves.

A maximum of 600 young scientists, who may be no older than 35 at the time of the meeting, are selected to attend each year by a scientific review panel, after being nominated by more than 200 academic partner institutions worldwide.

The Academy of Science of South Africa (ASSAf), with funding from the Department of Science and Technology, makes nominations annually after issuing a call to postgraduate students and postdoctoral researchers to apply. This year South Africa is the host country, and will have the opportunity to present itself as a research nation on the International Day. A larger than usual contingent of 20 young scientists – 10 females and 10 males – will therefore be attending the meeting from 30 June to 5 July 2019.

They will join 580 young scientists from 89 countries at this year's meeting, which will be attended by 42 Nobel Laureates. The programme includes numerous lectures, panel discussions and social events, and some young scientists will have the opportunity to present their own research work at one of the master classes or poster sessions, following an application process.

"These scholars will serve as ambassadors for the country in the area of physics and at the International Day that SA is hosting," said Executive Officer of ASSAf, Prof. Himla Soodyall. "They have an opportunity to engage with Nobel Laureates and other scholars in their field, and I hope that the young scientists will take advantage of these interactions and use the opportunity to build networks for future collaborative research."

The 20 young scientists selected to attend #LINO19 are:

- Tariq Blecher, Rhodes University / Square Kilometre Array
- Stive Djiokop, Nelson Mandela University
- Jake Gordin, University of Cape Town
- Thandi Gumede, University of the Free State
- Arthur Harrisson, University of Pretoria
- Julia Healy, University of Cape Town / South African Radio Astronomy Observatory
- Jan Louw, Stellenbosch University
- Genevéve Marx, Nelson Mandela University
- Itumeleng Monageng, University of Cape Town / South African Astronomical Observatory
- Francis Otieno, University of the Witwatersrand
- Valentine Saasa, University of Pretoria / CSIR
- Michael Sarkis, University of the Witwatersrand
- Hester Schutte, North-West University
- Katekani Shingange, University of the Free State
- Sinenhlanhla Sikhosana, University of KwaZulu-Natal
- Kimeel Sooknunan, University of Cape Town
- Tanita Ramburuth-Hurt, University of the Witwatersrand
- Johannes Thiersen, North-West University
- Nicole Thomas, University of the Western Cape / South African Radio Astronomy Observatory
- Danielle Venter, Nelson Mandela University.

Lindau Alumni

Rajesh Jantilal

In 2016 **Sphumelele Ndlovu** attended the 66th Lindau Nobel Laureate Meeting (#LINO16), which was dedicated to physics. At the time 'Sphume' was registered as a PhD student at the University of KwaZulu-Natal (UKZN), but was based at the Hartebeesthoek Radio Astronomy Observatory (HartRAO), where he had been invited to join the Professional Development Programme after completing his MSc in experimental physics.

His MSc research, on the 'experimental measurement of the fluctuations of a laser beam due to thermal turbulence', was just the type of experience needed in the HartRAO team working towards South Africa's contribution to the Lunar Laser Ranging (LLR) project, which uses laser light pulses to measure the distance between Earth and the moon. Reflectors were placed on the moon by three NASA missions (Apollo 11, 14 and 15) and two Soviet unmanned missions (Luna 17 and 21) between 1969 and 1973, so that the time taken for the reflected signal of laser pulses to be detected back at observatories that transmit them could be used to calculate the lunar distance. Of course, there is a huge loss of signal strength due to atmospheric effects and the large distance the pulses have to travel – about 770 000 km for the round trip – so the signal path must be optimised.

For his research on developing an analytical model to achieve optimal signal path efficiency, Sphume was awarded his PhD from UKZN's School of Engineering: Land Surveying (Geomatics) in April 2018. Incredibly, while doing his PhD he had also found the time to write a book about his life, called *Aiming for the stars*, which details how he overcame hardships and challenges. Raised in the rural village of eMaswazini by a single mother who sold chickens to provide for her family, Sphume's academic journey was almost derailed when 24 of his school's 28 teachers abandoned their posts due to strike action early in his matric year. As a result, he did not earn the matric exemption required to gain entry into university, but his good marks for maths and science meant that he was accepted into a bridging course at UKZN, known as the Science Foundation Programme. He was then able to start his degree two years after matric, and graduated with a BSc in Applied Mathematics and Physics in 2011. He progressed immediately to Honours and Master's degrees, the latter completed in only 11 months!

Sphume won the best PhD oral presentation at the 2015 South African Institute of Physics conference, and the following year he was selected to attend both the Lindau Nobel Laureate Meeting and the BRICS Young Scientists Conclave in India a few months later. Today he is the Deputy Managing Director of the Indabuko Institute, which he co-founded with Luyanda Noto, who also attended #LINO16. Situated on the CSIR's campus in Pretoria, Indabuko aims to provide next-generation energy storage systems that will last longer and are reliable, inexpensive and safe.

"Attending the Lindau Nobel Laureate Meeting in 2016 meant a lot of things to me," says Sphume. "I was actually selected as one of the 400 most qualified young scientists, from more than 80 countries, to be given an opportunity to enrich and share the unique atmosphere with 30 Nobel Laureates. I can't even say that was a dream come true, because I had never imagined myself being part of that environment or even meeting a single Nobel Laureate!"

