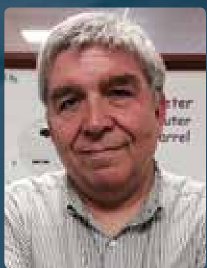
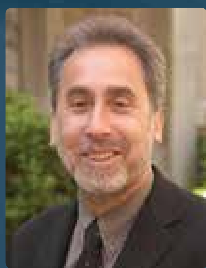
Spreading **the net**

Educational Specialist Kenneth Cecire and **Professor Mitchell Wayne** discuss the long-term benefits in making particle physics more accessible to a wider audience





Could you provide context to the masterclasses and the QuarkNet project; when did they first begin and what are their main aims?

KC: The masterclasses began in the UK in the late 1990s. Their main aim is to successfully bring particle physics data to students, to make measurements and understand a little more about how physicists conduct their work. Part of that is achieved through working on the data, and the other is by working directly with physicists.

Since then, QuarkNet has become very involved in the growth of International Masterclasses. QuarkNet staff and teachers collaborate with physicists to organise the masterclass institutes and videoconferences for the Americas and the Pacific, and to develop the Compact Muon Solenoid (CMS) masterclass measurements used worldwide.

MW: QuarkNet began in 1999. The aims are to bring high school teachers and students into particle physics and the research community in order to spread information and excitement about our field, and to teach and inspire future scientists. One of the original ideas was to involve participants in the early stages of big experiments running at CERN in Geneva, Switzerland. At that time, the future young researchers – graduates, postdocs and young faculty members – were in junior high and high school. We now provide national development programmes for physics teachers around the country by bringing them together and working with them on their research.

How do you balance the need for lab-based research with practical application and field work? Is there still a need for research for research's sake?

MW: Of course there is still a need for basic research. Most if not all of our practical applications came from basic research. A wonderful example of this was the recent 25th anniversary of the World Wide Web, which was invented at CERN during their basic research. When magnetic resonance imaging (MRI) was invented it was not intended for healthcare, but for looking at the properties of protons. There are so many areas that have advanced because of basic research. Of course, there is also an innate desire to understand and explore the world around us and I don't think you could turn it off even if you wanted to.

Educational resources are becoming increasingly integrated into online learning environments. Why is this beneficial to both student and educator?

KC: This goes to the heart of what we do at QuarkNet, and what our masterclasses try to achieve. Because we have online learning environments, first of all, we open new ways to learn. For example, one of the current actions taking place in the US is the flipped classroom; it is a new pedagogical model I've heard of where students go online, absorb a particular lesson through a video or interesting website and complete their 'homework' at school under the mentorship of a teacher. This reversal of lectures and homework changes the dynamic of teaching entirely.

Closer to what we do, however, is that we provide students and teachers with new kinds of opportunities. For example, visiting a university or talking with members of CERN and Fermilab in their own classrooms is already a tremendous opportunity, but data is another significant aspect. We give students the opportunity to put their fingers deep into data. They see science as it is being conducted.

Do you work with industry and/or other universities in your pursuits?

KC: The only example that comes to mind here would be through the cosmic ray detectors. We have developed relationships with vendors who can customise tailored electronics. We work with many other universities – that's the nature of particle physics, and we are collaborating all the time.

For QuarkNet, innovation is key. By what means does it remain cutting-edge in its teaching?

MW: Because we are tied to particle physics, innovation happens almost automatically. It's important to emphasise that it has been a long programme (more than 15 years) and as such we are always looking out for new ideas and techniques, and other programmes. What QuarkNet has now, in terms of its facilities as a national programme, is completely different from what it had at the beginning. For instance, in our cosmic ray eLab programme we provide free small particle physics detectors to classrooms that the students can use to collect data and then share across the world and with other classrooms. Masterclasses and eLabs are innovations that have been adopted by the programme as we have grown, and we will continue to adopt new ideas in the future. It's a continuous process.

