The Nobel Prize in Physics 2022: recognizing the steps towards our quantum future

On Tuesday 4th October the Nobel Prize in Physics 2022 was awarded jointly to Alain Aspect (France), John F. Clauser (USA) and Anton Zeilinger (Austria) "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science". The committee noted that "they each conducted groundbreaking experiments using entangled quantum states, where two particles behave like a single unit even when they are separated. Their results have cleared the way for new technology based upon quantum information". The South African Institute of Physics extends its heartfelt congratulations to the awardees for this tremendous recognition.

The popular account of entanglement is replete with connections to Schrodinger's cat and spooky connections between distant particles. For some time, it was deemed possible that perhaps Nature has hidden mechanisms to allow entangled particles to behave as they do – the world would appear ''normal'' if we just had all of Nature's insights. To follow the quantum trail that has since emerged, we must go back 50 years to the early 1970s, when John Clauser and doctoral student Stuart Freedman showed the first violation of a Bell inequality, a test of correlations as predicted by quantum mechanics versus other interpretations based on hidden variables. A decade later, Alain Aspect removed a major loophole by having time adjustable measurement settings, allowing the detection to be fixed only after the entangled photons left the source, so they could not conspire to give correlated outcomes. These two experiments confirmed that Nature has no unique reality, there is no spooky communication between the particles, and removing the possibility that hidden variables could explain the correlations observed in quantum entangled particles. Their work confirmed the unusual properties of quantum entanglement as predicted by theory, but the harnessing of that as a resource was still very much in its infancy.

It was only towards the turn of the century that entanglement as an experimental resource took off, starting with the first experimental demonstration of quantum teleportation in 1997 by Anton Zeilinger and his team, quickly followed by routine entanglement generation in optical laboratories (as well as non-optical approaches) the world over. His initial experiments followed that of Clauser and Aspect and used polarisation as a degree of freedom for qubit (two dimensional) entangled states. In 2001, Anton Zeilinger demonstrated the first extension to spatial modes as a basis, for high-dimensional entangled states, the so-called qudits. The explosion in activity since then has been dubbed the second quantum revolution, harnessing entanglement for secure communication, enhanced imaging and sensing, and faster computing, with investments exceeding billions of euros.

All three Nobel laureates have made their impact on African researchers through attending and teaching at quantum schools and workshops (see figure), contributing as people as much as by their science. Inspired by the trio, the first quantum entangled correlations in South Africa/Africa were reported only in 2012 by the quantum group at the Council for Scientific and Industrial Research (CSIR) (now at the University of the Witwatersrand, Johannesburg) using entangled Bessel photons, this following important work on single photon quantum key

distribution at the University of KwaZulu-Natal that led to the quantum stadium project in 2010. Today South Africa, too, has entered the quantum race with the adoption in 2021 of the South African Quantum Technology Initiative (SA QuTI) (supported by the Department of Science and Innovation (DSI)) and first tranche of funding being released. The SA QuTI is coordinated by the University of the Witwatersrand and executed through nodes across the country, including the National Metrology Institute of South Africa (NMISA), Stellenbosch University, Cape Peninsula University of Technology, University of KwaZulu-Natal and the University of Zululand. The plan is to nurture and grow a quantum community and convert science to technology.

This year's award is much deserved, and recognizes the early steps towards our quantum future, a once distant dream that now seems an imminent reality.

Figure 1: Alain Aspect (middle) with then students Jason Webster (left) and Isaac Nape (right) at a Quantum Africa workshop. Dr Nape is now a young emerging quantum leader at Wits.