"Sharing an environment with them – attending their panel discussions, having lunch at the same table with them, taking walks together and so on – for the whole week of the meeting, and them always being there to take our intelligent and stupid questions and answer them without making us feel less intelligent, made me realise that ubuntu is the most powerful tool that can be used to make our world a better place, all the time."

Lindau Alumni

In 2018 **Edith Phalane** participated in the 68th Lindau Nobel Laureate Meeting, which was dedicated to physiology and medicine. A PhD student at North-West University, Edith's research focusses on the long-term cardiovascular health of HIV-infected South Africans. She has overcome many challenges to get to this point, as she related to Ulrike Boehm for her blog, https://womeninresearchblog.wordpress.com, shortly before attending the meeting.

First, the death of her mother – the family's breadwinner – threatened Edith's ability to go to university, but she had worked hard enough to get financial assistance based on her academic achievements, and attended the University of Limpopo for her undergraduate degree. Another stumbling block came after she had to leave her MSc programme there after two years, without graduating, due to an administrative delay in obtaining ethical clearance.

"At a certain point I wanted to give up on my dream of pursuing my MSc and PhD in physiology because of this delay, but through the support of family, colleagues and friends I was able to hold on and switch universities," she explained. She registered at North-West University, and completed her MSc in one year! The following year, 2017, she started her PhD, but still found time to mentor learners by assisting them with their research projects for the Eskom Expo for Young Scientists.

Edith told Ulrike that other outreach work had been done with her colleague Blessing Ahiante, who also attended the Lindau Nobel Laureate Meeting. During May Measurement Month 2018, they helped raise awareness about blood pressure, diabetes mellitus, hyperlipidaemia and body weight amongst rural communities near Tzaneen.

"I believe that, as a researcher, you have not done justice if you do not go back to the communities and share your findings or knowledge on the project that you are working on, especially if it involves the lives of people," she said. "In particular, since I am working on cardiovascular disease development in HIV-infected individuals, it is of utmost importance to me to go into these communities to raise awareness on how to prevent and manage cardiovascular disease and how to prevent HIV transmission."

While at the Lindau meeting, Edith participated as a panel member for a discussion on 'Health innovation in Africa: the way forward', which was organised by the Global Perspectives Initiative as a side event. Two months later, she received another honour when she was awarded the Tata Doctoral Scholarship valued at R75 000 at the South African Women in Science Awards (SAWISA).

Reflecting on her participation in #LINO18, Edith remarks: "Attending the Lindau meetings is like entering the water, you will never come out dry. Engaging with fellow young scientists and the Nobel Laureates has motivated me even more to use my research outputs and knowledge to positively impact the lives of people."

"I would encourage every young scientist to use this wonderful opportunity, which comes only once in a lifetime. For that week I had the global village of science in my field of specialty, under one roof, to exchange knowledge and draw inspiration – there is nothing better than this for a young scientist."

Coding and Robotics to future-proof learners

Learners in South Africa will soon have the opportunity to take coding and robotics as school subjects.

Speaking at a media briefing in March, Minister of Basic Education, Mrs Angie Motshekga, said that the introduction of the new curricula will help prepare young people for the Fourth Industrial Revolution, which is driven by innovative technologies such as high-speed internet, automation, virtual reality, mobile supercomputing and artificial intelligence. These technologies will not only have a significant effect on daily life, but will also impact the job market.

"The curricula will ensure that our schooling system produces learners with the foundations for future work, and equip them with skills for the changing world," said Minister Motshekga.

Coding

The University of South Africa (Unisa) has partnered with the Department of Basic Education by making their 24 information and communications technology (ICT) laboratories countrywide available for teachers' training in coding. Other partners – including Google and Africa Teen Geeks – are assisting in developing a coding platform that will allow teaching to be customised to individual students, taking their aptitude, learning speed, background and responses into account.

"The plan is to make this coding platform available in all 11 languages, ensuring that rural and township children will be introduced to coding and robotics in their own mother tongue."

Coding will be introduced in 2020 as a pilot for Grades 7 to 9 in a thousand schools in five provinces, but

ultimately the plan is to train at least three teachers in each of the 16 000 primary schools to teach the subject.

Robotics

The robotics curriculum will enable learners to build and operate robots, growing their skills in science, technology, engineering and mathematics (STEM), while also helping to develop their creativity, critical thinking, design thinking and digital skills. These attributes would equip learners to contribute to building an innovative culture in South Africa.

"This robotics curriculum will not require any infra-structure or devices, but will need maker spaces to provide hands-on, creative ways to encourage students to design, experiment, build and invent – for example, through cardboard construction activities," said Minister Motshekga. "The projects will become more challenging as the grades progress. In Grade 9, the learners will be taught how to build a computer from scratch."

There are already a number of robotics competitions for learners in South Africa, including the World Robot Olympiad (WROSA), the FIRST (For Inspiration and Recognition of Science and Technology) Lego League (FFL) and Tech Challenge (FTC), and the recently launched Parabotics. In the WRO competition, the 10 winning teams participated in the WRO International Event in Thailand in November. The latest FFL national competition was won by Team ASAP from the German School in Cape Town, while Team Fifth Order from Hoërskool Waterkloof in Pretoria took first prize in the FTC national competition. Both teams were invited to the FIRST World Championship in Detroit, USA, in April.

Shaun Redgard (captain), Chantelle Booysen, Dr Hendrik Van Heerden (coach) and Edward Lee were declared the winning team at the 2019 International Natural Sciences Tournament, held in Estonia.

