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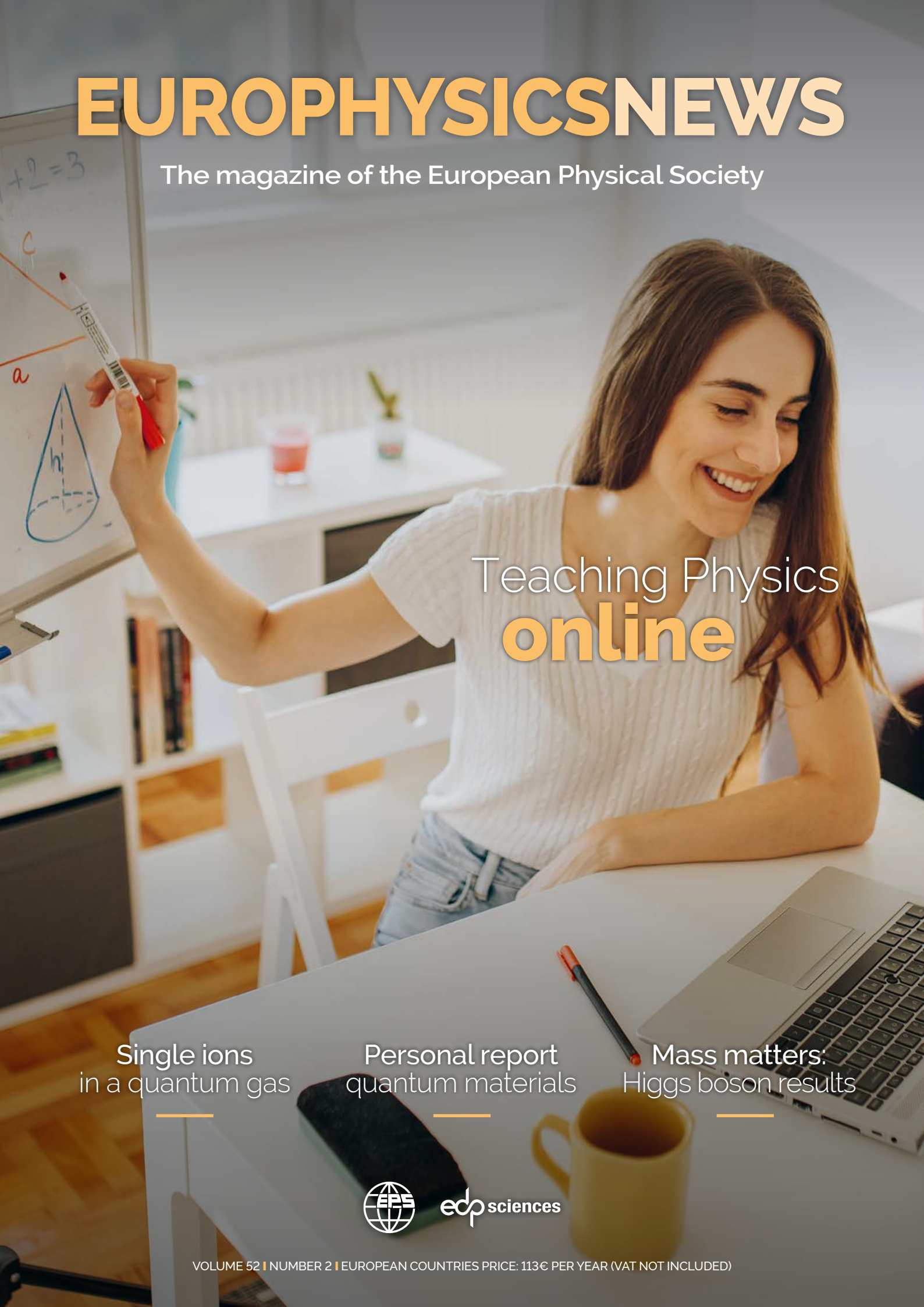
The magazine of the European Physical Society



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Cover picture: after a year of online teaching physics from home or from an empty lecture hall, in this issue some best practices. © iStockPhoto

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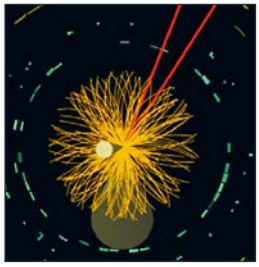
Technology-based assessment



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Mass matters: Higgs boson results

European Physical Society
more than ideas

The European Physical Society (EPS) is a non-profit association that advocates and promotes physics research and its contributions to the economic, technological, social and cultural advancement in Europe. Federating 42 national Member Societies, institutional and corporate Members from academia and industry, and more than 3'500 Individual Members, the EPS represents a community of more than 130'000 scientists. The scientific activities of the EPS are organised through 18 Divisions and Groups covering all branches of physics.
The seat of the Society is in Mulhouse (France). Detailed information about the EPS can be found on www.eps.org.

THE EPS IS SEEKING A NEW SECRETARY GENERAL

to succeed the present Secretary General who plans to retire in spring 2023. Employment is expected to begin in autumn 2022 to allow for a thorough on-the-job training.

- The Secretary General heads the EPS Secretariat which supports the activities of the President, the Vice President, the Executive Committee, and all other bodies of the Society.
- The person to be recruited should have a university degree, preferably in physics or another field in natural sciences, with several years of experience in science management and administration. A degree in political science, business administration or similar may also be suitable.
- The Secretary General shall be responsible for all administrative and financial matters of the EPS. The person supports the activities of the President, the Vice President, the Executive Committee, and all other bodies of the Society.
- The EPS is looking for a dynamic personality with leadership experience, excellent social and communication skills, and a strong interest in science policy and science advocacy, in particular at the European level. An enthusiastic commitment to the mission of the Society is expected. The position requires fluency in English, a working knowledge of French, flexible working hours, and availability to travel. A complete job description is available at ***https://www.eps.org/recruitment.***
- The EPS offers competitive employment conditions commensurate with age and experience, in an attractive environment close to the French-German-Swiss border triangle. The financial conditions will be based on the salary grid of public research institutions in France.

Applications with a detailed letter of motivation and a Curriculum Vitae should be addressed not later than 30 June, 2021 to the EPS President, Dr. Luc Bergé ***(president@eps.org)***.
Further information may also be obtained from the present Secretary-General David Lee ***(d.lee@eps.org)***.

[EDITORIAL]

A new Horizon for the EPS

The change in the EPS presidency provides an opportunity to implement new management methods and prepare the future of our Society. Elected in May 2020, I have now the honour to serve as President of the European Physical Society for the next two years. This is an extremely challenging task, made particularly difficult by a pandemic that prevents in-person exchanges between researchers and slows down the economic life of every learned society.

I would like first to pay a tribute to Petra Rudolf, my predecessor, for her unwavering commitment to the evolution of our Society over the past two years. Petra advanced the cause of promoting diversity in our community. She also founded training programmes to better approach decision makers and help young physicists from low-income countries. I am pleased that the EPS can still rely on her advice.

As new President, my objectives will be to enhance the visibility of the EPS, reinforce its cooperation with its Divisions, Groups and Member Societies, promote the young generation of physicists, open our activities to the industrial sector, strengthen our actions toward Eastern and developing countries. This is an ambitious programme, whose accomplishment will probably need adapting the management modes of the EPS. To this aim, I established four workgroups that involve members of the EPS Executive Committee.

The first group, "Reaching Industry", aims at developing the relationships of our Society with the industrial sector. With its members, we already launched a survey collecting the needs of physics-based companies and technical universities with respect to the present offers of the EPS. We received many feedbacks and a few interests in joining us as new Associate Members.

The second group, "EPS Forum", is acquiring experience to lay the foundation of our future EPS Forum. A learned society must have its own showcase reflecting its numerous activities. Most national physical societies have their general congress that often spans over several days. Unfortunately, the EPS does not have a similar event, except for its Council meeting, the agenda of which is mostly limited to reports. The cornerstone of my presidency will be to set up the EPS Forum, preceding the EPS Council meeting. It will include a one-day meeting between young graduates in physics and industrial companies, followed by another one welcoming the representatives of our Member Societies and of our Divisions and Groups. The EPS Forum will be a great opportunity to open new partnerships on scientific, societal and economic topics; it will give its full meaning to the umbrella organisation which EPS aspires to be.