MASTERCLASS IN AUSTRALIA, OCTOBER 2014

Feeling the pull of particle physics

For the past 15 years, an education and outreach programme at the University of Notre Dame has been building its reputation as a support system for students and teachers alike. In order to dispel physics appearance as an elusive subject, the QuarkNet programme offers stimulating tools to change the perceptions of budding young scientists

TO THE UNINITIATED, particle physics can seem a mysterious and impenetrable discipline despite some proponents of physics – Einstein, Newton, Heisenberg, Faraday – and their achievements being firmly rooted in the popular consciousness. The discovery at CERN of the Higgs boson in 2012 brought the field to the fore once again and has helped to re-establish physics as a worthy pursuit, but the disparity between what students are learning in school and how it is being applied at the cutting-edge of discovery can at times make the realities of a career in particle physics a daunting prospect.

For nearly two decades, physicists and education specialists have been running an inclusive programme in the US dedicated to bringing the subject to a much wider audience. Piquing the curiosity of students, helping teachers develop their skills and enabling a broader understanding of physics among the general public, QuarkNet offers a chance to see how the discipline is applied and what is involved with the realities of the field. "If you watched a documentary about string theory, you'd be amazed but it remains very arcane," states Kenneth Cecire, an Education Specialist and National Staff Teacher located at the University of Notre Dame (UND) in Indiana. Attempting to remove the perceived obstacles surrounding particle physics, the programme puts students in touch with its practitioners to show them what research they conduct.

Directing the University's QuarkNet Center alongside Cecire is Professor Mitchell Wayne. A specialist in elementary particle physics at UND, Wayne currently serves as one of programme's Principal Investigators. In addition to funding from the US National Science Foundation (NSF) and Office of Science at the US Department of Energy (DoE), QuarkNet also receives considerable support from Chicago's Fermilab and the ATLAS and CMS – Compact Muon Solenoid – projects at CERN. With over 50 centres across the country, each partnered to at least one national laboratory or research-based university, the collaboration at the heart of the programme represents a significant investment from the wider physics community in developing tomorrow's young scientists.

TEACHER DEVELOPMENT

All disciplines have time-honoured ways of being taught, and physics is no exception. If traditional methods have brought the subject this far then these methods must have their value, but QuarkNet also recognises the value in staying at the forefront of education. Despite bestowing important lessons, Cecire highlights the inadequacies in the way students are currently taught to collect and analyse data: "We would swing a pendulum 10 times, obtain data points and draw a conclusion. But the way physicists actually work is to take millions of data points". The ability to demonstrate these realities is largely dependent on the Internet and the level of communication it allows. The QuarkNet website offers learning tools for students and teaching resources that puts them in touch with the activities taking place at CERN and Fermilab so that research using the Large Hadron Collider (LHC), for example, is not hidden behind an impenetrable shroud of mystery. Instead of plotting the swing of a pendulum, students are encouraged to think about topics such as Einstein's theories of mass-energy equivalence, the nature of quarks and the Higgs boson.

Almost all centres have progressed from the initial three-year growth stage into the operational phase of the programme. QuarkNet was originally conceived as a long-term venture, taking time to establish a solid network of research relationships between students, teachers and physicists; as a person's interest in a subject at school is often deeply influenced by the quality of teaching they receive, QuarkNet aims to exploit this fact by enhancing teachers' skills to their fullest. After joining the programme, a teacher finishing their first year will have already spent a week working with colleagues at Fermilab on a research scenario, attended a seven-week research appointment at a geographically convenient institution and received support in their education from mentor physicists. "We have seen teachers build stature in their school and community; their principals and the students' parents look at them differently," states Wayne.

A PHYSICS MASTERCLASS

Organised around key questions concerning the origins of mass and the evolution of the Universe, the centres stay at the forefront of the discipline by allowing students to participate in activities such as particle detection through the programme's eLabs. With the CMS detector, for example, students learn to analyse data to find fundamental particles and rediscover previously measured results. Exploring the fundamentals of the subject, centres are also

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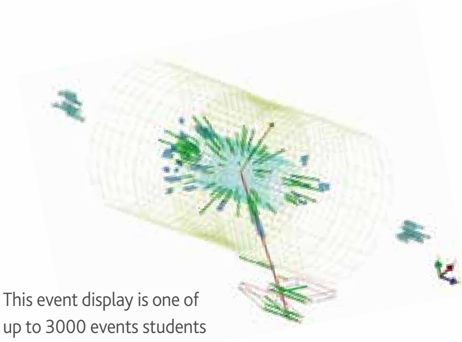

This event display is one of up to 3000 events students examine in a CMS masterclass. The red track shows a muon and the yellow arrow shows 'missing energy' - an indicator of a ghostly neutrino. Students determine that these might have come from the decay of W boson and feed this data into their results.

supported by the programme in obtaining the equipment needed for a more hands-on approach to physics. At the University of Cincinnati facility, for instance, pupils are given the opportunity to build and operate a cosmic ray detector and search for muon particles.