Beating the Russians at their own game

Three postgraduate students from the University of the Free State (UFS) returned triumphant from the International Natural Sciences Tournament in February, after being declared the winners!

The tournament was started by Russian scientist Dr Sergey Safanov in 2010 and has been held annually since then, but the UFS team only became aware of it when the current Tournament Director visited the UFS Chemistry Department in the middle of 2018. Participation in the tournament provides a unique opportunity for students to apply their knowledge in solving problems of a practical nature.

After qualifying to attend the tournament on the strength of their solutions submitted online for a set of problems posed by the organisers, the team headed overseas for the three-day event, this year held at the Tallinn University of Technology in Estonia. 'Team UFS' consisted of the captain Shaun Redgard (Department of Chemistry), Edward Lee (Department of Physics) and Chantelle Booysen (Department of Haematology and Cell Biology), as well as their coach, Dr Hendrik Van Heerden.

"There was quite a short period between qualifying and the event, so many of the qualifying teams couldn't make it because they had other responsibilities, or struggled to get visas or funding in time," says Dr Van Heerden. "We found out when we got there that we'd be competing against only five other teams, all from Russia."

Those teams were made up of students from eight different Russian institutions situated between 1 000 km and 4 200 km from Tallinn, which is the capital of Estonia and lies on the shore of the Baltic Sea, across the water from Finland's capital, Helsinki. So although many of the students had travelled some distance to participate in the tournament, this was nothing compared to the more than 15 000 km covered by Team UFS!

The tournament format is that all of the teams are given 10 problems, and have to choose eight to solve. They then compete in round-robin challenges, in which one team acts as the Speaker – presenting the solution to the problem – another is the Opponent and a third is the Reviewer. The Speaker's presentation is limited to 10 minutes, the Opponent's to five minutes and the Reviewer's to three minutes, but there is also back-and-forth discussion and questioning between these speeches, so each challenge lasts just under an hour.

"It's like a debate – you have to defend your scientific solution against other teams," explains Dr Van Heerden. "The Jury judges who made the best scientific argument on both sides."

The tournament was conducted in English, and most of the Jury members were experts from Europe. Asked whether the Russian teams were at a disadvantage because of the language barrier, Dr Van Heerden says that science was the determining factor, so language issues did not matter.

"There were some Russian teams that were very good, but we had stronger arguments for our science than theirs. We simply beat them at their game!" he quips.

During the final, Team UFS acted as the Speaker for 'The Chinese study' problem, the Opponent for 'The Olive' and the Reviewer for 'T-1000'. In all three roles, they did well enough that their combined total score was the highest, making them the winning team. The runner-up was the wonderfully named Team 'How Do You Like That, Elon Musk?', while Team 'Shock Wave' came third.

Dr Van Heerden noted that consideration is now being given to approaching other universities in South Africa about holding a national round of the competition.

Brain-teasers

These are some of the problems the UFS team tackled. See if you can solve them!

T-1000

The colour of some insects is based not on pigments, but on the surface morphology. Recently, scientists were able to apply a similar approach to metals, as a result of which the surface acquired super-hydrophobic properties and became almost completely black. Suggest your own methods for creating different solid colours of metals only by modifying the surface structure of the metal or alloy itself. Assess the thermal, chemical and mechanical stability of such a surface, depending on what colour is created. Suggest applications for the metal products with such a surface.

The Chinese study

During 2018 some batches of the drug valsartan, the active substance of which was produced by the Chinese company Zhejiang Huahai Pharmaceuticals, were recalled from the pharmaceutical market. The reason for the recall was the presence of a dangerous impurity, N-nitrosodimethylamine (NDMA), in the active pharmaceutical substance. NDMA is highly hepatotoxic and is classified as a proven carcinogen. Its presence in valsartan is believed to be caused by changes in the production method of the active substance. What do you suppose was the source of NDMA in the active pharmaceutical substance? How should the way it is produced be modified to avoid the appearance of this impurity? Is it possible to effectively purify the supplied substance from NDMA? If this is possible, suggest an alternative production scheme, which excludes the appearance of NDMA in the substance.

Breakthrough Starshot

Breakthrough Starshot, announced in 2016, is a programme that aims to send micro-probes to the Alpha-Centauri star system. This will be the first interstellar flight of an object developed by humans. The probe used in the programme is a set of measuring instruments weighing 1 gram and equipped with a solar sail. An array of lasers is supposed to be used to accelerate the entire structure to 20% of the speed of light. One of the unsolved problems of the project is the material of the solar sail: since it is accelerated to high speed, the sail can suffer from star dust or overheat by reflected light. Suggest a physical model of the solar sail and your material options, which would have a high light-reflection factor, be heat-resistant, lightweight and durable.

The Olive

According to various estimates, more than half of all sold olive oil is counterfeit. One of the main methods of adulteration is adding cheaper low-quality oil. This threatens to cause great economic damage to stores and large oil producers, plus cases of serious health problems and even death of consumers have been recorded. To date, the control of quality and authenticity of olive oil requires a series of analyses, which is too labour-consuming, since each batch of oil must be analysed. Suggest a method, or the minimum possible number of analyses that could be easily applied to numerous samples, to detect the addition of other oils to olive oil in an amount of more than 1% by weight.

Vitamin sea

With the development of aviation, moving around the world has become very simple and affordable, and within a day you can get to anywhere in the world for work or vacation. Evolutionarily, the human body is not adapted to such a drastic change in external conditions, which leads to significant discomfort and possible health problems. Explain the mechanisms that occur in the body during the adaptation to new environmental conditions when travelling to different climatic zones, and suggest a way to accelerate acclimatisation based on the described mechanisms.