The third group, "Physics for Development and Eastern States", is dedicated to twofold partnerships: First, we shall increase our help to physicists native from developing countries, together with our collaborating societies and in the framework of the International Year of Basic Sciences for Sustainable Development (IYBSSD) planned in 2022. Secondly, to reinforce European integration, the EPS will co-organise various events involving national physical societies of Eastern and Southern Europe, such as physics summer schools or societal meetings.

Last but not least, the fourth group, "Search for the next Secretary General", aims at finding the successor of David Lee, who has been an inspirational Secretary General for the past twenty-three years, promoting new initiatives with the support of a very efficient Secretariat. David will retire in Spring 2023. He is leaving a managerial footprint that will not be easy to fill.

In conclusion, in the coming years the EPS will reinforce its visibility around one seminal event, the EPS Forum, which will meet the needs of physics-based companies and those of our young generation of physicists. It will be the place for fruitful exchanges between our Divisions and Groups, action Committees and Member Societies. The workgroups already map out the new management style of our Society. I want to thank here all their members who committed themselves with dedication and competence to our ambitious programme for the EPS. ■

■ **Luc Bergé,** *EPS President*

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Determination of the fine structure constant with atom interferometry

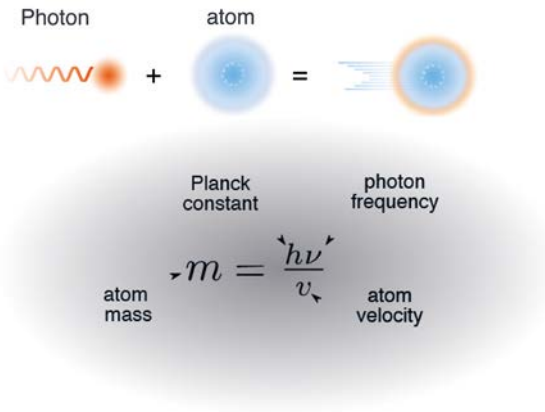
Introduced in 1916 by Sommerfeld to describe the hydrogen atom energy levels, the magic number $\alpha \approx 1/137$, called the "fine-structure constant" has fascinated generations of physicists. Since then the significance of α has evolved. It is now the constant that characterises the strength of the interaction between light and charged elementary particles. For experimentalists, measuring α with high accuracy is an exciting challenge, as this measurement requires both sophisticated experiments and an in-depth understanding of many subtle physical phenomena. This explains why over the last sixty years, only a few teams in the world have succeeded in measuring α with an average gain in accuracy of a factor of 10 per decade.

The constant α can be deduced from the binding energy of a hydrogen atom, known with 12 digits, and the mass of the electron. The electron is too light, and it is difficult to measure directly its mass precisely. Fortunately, the ratio between atoms mass and the mass of an electron is known for several atomic species. By the use of the mechanical effect of laser light on ultra-cold atoms, the mass of a rubidium atom was recently measured with an unprecedented accuracy. This result leads to a new determination of the fine structure constant $1/\alpha = 137.035999206(11)$. The accuracy is about 3-fold improvement over the previous best determination using the cesium atom. However, the two values of the fine-structure constant differ significantly. This new result will therefore have a great impact on the Standard Model tests which rely on the knowledge of the constant α.

How to measure atomic mass with laser light?

When an atom absorbs a photon, it gets a recoil with a velocity that depends on its mass: the lighter it is, the faster it goes. To measure this velocity, of the order of 6 mm/s for rubidium, the atoms are first cooled in a magneto-optical trap down to a temperature of 4 μK. The ultra-cold atoms, basically "at rest", are then accelerated by the absorption and stimulated emission of exactly 500 photons. The measurement of the velocity transferred by the 500 photon's kicks, is based on an atomic interferometer: indeed, at this temperature, matter behaves like waves. Using laser beams, it is possible, like in optics, to split and recombine atomic waves and to measure the accumulated phase shift along two different trajectories, which depends on the velocity of the atoms.

[1] https://physics.nist.gov/cuu/Constants/index.html



▲ FIG.1: When the atom absorbs a photon, it gets the energy and momentum from the photon: this causes the atom to recoil.

These techniques have been implemented in a cutting-edge experimental set-up where a relative statistical uncertainty of 1.2×10^{-10} in 24 hours measurement's time has been achieved.

When looking for the 11th significant figure, every detail matters: the slightest effect likely to affect the measurement should be analysed and, if possible, measured experimentally. For this, it is crucial to be able to accumulate enough measurements. By improving the signal-to-noise ratio by a factor of 10, our experiment stands out clearly from its competitors. For the first time, the experiment has made it possible to evaluate numerous systematic effects, such as the bias induced on the recoil by aberrations of the wave fronts of the laser beams.

Why is this new measurement timely?

Measuring the mass of a rubidium atom at this level of precision will have a major impact on the list of reference values of the most important constants in physics for scientists[1]: from now on, a quarter of these constants, updated every 4 years by CODATA (the Committee on Data for Science and Technology), will see their uncertainties reduced. This is the case for the mass of other particles that can be deduced from the mass of the rubidium atom but also from the fine-structure constant and other electrical constant such as vacuum permeability.

Knowing precisely the constant α is crucial to evaluate the theoretical predictions of the Standard Model that involve electromagnetic interactions. The main prediction tested here is the calculation of the electron magnetic moment from quantum electrodynamics. The new measurement of α provides a prediction of the electron magnetic moment that better agrees with the experiments. This agreement confirms that the electron has no substructure and is really an elementary particle.

However, the Standard Model prediction of the muon's magnetic moment differs from the experiment. This is the subject of a lively debate within the physics community. Recently, intensive efforts realised in the framework of an international collaboration, have improved the theoretical prediction of the muon's magnetic moment, confirming the discrepancy with the experiment. On the other hand, a new measurement from the Fermilab is expected soon with improved accuracy. If the difference with theory is once again confirmed to be significant, it could be hint to a new physics beyond the Standard Model. The same effect would be observable on the electron but according to a naive scaling, the electron would be about 10^4 less sensitive due to its smaller mass.

The next challenge will be to seek for this tiny effect in the electron sector as well. To succeed, 1) the accuracy of the measurement of the electron's magnetic moment would need to be improved by at least a factor of 10, 2) the puzzle of the discrepancy between the values of the fine-structure constant from the cesium and rubidium would have to be solved and 3) The accuracy on the constant α should be again improved. A lot of exciting experiments are still ahead of us! ■

Pierre Cladé and Saïda Guellati-Khélifa,
Laboratoire Kastler Brossel, Paris, France