One of the programme's greatest successes has been the masterclass. An educational innovation adopted by the International Particle Physics Outreach Group (IPPOG) and first piloted by QuarkNet in 2006, 2014 marks the 10th anniversary of these special one-day events. Primarily focused on letting students experience the realities of the particle physics world, last year 20 QuarkNet centres and 11 international partners participated by packing pupils off to nearby universities and research institutes to carry out measurements on real data from particle physics experiments. By linking up the groups via videoconference, participants also get to discuss their results with each other and get a taste of what it is like to be involved in international research collaboration.

QuarkNet participation in masterclasses is itself part of an international collaboration. During International Masterclasses in March and April, videoconferences were moderated from CERN and Fermilab. In the preceding six months, Notre Dame and QuarkNet take part in an intense preparatory effort orchestrated in concert with partners in IPPOG, at the Technical University of Dresden and at masterclass institutes around the world.

Designed and set up by physicists and educators like Cecire, masterclasses provide amazing opportunities for both students and teachers to work with actual data from experiments running at CERN and Fermilab. "For me, it is great hearing about students who started out with masterclasses and are now becoming physicists," states Cecire. Not everyone will follow a path in particle physics but as long as the uninitiated find it more approachable, QuarkNet is working. Now the popularity of the masterclasses have grown so much that the model is being adopted in the Middle East, South Africa and Asia, and in Latin America where the team at UND has recently forged a relationship with the Pontifical Catholic University in Santiago, Chile.

FOR THE GREATER GOOD

To find evidence of the programme's success, one can look at the continual maintenance of standards upheld through its ongoing assessment and evaluations of teachers and student's knowledge, but, as Wayne discusses, its real benefits are not so easily quantified: "Maybe the best achievement is that we are changing teachers' and students' mental models of how science is carried out". Despite such an indistinct goal, the long-term value of this approach to education is evident in the continued funding and passionate dedication of its organisers and participants. Already broadening the audience for particle physics, current hopes for the future are to widen the programme's inclusivity further so that the most underserved in the US, such as Native American communities, can profit from its reach. Physicists understand the importance of their field to approaching world challenges and of attracting young minds toward the STEM disciplines enough to contribute their time on QuarkNet for free. As Wayne reiterates: "There are between 150 and 200 physicists and mentors involved, and none of them wish to get a dime out of the programme."

INTELLIGENCE

QUARKNET MASTERCLASSES

OBJECTIVES

- To reform physics education through methods of experimental particle physics research
- To bring cutting-edge, authentic particle physics data into high schools in ways that it can be used by students to learn science as science is performed
- To professionally develop high school teachers through active engagement with particle physics research, data and people

KEY COLLABORATORS

Marjorie Bardeen; **Robert Peterson**; **Edit Peronja**, Fermilab, USA • **Thomas Jordan**, University of Florida, USA • **Daniel Karmgard**, University of Notre Dame, USA • **Tom McCauley**, CERN, Switzerland • **M Jean Young**, MJ Young and Associates, USA

PARTNERS

CERN • The ATLAS collaboration • The CMS collaboration • International Particle Physics Outreach Group (IPPOG)

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KENNETH CECIRE received his BSc from the University at Albany and his MA from the City College of New York. Cecire has been a physics educator since he began graduate school in 1979 and has taught in both independent and government high schools over a span of 20 years.

MITCHELL WAYNE received his BSc, MS and PhD from the University of California, Los Angeles. His current research focuses on the study of proton-proton collisions at the world's largest energies with the Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC) at CERN, in Geneva, Switzerland.

QuarkNet

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