WALL-E 2.0

In 2009 the commercial communications satellite Iridium 33 collided with the decommissioned communications satellite Kosmos-2251. This collision created a large amount of debris, and increased the mass of industrial waste in the Earth's orbit. Space debris is a severe problem for launching and operating spacecrafts, yet still there are no reliable ways of cleaning it up. Propose your own technology for removing space debris, as well as assess and justify its recyclability.

Char Ecosystem

The StarCraft series of computer games features the planet Char – a volcanic world with a high temperature (due to which the lava does not freeze even on the surface) and a complete lack of vegetation. However, it is inhabited by a huge number of alien creatures called zergs. Judging by their appearance, all zergs – even the weakest and most numerous of them – are predators. How could the Char ecosystem be arranged then? What serves as food for so many predators if there are no traces of autotrophs on the surface of the planet? Your solution should not contradict the known laws of biology and ecology. You can find more information about this fictional planet at:
https://starcraft.fandom.com/wiki/Char.

Smartdryer

When travelling, a person may need various heating devices – a hair dryer, a kettle, a shoe dryer, a heater, etc. All have a similar operating principle, but they differ greatly in power and efficiency. Offer the concept of a compact universal heating device that performs the functions of the above devices in reasonable time for each case.

International Natural Sciences Tournament:
http://www.scitourn.com/inst/

The pen is mightier...

The Young Science Communicators competition, organised by the South African Agency for Science and Technology Advancement (SAASTA), provides a platform for young people studying science to share stories about their work and develop their communication skills. More than 200 entries were submitted for the most recent round of the competition, which included five categories – article, open, indigenous language, video and audio.

Here *Quest* features the winner and runner-up of the article category.

WINNER

Spilling the 'salt' on a shaky situation

By Michél Strauss

It needs more salt! A common phrase uttered around the dining table of most. For what harm lies in an extra pinch of salt here or there?

Cardiovascular disease! A damaged heart and blood vessels! The mere thought of tackling a leading cause of non-transmittable disease-related deaths, not only in Africa, but globally, seems overwhelming. It would appear that one needs a big solution for a big problem.

However, despite medical advances allowing for more effective pharmacological approaches to decrease cardiovascular disease, it remains a stumbling block in areas where poverty or limited access to health care prevails.

For thousands of years salt, an ionic compound comprised of sodium and chloride, has been used as a preservative and seasoning agent in food. While accessibility to processed foods has contributed to an increase in dietary salt intake, the sodium content of several staple foods, including bread, cereals and margarine, has also been identified as being excessively high. Yet despite the already high sodium content of processed foods, many of us still have the habit of adding extra salt at the table or during cooking. This leads to the question of how many South Africans are informed about the salt content of their food, and also about the health risks associated with something as small as our habitual salt use.

Therefore more attention has been brought to achievable health strategies that will be beneficial to all – including diverse and far-reaching communities. A big solution starts with a change in small habits.

Cardiovascular risk: rubbing salt into the wound

Scary statistics from 2010 indicated that almost 1.65 million cardiovascular disease-related deaths, globally, were attributed to a high salt diet. But how does that extra pinch of salt influence your cardiovascular health? And how much is too much?

Both sodium and chloride, which make up salt, play essential roles in the regulation of various physiological systems, from cellular to kidney and heart function. The current recommendation from the World Health Organisation (WHO) is less than 5 grams of salt per day. The global salt intake is, however, almost double this amount. In South Africa the daily salt intake is approximately 8.5 grams per day.

The most widely described risk associated with excessive salt intake is high blood pressure, also known as

Omari Bernard

TYPICAL NUTRITIONAL INFORMATION		
Typical Nutritional Information (as packed)	Per 100 g	Per (2.5 g) Serving
Energy (kJ)	1302	32
Protein (g)	3.4	< 0.1
Carbohydrate (g)	19	< 1
of which Total Sugar (g)	0.3	< 0.1
Total Fat (g)	25.4	0.6
of which Saturated Fat (g)	18.5	0.5
Dietary Fibre (g)	0.5	< 0.1
Total Sodium (mg)	17206	430

hypertension. From a pathophysiological point of view, this is resultant of an increase in blood volume (water retention following high salt intake) that increases the pressure in your blood vessels. This also increases the amount of blood that returns to your heart and will be pumped through your circulation – therefore increasing your heart's work rate. Amazingly, our bodies are equipped to maintain a healthy environment via the inter-regulation of several physiological systems to once again lower this pressure and your heart's work rate. At some point, however, these systems become dysfunctional and the protective mechanisms are lost – increasing the load on your cardiovascular system. Additionally, salt may cause blood vessels to become stiff – thereby contributing to high blood pressure. Intriguing new evidence even suggests that salt affects the gut bacteria that may play a role in hypertension development.

South Africa on the forefront: be part of the solution

With the alarmingly high salt intake and the undeniable cardiovascular risks, it is unsurprising that global leaders from the United Nations and the WHO acknowledged salt reduction as a priority. Few countries, including South Africa (the first African country), have implemented mandatory sodium reduction legislation, lowering the sodium content of staple foods in an effort to reduce daily salt intake.