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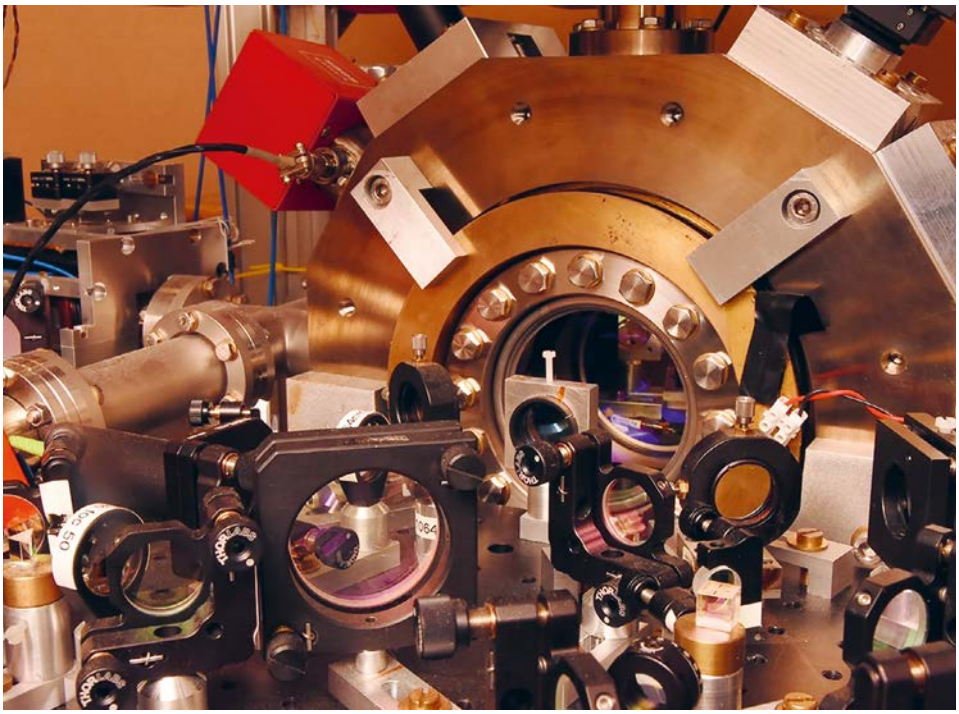
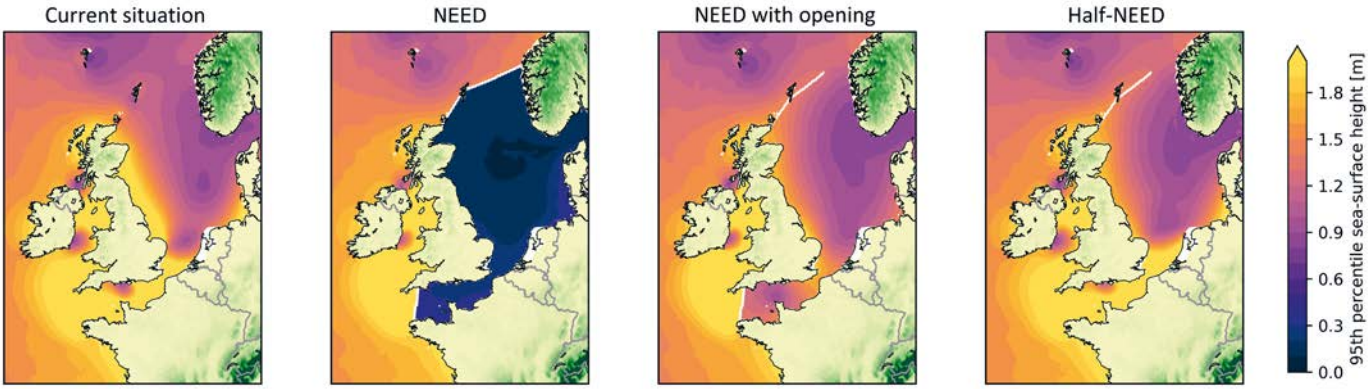
▼ FIG. 2: View of the set-up for laser cooling



NEED Northern European Enclosure Dam

To protect fifteen northern European countries against sea level rise, a highly ambitious plan was put forward to build massive sea dams across the North Sea and the English Channel, which will cut off the North Sea from the rest of the Atlantic Ocean.

DOI: https://doi.org/10.1051/epn/2021201



▲ Preliminary results show the sea surface height exceeded once every 20 years, or less. Obtained using a numerical simulation [1]. Half-NEED reduces the amplitude significantly in some regions and could maybe be effective.

Although we desperately want this plan [1] never to become a reality, future projections of high-end sea level rise (SLR) of over 7 m in 2300 may warrant a solution of this proportion [2]. Considering the high risks of such scenarios and the long lead time for adaptative solutions to be put in place[3][4], it is essential to plan ahead for solutions in case the high-end scenarios do become a reality.

The costs to construct NEED are estimated at about €250-€500 billion. Spread out over 20 years and over the 15 protected countries, it would cost less than 0.2% of their GDP and could be a cost-effective solution. Now, after a year since publication of the idea, we have not heard from an expert who claims NEED cannot be constructed. This includes the requirement to pump out ±40.000 $m^3 s^{-1}$ of river discharge into the Atlantic. Yet, there are concerns about the implementation time and the impact of NEED on ecosystems, the maritime shipping industry and terrorist threat. The latter however is worse for coastal dikes, as breaking NEED will first flood a huge catchment area that can delay flooding of coastal cities by months, whereas breaking coastal dikes will cause cities to flood within hours.

Recently, Engineers Wim Uijttewaal and Bas Jonkman of Delft University in the Netherlands suggested to start by building only half of the enclosure between Scotland and Norway and remove the part between France and England entirely. Although this doesn't protect against the global-mean SLR itself, preliminary results (see figure) do suggest this could reduce the sea level height extremes with more than 1 meter locally, thanks to a damping of tidal amplitudes and storm surges. "Half-NEED" could thus reduce sea level extremes and therefore allow for some global-mean SLR in order to maintain the same protection standard of our coastal dikes. If the incremental plan of "Half-NEED" works, it provides protection, while leaving the ecosystems and shipping industry relatively untouched. And if all fails, we can still enclose the whole basin.

We emphasise that NEED is symptomatic treatment of the consequences of climate change. The best solution remains to intensify climate change mitigation efforts now. NEED however, is a powerful image capturing the possible consequences of climate change and is therefore mostly presented as a warning. Not a solution we should aim for, but a reality we should avoid and to be sure, investigate. ■

> **We emphasise that NEED is symptomatic treatment of the consequences of climate change. The best solution remains to intensify climate change mitigation efforts now.**

■ **Sjoerd Groeskamp,**
NIOZ Royal Netherlands Institute for Sea Research, Texel, Netherlands
■ **Joakim Kjellsson,**
GEOMAR Helmholtz Centre for Ocean Research Kiel

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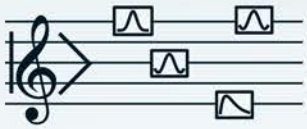

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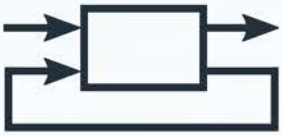

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100 years Netherlands' Physical Society

In 2021, the Netherlands' Physical Society (NNV) celebrates its centennial. The society was founded on April 2nd, 1921, by an impressive group of physicists. Among them three Dutch laureates of the Nobel Prize in Physics: Hendrik Antoon Lorentz, Heike Kamerlingh Onnes and Pieter Zeeman. In the past, famous physicists like Leonard Ornstein, Hendrik Casimir and Frits Zernike played a role in the NNV. On April 16th, 2021, during the FYSCA2021 conference, the Commissioner of the King awarded the NNV the predicate Royal.

What started as a convocation of nine persons, grew in the next age into a vivid society of about 4,000 members. Among our members are physics students, teachers, academics and physicists working in industry and at the public authorities. Part of our members is very loyal, over 250 people are NNV member for more than 50 years. In fact one person even became a member 79 years ago.

Crown jewels of the NNV

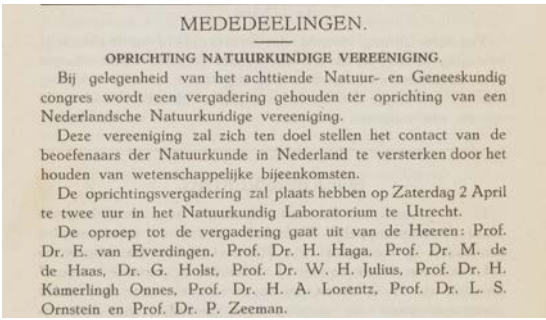
We would like to mention some of our crown jewels. First of all we publish the monthly Dutch Journal of Physics. This is the professional journal on physics in Dutch. Well written and containing articles on physics research as well as content about people and all kinds of physics novelties. Once a year the journal has a special edition dedicated to a specific topic: Physics and Food, Physics and Sport, Physics and Art, Elementary Particles are some of the specials of the last years.

Beside this, we organise a yearly conference FYSICA, normally in cooperation with the physics department of a Dutch university. We always try to have a Nobel laureate as one of the plenary speakers. In the last fourteen years we managed to have fourteen Nobel Prize laureates. A contest for young speakers is one of the regular parts of the conference; the audience votes for the winner and that is always a big success. The conference has about 500 participants, varying from student to professor and from teacher to people from industry – it is a great opportunity to network.

We award several prizes, among them the award for the Physics Teacher of the Year at secondary schools. And we are very proud of our NNV Diversity Award, which is handed out once every two years to the physics institute that is most successful in achieving an open diversity policy.

And last but not least we mention our activities for secondary schools. We organise trips for pupils and their teachers to a variety of European research institutes in Geneva, Berlin, Hamburg, Aachen, Grenoble and La Palma. Every year, about 700 pupils and teachers travel with us. During these days the travellers are plunged into physical research and this is a life-changing experience. They are so enthusiastic about research when they return!

In the early zero's, the NNV took the initiative to start an educational website on physics. This site, www.natuurkunde.nl has been built with the help of all partners in the physics community in the Netherlands. Twenty years later, the site is very well known by teachers and pupils. In 2020 the site had 1.3 million unique visitors, quite amazing in a country with 17 million citizens.



MEDEDEELINGEN.

OPRICHTING NATUURKUNDIGE VEREENIGING.

Bij gelegenheid van het achttiende Natuur- en Geneeskundig congres wordt een vergadering gehouden ter oprichting van een Nederlandsche Natuurkundige vereeniging.

Deze vereeniging zal zich ten doel stellen het contact van de beoefenaars der Natuurkunde in Nederland te versterken door het houden van wetenschappelijke bijeenkomsten.

De oprichtingsvergadering zal plaats hebben op Zaterdag 2 April te twee uur in het Natuurkundig Laboratorium te Utrecht.

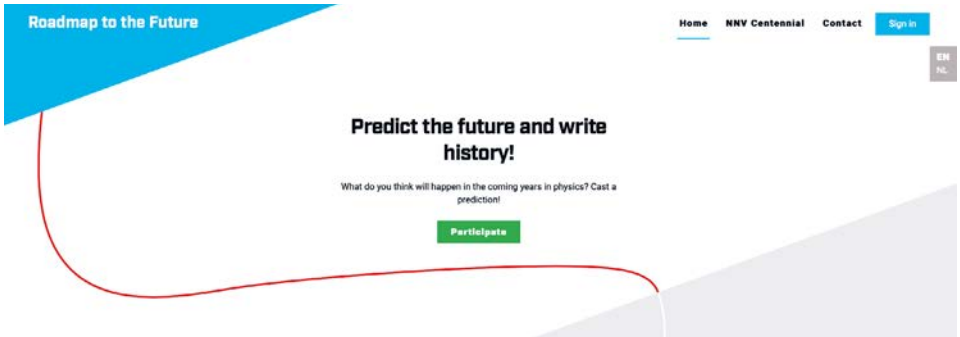
De oproep tot de vergadering gaat uit van de Heeren: Prof. Dr. E. van Everdingen, Prof. Dr. H. Haga, Prof. Dr. M. de de Haas, Dr. G. Holst, Prof. Dr. W. H. Julius, Prof. Dr. H. Kamerlingh Onnes, Prof. Dr. H. A. Lorentz, Prof. Dr. L. S. Ornstein en Prof. Dr. P. Zeeman.

▲ Convocation to attend the founding meeting of the Netherlands' Physical Society on April 2nd, 1921

Celebrating our centennial

To celebrate our centennial we organise activities throughout the year. We organise festivities for our members, but also seek the connection with non-physicists to show the beauty and importance of physics. In this article, we highlight some of these activities. We pointedly invite our

▼ The set of posters



▲ Predict the Future and write history!

European colleagues to participate in the website 'Roadmap to the Future' and our online conference 'FYSICA 2021', in which the language deliberately is English.

Posters for classrooms

We kicked-off with the publication of a set of six colourful and informative posters for physics classrooms. The posters are for free and we developed a brochure with additional information on the topics shown on the posters. The posters are about: astronomy, medical physics, energy networks, aerospace, computing power, a career in physics. Each poster contains a QR-code leading to a video. The posters were well received by the schools.

Poetry contest

A poetry contest is currently going on. We are aiming for a description of the 17 particles of the standard model in poetry. People are invited to make a poem on a particle and the jury with Nobel Prize laureate Gerard 't Hooft will judge the entries. Our inspiration for this contest was the existing periodic table in haiku.

Guest lectures

On the International Day of Women and Girls in Science – February 11th – we connected female physicists and teachers/pupils for a guest lecture at school. Due to the Covid-19 situation the lectures were online. About 1,000 pupils enjoyed a guest lecture, varying from quantum fractals to exoplanets and from cosmology to sustainable energy. The guest lectures were even mentioned on national television.

Predict the Future and write history!

In this special year we want to take a look at the future as well. For this reason we launched the (bilingual English and Dutch) website Roadmap to the Future. We invite all readers of EPN to take a look at this website and participate. The website is meant to predict the (physics) future collectively. We chose 25 future developments, breakthroughs and inventions. Think of examples like:

- The first residential address outside earth.
- The availability of first chips based on 1nm linewidth.
- The decrease of CO_2 concentration in the earth's atmosphere.
- The addition of scent to telephone standards.

The website is open for everyone, for physicists and non-physicists. It is fun and also inspiring, so please participate! We are looking forward to visualise the future as we all expect it to be. www.padnaardetoekomst.nl/en/

Special Edition of our Journal

At the end of February we published a special edition of our journal. Robbert Dijkgraaf, most famous physicist in the Netherlands, honorary member of our society and director at the Institute for Advanced Study in Princeton, New Jersey (USA), acted as guest editor of this edition. We chose the name of this special with a wink: Robbert. The launch of the Robbert was broadcasted at prime time on national television. The journal shows the beauty and the enormous range of physics. The target group of this edition is everyone from 15-16 years old with an interest in physics. With 30,000 copies we could inform a big audience on physics, many copies were sent to schools.

Royal NNV

In the afternoon of April 16th, we organised our annual conference FYSICA 2021. Two Nobel Prize laureates, Roger Penrose and Reinhard Genzel, gave a keynote talk. During the conference, Arthur van Dijk, Commisioner of the King, awarded the NNV the predicate Royal. From now on we are Royal NNV.

EPS historic sites

We plan to unveil two EPS historic sites this year. The laboratory of Nobel Prize laureate Pieter Zeeman in Amsterdam (rebuilt into private apartments) and the Sonnenborgh in Utrecht, which is the place where the Royal Netherlands Meteorological Institute (KNMI) was founded by professor Buys Ballot in 1854. Now it is a museum and a historic observatory. ■

■ **Noortje de Graaf,**
director Netherlands' Physical Society

▼ Arthur van Dijk, Commissioner of the Kind, presents NNV Chair Diederik Jekel the charter of the predicate Royal.

In memoriam, Paul Crutzen (1933 - 2021)

On 28 January 2021, the Nobel Laureate Chemistry 1995 Paul Crutzen died at the age of 87.

He was awarded the Nobel Prize for his work on stratospheric ozone depletion by the catalytic nitrogen cycle. This was controversial at the time. The prevailing theory was based on ozone loss through photodissociation, while competing theory focussed on catalytic loss by hydroxyl radicals (OH, HO2). In 1970 Crutzen demonstrated that nitrogen oxides are the dominant loss mechanism in the mid-stratosphere (20 - 40 km). Subsequently, in 1974, Mario Molina and Sherwood Rowland showed that chlorofluorocarbons also deplete stratospheric ozone, based on a third catalytic cycle involving halogens. The 1995 Nobel Prize was shared with Molina and Sherwood.