Interestingly, in South Africa a 0.85 gram salt reduction could prevent approximately 7 400 strokes and heart attacks per year. Thus, South Africa is on the forefront when it comes to taking on a more sustainable solution to improve the national burden of hypertension and cardiovascular disease, of not only the wealthy but all South Africans. Taking into consideration all of the above, our habits still remain in our hands, and it is up to us to make the cautious decision with regards to our salt use and cardiovascular health.

A little food for thought: think twice before adding that extra pinch of salt.

Michél Strauss is currently completing her PhD degree in physiology at North-West University. Her research is centred on gaining a better understanding of the development of cardiovascular disease, with the focus on black South African populations. Her research forms part of the African-PREDICT study, which aims to identify and highlight early cardiovascular risk factors in the youth, to assist in the implementation of more successful prevention strategies. It was meeting the participants in the study, and seeing how some of them were unaware of how their lifestyle choices could influence their health, that motivated her to write this article.

RUNNER-UP

Superbugs: the end of an antibiotic era?

By Yashini Naidoo

NIAID

Growing up, I never understood the compulsion my mum had with washing her hands – at home in the kitchen, after the bathroom, out in public restrooms. Why did she insist that I do it? Her response: "Germs, they will make you sick". Germs, some better known as bacteria, are microorganisms that exist in their millions in every environment. They outnumber every other kind of life form. Many are useful but some are dangerous, especially those that cause disease. Before the 20th century, infectious diseases were the main cause of mortality worldwide. Aggressive bacteria that were reproducing at alarming rates led to serious illness and death.

Antibiotics, introduced in the early 1940s, changed the world by saving countless lives. The period from 1950 to 1960 was considered the 'Golden Age' of antibiotics, as many of them used today were discovered back then. The success of antibiotics by the end of the 1960s was so impressive that clinicians believed that the battle against bacterial infections was won.

Pexels


Pixnio

Soon after the clinical introduction of antibiotics, though, antibiotic-resistant bacterial strains began to surface. Antibiotic resistance threatened to turn back the clock by spreading at an alarming rate. Bacteria demonstrate resistance to antibiotics in many complex ways, but mostly from the overuse, abuse and a lack of enforced regulation of antibiotics. In the first decade of the 21st century, antibiotic resistance became a fast-growing problem, with the front-runners being 'superbugs'. Superbugs are strains of bacteria that are resistant to several antibiotics, making them difficult to treat.

How has this problem translated in South Africa? We have a very high HIV/AIDS burden and, added to that, a high prevalence of risk factors for other communicable diseases such as TB. This results in a high occurrence of infectious diseases, triggering the extensive use of antibiotics. The result: an increase in resistance.

The overuse of antibiotics propagates the spread of antibiotic contaminants in the environment, specifically in our water. One of the biggest problems South Africans face currently is the availability of and accessibility to clean water. Many communities in SA only have access to water that is unprotected and unsafe for consumption. Around 26% of the sewage in SA is inadequately treated before being discharged into rivers and streams, causing a major threat to communities accessing this water. Studies from Stellenbosch University and the Medical Research Council have reported a massive increase of pharmaceuticals in surface waters. Among the many pharmaceutical classes found, antibiotics were present in large amounts.

Scientific studies suggest that approximately 75–90% of antibiotics enter sewage systems and water resources. This is not just from human consumption. Antibiotics are used in livestock in the treatment and prevention of disease and to promote growth in healthy animals. Wastewater treatments do facilitate the breakdown of these compounds, but the toxicological effects of these compounds are not fully understood.


Joel Wright

Simply put, we are not sure how this affects people drinking contaminated surface water from lakes, dams and rivers and how or if this accelerates the dissemination of antibiotic resistance. The recent water shortage in the country has the potential to exacerbate the problem because drought situations encourage fewer hygiene practices in favour of saving water. Less handwashing increases the transmission of bacterial infections like *E. coli* diarrheal disease. The treatment of infection results in the use and overuse of antibiotics which perpetuates this unending spiral of resistance.

What can we do to help the burden of antibiotic resistance? One of the biggest problems we face is the lack of awareness. The World Health Organisation lists a few simple ways to help reduce the spread of resistance. For instance, do not demand antibiotics when visiting the doctor because antibiotics cannot be used for viral infections like influenza. Be certain to finish the course of antibiotics prescribed to you. Be sure to take antibiotics only when they are prescribed by a doctor and, finally, do not share antibiotics with others.

Every November is World Antibiotics Awareness Week, encouraging good antibiotic practices, and this starts with us. Furthermore, there is unprecedented importance in this statement: "wash your hands".

Yashini Naidoo is a PhD student at the University of Pretoria. She is investigating antibiotic resistance in Namibian Desert Soil as part of a global effort to inform and assist the One Health concept in antimicrobial resistance. She would like readers to recognise the impact of improper use and overuse of antibiotics, and be aware of how we can all help to alleviate this burden.

The winning entries of the other categories of the competition can be viewed at: https://www.saasta.ac.za/competitions/young-science-communicators-competitions/.

Indigenous Knowledge

Legal developments, higher learning and research funding

On 5 March 2019 the Protection, Promotion, Development and Management of Indigenous Knowledge Systems Bill was finally passed by Parliament and sent to President Cyril Ramaphosa for signing into law, having initially been published for public comment in February 2015 and then tabled in Parliament in April 2016.

The Bill is designed to give legal effect to the Indigenous Knowledge Systems (IKS) Policy approved by Cabinet in 2004. Its main objective is to protect the indigenous knowledge of indigenous communities from unauthorised use, misappropriation and misuse.