Around 1990, after publication of the first IPCC scientific assessment of climate change, German media labelled him a "prophet of doom". His sober answer: "This is what we find; our climate models are based on well-established physics and chemistry". Crutzen did not shy away from public debate, saw it as his social duty to communicate the consequences of climate change. Earlier he had made headlines with his publication on Nuclear Winter as a result of nuclear war. Similarly, he hit the news with the depletion of the ozone layer by NOx emissions emitted by high-flying supersonic aircraft. He also stated that the Industrial Revolution had started a new geological era, the Anthropocene. Geologists still argue about it.


Image credit: Teemu Rajala

Paul Crutzen grew up in Amsterdam under adverse conditions of economic crisis followed by German occupation. Some of his Jewish classmates disappeared, others were dying of starvation during the "hunger winter" 1944-45. After the war, he took A-levels and trained as a civil engineer, his parents unable to afford an academic study. He worked from 1954 at the Amsterdam City Council designing some of its many bridges. Mid-fifties, at a Swiss summer camp, he met Finnish Terttu Soininen and married her in 1958, settling in Sweden. He got a job as computer programmer at Stockholm University's Meteorology Department, untrained, but then: who was. He was encouraged to attend lectures, got his Master's in 1963, a PhD Meteorology in 1968 and a Doctorate Philosophy in 1973. Stockholm University had a long tradition in climate science, dating back to Svante Arrhenius who in 1896 first identified the greenhouse effect of atmospheric CO_2. From 1968 to 1970, Crutzen spent a crucial period at the Institute for Atmospheric Chemistry in Oxford, UK. In 1974 he moved with his family, now including two daughters, to the USA to become Research Director at the National Center for Atmospheric Research in Boulder, Co. From 1980 until his retirement in 2000 he was director of the Max Planck Institute for Atmospheric Chemistry in Mainz, Germany. From 1997-2002 he was professor of Aeronomy at Utrecht University, the Netherlands.

In the 1980's Crutzen looked for ways to validate his simulation models with measurements. This required a global observation system that did not exist. In 1988, he and his staff submitted a proposal to the European Space Agency for a UV-VIS-NIR spectrometer dubbed SCIAMACHY. Dutch SRON and TNO-TPD provided a space-qualified instrument design. In 1992 the European ENVISAT mission was approved with SCIAMACHY on board. Launch took place in 2002 delivering the first 10-year global dataset of climate and air quality species of the Earth atmosphere.

Paul Crutzen received a Dutch Knighthood and honorary membership of the Royal Netherlands Chemical Society. Recently, he was awarded the golden Lomonosov-medal of the Russian Academy of Science. Both the message and the messenger Paul Crutzen will be an inspiration to those who follow his lead in the fight against climate change. ■

Adelbert Goede,
Fellow of the European Physical Society

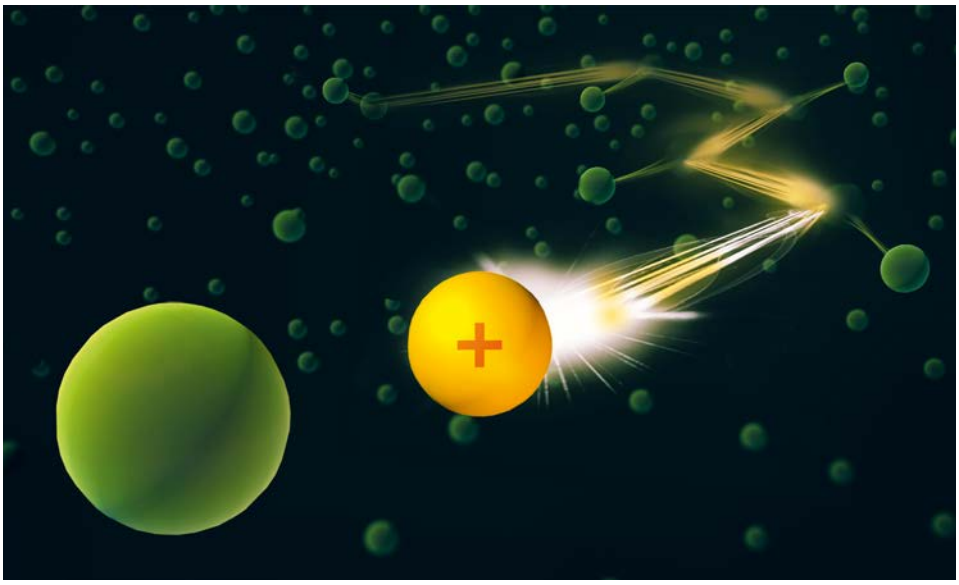
Tracking single ions in a quantum gas

Experiments with cold ions at the University of Stuttgart pave new paths to explore low-energy transport of charged impurities through a Bose-Einstein condensate.

Measuring transport of mobile charges through a medium has been key to find numerous new and unexpected phenomena. A prime example constitutes the observation of dissipationless current flow in a superconductor. Unraveling the microscopic details behind such transport processes, however, is often very challenging, specifically when quantum effects play an important role. In that context, laser-cooled atomic gases are wonderful model systems which provide unique experimental tools to implant single impurities into quantum matter and to study their dynamics on a microscopic level.

Our team at the University of Stuttgart has recently succeeded in placing and controlling a single cold ion impurity into a Bose-Einstein condensate formed by a gas of ultracold rubidium atoms. The ion has been created from a single Rydberg atom, an atom which is excited with lasers to a high-lying electronic orbital. Rydberg atoms interact very strongly with each other, which prohibits the simultaneous excitation of more than one atom at a time, a phenomenon known as Rydberg blockade. Applying a carefully adjusted sequence of electric field pulses allowed us to ionise this Rydberg atom, leaving behind a single cold ion with an initial kinetic energy of less than $k_B \times 50\ \mu$K.

A small applied electric field of a few mV/cm then accelerated the charged impurity. After a variable transport time of up to ~20 μs the impurity was finally guided to a single-ion detector. A measurement of its arrival time at the detector made it possible to trace the ion on its way through the Bose-Einstein condensate. The experiments clearly showed that the ion motion is dictated by frequent collisions with the condensate atoms. This leads to a kind of friction for the ion dynamics and a resulting diffusive charge transport. The measured ion mobility also agreed very well with a transport model which included the microscopic character of ion-atom scattering at very low collision energies ranging from only tens of μK to tens of mK temperature.



▲ Artist impression of the diffusive transport of a single ion through a Bose-Einstein condensate.

The observed ion-atom collisions at these energies could still be well described by a semi-classical description, known as Langevin scattering. Yet, the reported experiments now provide an excellent starting point to explore smaller and smaller energies for the impurity transport and to search for quantum effects dictating the ion mobility. Indeed, for mobile charge impurities embedded in a quantum gas new types of polarons, exotic "snowball" molecules, or fast charge hopping processes have been proposed and are expected to strongly affect the impurity dynamics at ultralow temperatures. With the goal to hunt for these elusive phenomena, our group is already working on a second-generation quantum gas apparatus, which hosts a new type of pulsed ion microscope. In future experiments, this instrument will allow us to image the ion embedded in the quantum matter directly and with an unprecedented spatial resolution of less than 200 nm. ■

> **Rydberg atoms interact very strongly with each other**

Florian Meinert,
Junior Research Group Leader at the 5th Institute of Physics, University of Stuttgart (Germany)

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Exploring quantum materials

The Dutch Physics Council awarded Koen Bastiaans the 2020 Ehrenfest-Afanassjewa award for his dissertation "Probing quantum materials with novel scanning tunneling microcopy techniques". Here is his personal report for EPN.

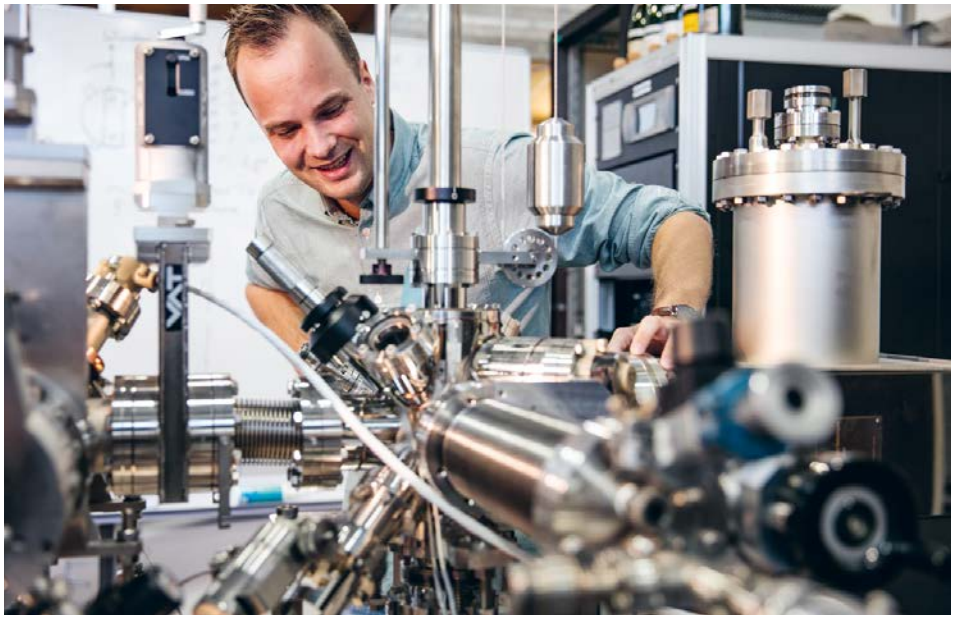
Phases of matter

Suppose we would be asked to think of an electrically conducting material. Probably the first thing that would come to our mind is a solid material, probably a metal. A structural solid is characterised by a close packing of the constituent particles (atoms) in a repeating pattern which gives the material its stability and definite shape and volume. In a solid, because the atoms are so rigidly arranged, they cannot move freely throughout the material. In some sense you could say that the building blocks of the solid don't "conduct". But what about the electronic phase of this material? Remember, we were asked to think of an electrically conducting material. Each atom in the material brings a set of electrons. If these constituent particles of the electronic system would also be rigidly arranged, the electrons would not be able to move through the material, as if they were a solid. However, in a conducting material the electrons are mobile! This controversy shows that the electronic phase cannot be solid. As is turns out, the electronic phase of most simple metals is best described by a gas or liquid phase, treating the electrons as non-interacting particles that move through the solid.

> **"Now we enter the realm of the quantum materials. Here the electrons start to notice and influence each other strongly, becoming so-called strongly correlated."**

Quantum materials

But what about materials where the interactions between the electrons become so strong that this simple picture starts to fail? Now we enter the realm of the quantum materials. Here the electrons start to notice and influence each other strongly, becoming so-called "strongly correlated". The collective behaviour of the electrons will start to dictate the macroscopic electronic properties of the material. Out of this microscopic strongly-correlated soup of electrons, macroscopic properties can emerge that are quantum mechanical by nature. In addition to that, such complex electronic states can also require ingredients such as topological order or quantum criticality, bringing "quantum" into the material.



▾ Koen Bastiaans in the lab at Leiden University.

Atomic-scale quest for understanding

For several decades now the field of quantum materials is challenged to understand these emerging states of matter, as well as the driving physics behind them. Interestingly the interplay between the electronic and structural phases seems to play an important role. For that reason, I personally like to investigate them using a scanning probe that is able to visualise both the electronic and structural phase of the material, simultaneously, on the atomic scale. Motivated to solve the mysteries of quantum matter, I developed novel experimental probes that can give new insights into these materials. For example, by measuring the noise of the electrons I could get an experimental handle on their collective behaviour and see new quantum physics that nobody had seen before. For this endeavor I was awarded the Ehrenfest-Afanassjewa award by the Dutch Research Council. The award is named after the couple Paul Ehrenfest and Tatiana Afanassjewa who had the exceptional ability to stimulate young researchers to leave the beaten track and boldly explore new ideas. ■

Koen M. Bastiaans,
Leiden University

Cryogenic Innovators ICEoxford achieve optimal performance for optical quantum computing applications at 1Kelvin and below.

Do you need something cold and still? I mean *really* cold and *really* still. Colder than outer space and with a displacement of no more than the width of a few atoms…

The development of quantum computing has brought low temperature physics into the headlines. It has also ignited a surge of advances amongst cryogenic equipment manufacturers building the ultra-low temperature, and ultra-low vibration, environments needed to preserve 'Qubits' and optimise single photon detection.

One company leading this space is ICEoxford, a UK based company founded in 2004. "We build our business around three values: performance, customisation and customer care. Our systems must break boundaries and achieve the highest specifications available to meet the needs of our customers" says Chris Snelling, Sales Director.

"ICE employ an approach of collaborative product development. We work with leaders in research to build bespoke systems that achieve unique specifications. These customised one-offs later become our standard products", Chris explains. The approach has produced an extensive range of cryogenic systems and a diverse customer base, ranging from neutron and X-ray beamline scientists to quantum computing start-ups.

▲ The DRY ICE 1K HIGH COOLING POWER: capable of cooling powers of 320mW @ 1.0K and a base temperature of 0.77K.

The DRYICE1.0K cryostat is an example of the method in action. The cryostat was originally designed for MIT to optimise the performance of single-photon detectors whilst managing a large experimental heat load. From this design, ICE developed three different designs that can operate below 1.0K in continuous operation and below 0.8K in single shot.

ICE's most recent development, the DRYICEDYAD, has been produced for Imperial College London. The DYAD is designed for ultra-low vibrations (<5nm) and temperatures below 1.7K. The sample unit is held separately on an optical table with helium transferred from the main cryostat through a low vibration thermal link. It is also modular; the sample unit can be changed between an exchange gas module and a vacuum module. Customisation, including coaxial wiring, a superconducting magnet, nanopositioners and low temperature objectives, is also available.

So where next for ICE? 'In the early days, companies were competing strictly on temperature and vibration. Now we see customers demanding more system add-ons: more wiring, noise filtering, and sample manipulation. The need for next level software is why we developed V3. It is all part of ensuring our systems are easy to use, with turn-key operation, fewer errors, and modular designs that enable the user to upgrade their experimental set up as their research develops.' comments Paul Kelly, Co-founder of ICE, 'More generally, with quantum advantage now achieved, we expect the trend in quantum to continue, and if the prospective commercial applications take off it'll go supersonic in the not-too-distant future. We are also looking at exciting developments in HTS technology. But, however the field progresses, our commitment is to supply agile tools that are well-supported, can be customised, and outperform the competition.' ■

▲ ICE can offer customised experimental wiring including up to 100 coax lines on systems in the DRY ICE 1K Series

◀ The DRY ICE DYAD, offering a combination of ultra-low vibration and excellent optical access at temperatures below 1.7K.

Education session
at the First European Quantum Week

Mažena Mackoit-Sinkevičienė – Center for Physical Sciences and Technology, Vilnius, Lithuania

In November 2020, the first European Quantum Week took place. The event was initiated by the European Commission and the Quantum Technologies Flagship. In Lithuania, the Vilnius EPS YM section was invited by the national organiser to contribute and helped to set up a virtual event attracting almost 1600 young people.

The Quantum Week Educational Session 2020 (EQW[1]), initiated by the European Commission and the Quantum Technologies Flagship, is a new movement that should bring all European countries together each year in November, as a long-standing EU tradition, for a common educational goal. During EQW, researchers from each country give public lectures to the general public and students in the national languages of the EU member country about the possibilities of quantum technologies and the latest achievements in these fields. The year 2020 was crucial as the opening year of the EQW and the European Physical Society Young Minds section in Vilnius (EPS YM Vilnius) was delighted to have received an invitation to join and become part of this educational movement. The main (national) organiser of the first EQW in Lithuania was the Center for Physical Sciences and Technology (FTMC) together with EPS YM Vilnius as a partner.