Anyone intending to use indigenous knowledge for commercial purposes will need to apply for a licence to do so, and the benefits arising from such commercial use will be fairly shared. In addition, indigenous knowledge practitioners – such as traditional healers, or *sangomas* – will in future need to be certified by accredited assessors in order to 'practise for gain'.

Once the Bill has been signed into law, the new Act will be implemented by the National Indigenous Knowledge Systems Office (NIKSO), which was set up as a unit within the Department of Science and Technology (DST) in 2006 to facilitate the IKS Policy objectives.

The DST has also established an Indigenous Knowledge-based Bioinnovation Programme, which has six platforms: African medicines, cosmeceuticals, nutraceuticals, health beverages, technology transfer and incubation, and commercialisation.

The DST is supporting a number of small enterprises, cooperatives and individual entrepreneurs in their indigenous knowledge ventures by, for example, providing training in aspects such as agricultural practices and financial management, as well as assisting in the development of business plans for marketing and commercialisation.

Learners interested in focussing on indigenous knowledge studies at university can choose between North-West University (NWU: Mafikeng campus) or the University of Venda (Univen), both of which offer an undergraduate Bachelor of Indigenous Knowledge Systems degree.

At postgraduate level, a number of universities have strong research programmes in indigenous knowledge, some projects being funded through the Indigenous Knowledge Systems Funding Instrument, administered by the National Research Foundation. The funding instrument focusses on experimental research that will lead to mutual benefits for both researchers and communities, under the following themes:

- IKS and bioeconomy (African traditional medicine, food security, technology, nutraceuticals, health, beauty and cosmetics)
- IKS epistemology (ubuntu and cosmology, taxonomies, pedagogies and methodologies)
- IKS and climate change (environmental management)
- Women and IKS-based technology innovations
- IKS and energy (alternative and clean sources)
- IKS practices among specific communities, in particular of Khoi, Nama, Griqua and San communities
- Issues involving the San and Khoi communities
- Novel and creative thinking that will shift the boundaries of IKS knowledge production and that address national priorities in South Africa
- Capacity building, development of high-end skills on knowledge generation and human capacity development
- IKS and astronomy
- IKS legislation and public policy
- Indigenous farming practices
- Story-telling and music.

Recognising the need to raise awareness about the importance of indigenous knowledge, *Quest* will include content on IKS research in future issues.

Did you know?

2019 is not only the International Year of the Periodic Table. It is also the International Year of Indigenous Languages (IYIL2019), proclaimed by the United Nations to raise awareness of the need to preserve, revitalise and promote indigenous languages around the world. Languages play a crucial role in our lives as a tool for communication, education and social integration. They are also at the heart of each person's unique identity, cultural history, traditions and memory, making them an important part of indigenous knowledge.

Ubuwazi nje?

Ukuthi u 2019 akusiwo nje kuphela unyaka we tafula le periodic emhlabeni wonke. Kodwa unyaka wezilimi zendabuko emhlabeni wonke jikelele (IYIL2019), ngokusho kwenhlangano yezizwe kubalulekile ukuthi kuqwashiswe, futhi kuvuselelwe ulwazi ngezilimi zendabuko kumhlaba wonke. Izilima zidlala indima esemqoka ezimpilweni zethu njengendlela yokuxoxisana, yokufunda no kuhlanganisa imiphakathi. Ziwumgogodla womuntu ngamunye ukutshengisa imvelaphi yakhe, imvelaphi yamasiko, namasiko akhe jikelele, yingakho zibalulekile njengenxenye yolwazi lwendabuko.

Translation by Zamantimande Kunene

Traditional medicines in sport

Soccer star Teko Modise revealed startling details in his 2017 biography about *muthi* rituals performed by the Orlando Pirates team before games. The secrecy surrounding such practices makes quantitative data collection difficult, but a recent study published in the *Indilinga African Journal of Indigenous Knowledge Systems* (Mulungwa *et al.* 2018) explored the use of African traditional medicines and rituals in South African football by interviewing five former professional players. Three of these study participants were Sotho, while the other two were Ndebele and Tswana, hailing from Limpopo Province, North West Province and Mpumalanga.

All indicated that they had used traditional medicines for treating illness and injuries, enhancing their own sport performance, and partaking in team rituals. Some of the substances mentioned are known to have harmful effects, however, while lack of knowledge about the ingredients in traditional medicines administered by the team *sangoma* may put players in breach of World Anti-Doping Agency (WADA) rules. For example, although cannabidiol from cannabis *(dagga)* is permitted, it is very difficult to extract in pure form from the plant's other components, which are prohibited in sport. These banned substances may be detected in urine samples for weeks or months after cannabis use.

Celso Flores, Wikimedia

Fish parasite named after Xena, warrior princess

Worldwide, the crustacean genus *Elthusa* comprises 33 species, all of which are parasites of fish. Most attach themselves inside their host's gill cavities, although two species inhabit the mouth cavity. Previously only one species was known from South Africa, but a recent survey discovered three new species, described in the open-access journal *ZooKeys* (Van der Wal *et al.* 2019).

The research team from North-West University – Serita van der Wal, Prof. Nico Smit and Dr Kerry Hadfield – named one of these species after the fictional character Xena, the warrior princess, because the females appeared particularly tough. Additionally, the holotype (the first specimen used for the identification and description of the previously unknown species) is an egg-carrying female.

Formally recognised as *Elthusa xena*, this new-to-science species is so far only known from the mouth of the Orange River, on the west coast of South Africa. It was recovered from an intertidal Super klipfish, *Clinus supercilious*, and is in fact the first time an *Elthusa* species has been recorded from any klipfish species. To describe the new species, the scientists borrowed all South African specimens identified as belonging to the genus *Elthusa* from both the French National Museum of Natural History in Paris and the Iziko South African Museum in Cape Town.

Serita van der Wal

Books

The first safari: Searching for François Levaillant

By Ian Glenn • 230 pp. Jacana Media. R260

François Levaillant is considered a pioneer of South African ornithology, as he described more than 150 species of birds observed during the four years he spent here in the early 1780s. He wrote accounts on the behaviours of many of these, and took stuffed specimens back to Europe, where they were sold to museums and private collectors. According to this book's blurb, *Levaillant's Travels into the Interior of Africa* – first published in French in 1789 – was a best seller in Europe and remained the most widely translated text on South Africa until Nelson Mandela's autobiography two centuries later!

Crediting Levaillant with the 'first safari' is a bit of a stretch, though, since a number of naturalists had gone before him, and Levaillant clearly followed the same routes as Robert Jacob Gordon, with whom he stayed in Cape Town. Glenn's book does not offer much about Levaillant's travels in any case. Instead, it covers his own experiences in researching Levaillant's life and trying to find his notebooks and bird collection over a period of 25 years. It reads a little too much like a thesis, rather than popular non-fiction; indeed, Glenn states in his preface that much of the material has been 'rehearsed' in academic publications. Nevertheless, it should appeal to birders, biographers and budding historians.

Beachcombing in South Africa

By Rudy van der Elst
144 pp. Struik Nature. R180

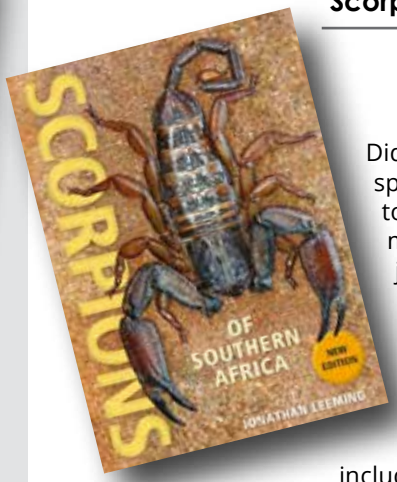
This is a worthwhile addition to the bookshelf of anyone who spends a lot of time on the beach, and is the perfect gift for those who regularly holiday at the coast. It's a compact little book but is packed with information, attractively presented in a way that will appeal to young and old. Rather than being a field guide for identification down to species level, it gives a broad overview of the plants and animals of the seashore, providing enough detail to recognise the main groups and some common species. There are chapters on 'floaters and drifters' (such as goose barnacles and bluebottles), 'sea-beans' (seeds and fruits distributed by the sea), and everything from shark egg cases to shrimps, shells, shore birds and more.

The book also covers maritime objects that might have washed up, like buoys and floats, fishing lures and light sticks, and scientific equipment, including fish tags and drift cards. Boxes on topics such as the sardine run, seaweed art, sea salt, seal population management and even dolosse – the concrete structures designed by a South African harbour engineer to dissipate wave energy – provide additional interest.

The author, Rudy van der Elst, is well qualified to write this book because he was director of the Oceanographic Research Institute (ORI) in Durban before his retirement. He now lives in Mossel Bay, where he has a little more time for beachcombing and other coastal pursuits.

Scorpions of southern Africa

By Jonathan Leeming
96 pp. Struik Nature. R230



Did you know that some species of scorpion are able to live without food for more than a year? This is just one of the fascinating facts mentioned in this updated edition of a book that was first published in 2003. It has a new design, which is neat and colourful, and includes an additional 12 species in the identification guide making up about a third of the book.