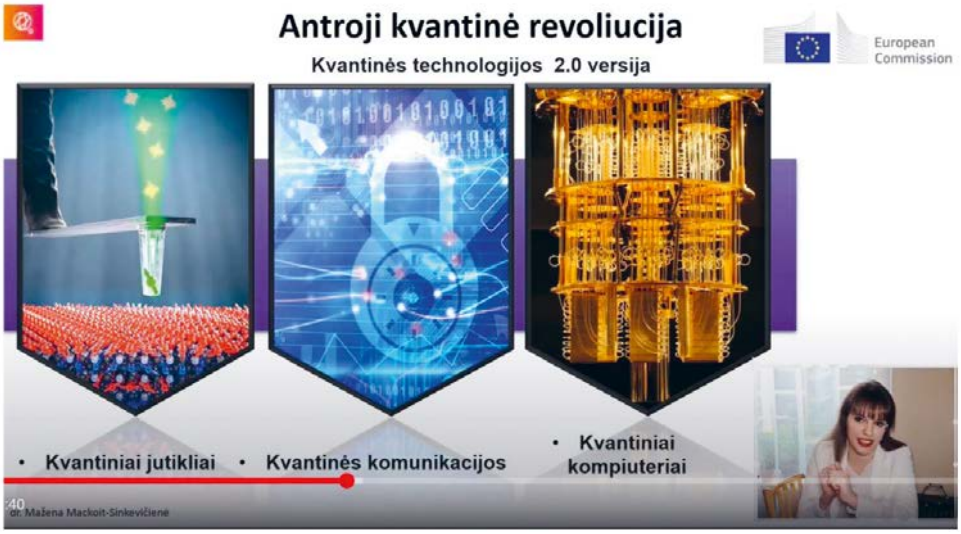
Vision of EQW

By now, physicists have already learned how to manipulate objects in the quantum world, *i.e.*, how to extract quantum effects at the level of a single particle, how to detect single photons and entangle quantum states with each other, and so on. Right now, new career opportunities are emerging, innovative start-ups are being created, and quantum technology divisions are being set up in large companies. If we want to create quantum technologies in Europe or to develop and contribute to the existing ones, we need students who will study natural sciences, engineering, business, and communications. We believe that people working in such an 'industry of tomorrow' should already be studying physics, going deeper into quantum sciences. Therefore it is particularly important to spread this message in our society today. Right now is a great time to raise awareness about quantum technologies in society, especially among young people. This is the purpose of the EQW.

Currently, we are already halfway through the second quantum revolution, but only a small group of people – mainly scientists and innovators

[1] https://eqw.qt.eu

▼ Looking at the map of EU countries participating in European Quantum Week, we see that much of Europe has joined the initiative, as many as 26 EU countries.



▲ EPS YM Vilnius President Dr. Mažena Mackoit-Sinkevičienė gave a talk about quantum science, in an understandable way and interesting to the general public.

- know about it. The Vilnius EPS YM section wanted as many people as possible to hear and better understand the perspectives of quantum science during the lectures in the EQW educational session. People should stop fearing the word 'quantum' and understand the full potential of such technologies.

EPS YM lectures during EQW

During the two interactive lectures, each including a 15 min Q&A session, in the EQW educational session, Mažena Mackoit-Sinkevičienė, President of the EPS YM Vilnius and initiator and one of the organisers of the European Quantum Week, gave a talk about quantum science in a manner understandable and interesting to the general public. Although quantum mechanics is only taught at the university to sophomores, she is convinced that after this lecture, students and science fans have received the key message: quantum technology operates according to the laws of quantum mechanics, which occur at the subatomic level. When it comes to extremely light and small particles, we cannot apply Newton's laws of classical mechanics to describe their interactions; matter in the smallest extent is not continuous and particles do not behave completely like real particles, but also like waves at the same time. It was important to emphasise that students already use devices employing quantum physics daily. Those are computers, or any IT item, DVD or Blu-ray players, GPS, *etc.* All these devices are based on our understanding of quantum mechanics. Lasers allowed us to speed up communication, scan barcodes, perform a nuclear fusion, and accurate measurements. Meanwhile, the use of lasers and knowledge of quantum physics opens opportunities to make photosynthesis more efficient. Today, a magnetic resonance (MRI) machine is available in almost all hospitals. High-density hard drives that take advantage of gigantic magnetoresistance allow information to be stored with unprecedented density. The CCD image camera has already become a key tool in every phone camera where light is captured electronically, rather than on film, as was the case recently. The second part of her lecture in the EQW session was about the second quantum revolution where quantum computers, quantum communications, and quantum sensors could be used. EPS YM believes that every educational initiative of researchers helps the public to become more aware of the meaning and significance of science.

Outreach and EPS YM visibility

The main message we have sent to Europe and the international community is that the EPS YM Vilnius together with FTMC wants to educate the public on this issue and attract young people who would join the common scientific potential and the development of future technologies. Unambiguously - this goal has been achieved. Also, with the help of the Lithuanian Society of Physicists, EPS YM Vilnius was able to reach and encourage many Lithuanian schools to participate in the session. It is interesting to mention that the interactive lectures (lecture and its repetition) were not only observed by gymnasium students and high school students, but also by representatives of various companies, PhD students, adult schools, and vocational training centres. There were also parents who asked to register for the lecture several families - science enthusiasts. Although we expected students from grades 9-12 to attend the lectures, younger students from grades 7-8 also joined and participated actively. A total of 1594 participants registered for the EQW educational session in Lithuania: 62 individuals and 1532 students together with their teachers. These large participant numbers, and the diverse educational levels, highlight that there is a great societal interest in quantum technologies and that Lithuania and Europe are well prepared to develop and establish these technologies in the future. ■

About the Author

Mažena Mackoit-Sinkevičienė is a theoretical physicist. Her current research interests are related to solid-state quantum technologies, in particular, technologies based on optically active defects that act as single-photon sources in two-dimensional materials. She joined YM in 2016, and is currently President of the YM section in Vilnius, Lithuania. In October 2020, she received her PhD in Physics at FTMC. She works as a Junior Researcher at FTMC and Lecturer at Vilnius University Faculty of Physics.

CHALLENGES AND DEVELOPMENTS IN TECHNOLOGY-BASED ASSESSMENT: POSSIBILITIES IN SCIENCE EDUCATION

Gyöngyvér Molnár – DOI: https://doi.org/10.1051/epn/2021202
University of Szeged, Institute of Education, Research Group on the Development of Competencies

Motto: 'If you cannot measure it, you cannot improve it.' ***– Lord Kelvin***

Nowadays, your smartphone offers workout programs for you if you decide to lose weight after you enter a few important parameters (*e.g.* height, weight, age and gender) and your goal. As you do sport, your smartwatch continuously monitors your time, calories burnt, pulse rate, heart rate *etc.* More accurate, personalized workout programs are provided for you based on these data. In parallel, technology can contribute to personalizing education by even predicting what types of tasks and activities would be most beneficial for different students.

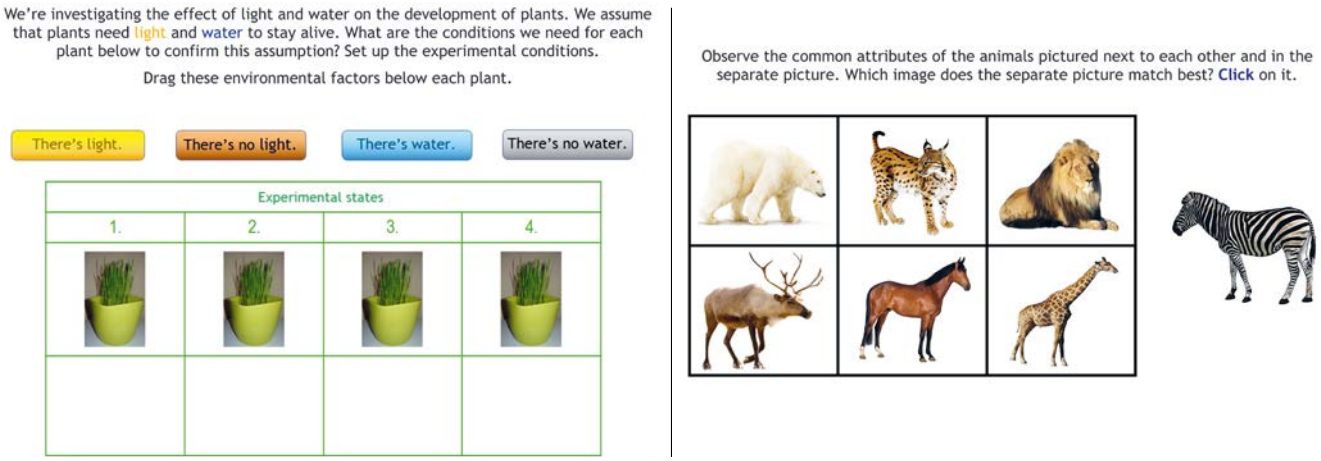
From paper-based to technology-based assessment