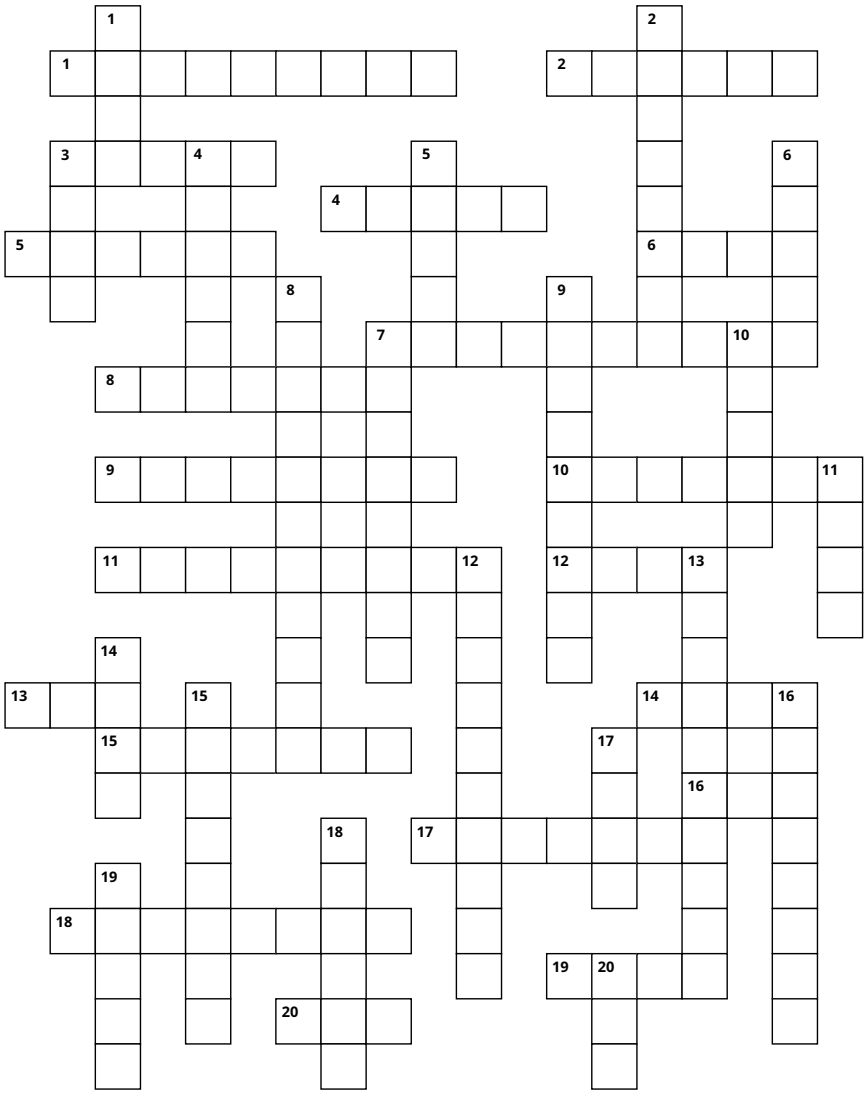
Although there are more than 135 scorpion species in southern Africa, belonging to four different families, the guide covers only the 69 species most likely to be encountered. For each of these, a short description of identifying features and habitat is accompanied by a photo and a map showing the known distribution of the species.

Other sections of the book explain how to distinguish the more venomous from mildly venomous species, and describe the consequences of being stung – three species are responsible for a small number of fatalities annually.

There is a comprehensive overview of the anatomy, behaviour and reproduction of scorpions, which includes their various adaptations to living in a harsh environment. The final section provides tips on observing scorpions, most of which are nocturnal, and addresses their conservation.

Test your knowledge

Most of the answers can be found in this issue of *Quest*.



Across

1. This reduces the storage capacity of dams
2. A component of salt
3. A type of fossil involving an impression
4. South Africa's online marine monitoring system
5. A new curriculum for computer geeks
6. Acronym for 2019 celebratory year
7. Bony plates in the skin of reptiles
8. South Africa's warm sea current
9. Relates to scientific investigation of crimes
10. Livestock trampling and grazing can increase this, resulting in land degradation
11. This lizard bites its tail when threatened
12. The current in 8 flows down this coast
13. A marine conservation 'tool'
14. The hominin fossil Little ...
15. ZACube-2 is one of these
16. The species name for a fierce dinosaur
17. Part of the inner ear
18. The term for birth of live young after nourishment within the mother's body
19. The type of radiation used in microCT
20. A system for tracking ships

Down

1. The Latin word referring to 'living'
2. Metal 3D printing is called ... manufacturing
3. Astronomers measure its distance with reflected laser pulses
4. The Nobel Laureates will gather here
5. Cyclical movement of the sea
6. An international convention relating to shipping
7. Calcareous plates in brittle stars
8. The group that includes starfish and brittle stars
9. A member of the Cape Supergroup
10. Relates to imitating
11. A term indicating extreme smallness
12. The scientific name for brittle stars
13. Micro-computed ...
14. The chemical formula for table salt
15. A geological term for sudden burial
16. The science of classifying, describing and naming organisms
17. Consuming too much is a health risk
18. Crab that uses an empty shell for shelter
19. The term for an animal that walks on two legs
20. An abbreviation for the process of developing new or improved products and systems

QUEST MATHS PUZZLE NO. 49

What is the highest four-digit number, with no zeros, in which the first digit is one-quarter of the third digit, the second digit is three times the first digit, and the third and last digits are the same?

Answer to Maths Puzzle no. 48: One possibility is 954 – 459 = 495

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The Periodic Table of Chemical Elements

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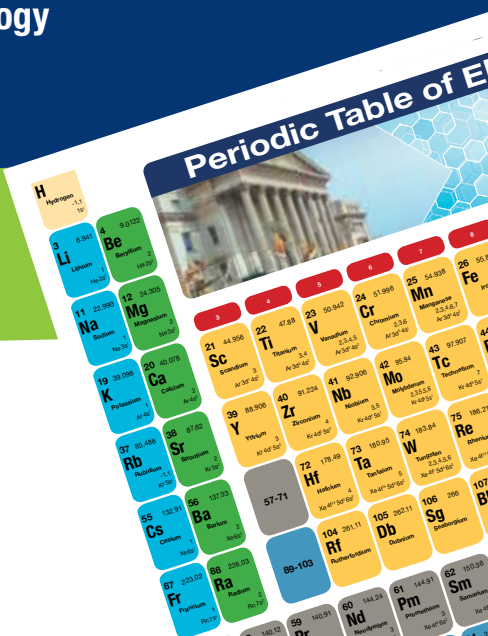
- Is a unique tool, enabling scientists to predict the appearance and properties of matter on the Earth and in the rest of the universe



If your school would like a copy of a periodic table, please contact obidie.maunze@wits.ac.za

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