Educational assessment has been among the most dynamically developing areas in education since the turn of the millennium. In this period of time, large-scale international assessments (*e.g.* OECD PISA[1] and IEA TIMSS[2]) have become regularly administered by the world's leading test centres, resulting in a huge improvement of data transfer technology and data analysis methods. Two decades ago, paper-based assessments were the most widespread and accepted means of assessment, but due to rapid development, the tools for paper-based assessments represented serious constraints on further improvements. A qualitative change and a new kind of assessment had to be made to meet the learning and assessment needs of the 21st century.

The direction of these developments has been determined by technology, especially by computers, thus offering extraordinary opportunities. We can administer tasks in a more realistic, application-oriented, engaging and authentic context with computer-based assessment; we can use innovative item development opportunities, producing dynamic, interactive multimedia items. For example, in science education, students can engage with simulations and apply their knowledge of scientific

[1] See https://www.oecd.org/pisa/

[2] See https://www.iea.nl/studies/iea/timss



▲ **FIG. 1:** Two examples from the reasoning dimension of science (both are Grade 6-level tasks)

concepts to solve problems. We can design more valid assessments. For example, using an audio version of science tasks and instructions, we can exclude the level of reading skills from the final achievement. Technology-based assessment makes it possible to provide instant, objective, standardized feedback, thus replacing previous long feedback times, and to use adaptive test algorithms to fit the difficulty level of the tasks to the knowledge and skill level of the students (see Csapó *et al.*, 2012).

Adaptive testing makes assessment results more exact and makes assessment fully personalized. In traditional testing, each person receives the same tasks in the same order. In contrast, in adaptive testing, each person completes different tasks, with the most diagnostic power from an item bank. The results can be compared because the items are scaled and defined on a common difficulty and ability scale, even though the students took different tests. The difficulty level of tasks thus administered is tied to the ability level of the students, offering them an optimal challenge. Testing therefore does not become boring or cause anxiety. This can have a positive effect on students' interest and test-taking motivation, which is crucial for the frequent use of tests. This type of testing was even implemented in the PISA 2018 main survey for the domain of reading.

These issues – instant feedback and adaptivity – are also among the secrets that make video games so popular. We do not need to wait weeks or longer to receive feedback on our performance, and we do not need to solve problems which are too difficult for us. If we have to wait days, weeks or months for feedback or start playing the game at a level that is too difficult for us and have no success or if it is too easy and poses no challenge for us, we will never, ever play that game. These are the areas where technology-based assessment and game-based learning are converging, with numerous innovations possible in both.

Today, computer-based assessment offers more effective assessments (*e.g.* they are cheaper, the data flow is faster and safer, indicators of test goodness are higher, student motivation is higher, and feedback is quicker) than traditional paper-based or face-to-face testing. Using at least some of the advantages of computer-based assessment, international summative tests have already been transitioned from paper-and-pencil to digitally-based assessments, and all important assessments will probably follow suit within a reasonable time.

From summative to personalized diagnostic assessment

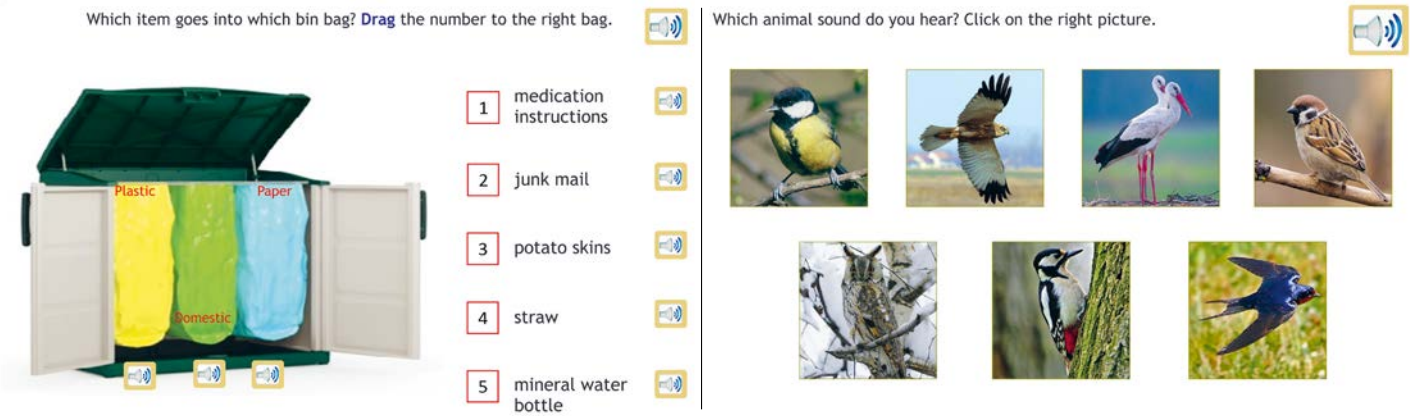
In 2021 there is no longer any question whether we can develop complex, real-world, authentic, high-quality tests. COVID-19-related school closures and digital teaching have reinforced the idea that the 'one-size-fits-all' approach is not effective, either in general or in educational assessment in particular. The almost exclusively used summative test[3] results have limited usefulness with regard to learning and teaching processes to personalize intervention and student-level feedback in general (Csapó & Molnár, 2019). They are good for accountability purposes (see Koretz, 2018) in 'normal teaching times', but they do not meet the individual needs of students. They do not provide actionable feedback for learners to aid in improving their learning process. The COVID-19-related interruptions or modifications in high-stakes national assessment provide an opportune moment to re-think the essence of assessment (Cairns, 2020) and the elimination of summative tests[4].

This crisis is a good reminder that beyond summative, high-stakes testing a more a learning-centred, low-stakes approach[5], using the power of prompt, proper ● ● ●

[3] Summative assessments are used to evaluate student academic achievement at the end of a defined instructional period (e.g. a unit, course, semester or school year). Examples of summative assessments include end-of-unit tests, end-of-term tests and standardized tests for the purposes of school accountability, e.g. the SAT and Matura.

[4] Potential changes to if not elimination of the SAT: https://www.insidehighered.com/admissions/article/2021/01/25/changes-sat-prompt-discussion-future-college-board

[5] Low-stakes assessment (as opposed to high-stakes assessment) is any form of evaluation that does not heavily impact students' educational outcomes or final grades at school. The purpose of low-stakes assessment is to provide students with information on their actual performance and to provide an opportunity to improve their achievement prior to final grading.



▲ FIG. 2: Two examples from the application dimension of science (both are Grade 5-level tasks)

● ● ● – that is, efficient – feedback is relevant and appropriate. This approach was not possible in the days of paper-based testing, but is now fully realisable with technology-based assessment. Like the world of video games, tasks and tests which match students' ability level (adaptive or tailored tests) and assessment with regular and objective feedback are also motivating in education, can even result in flow, and enable teachers to tailor instruction and support students' development more effectively.

Technology-based diagnostic assessments for identifying early learning difficulties in science

In the history of science education, three main goals have remained clear from the very beginning of schooling and public education up to the present day: (1) to cultivate students' minds, general cognitive abilities and thinking skills; (2) to develop usable, transferable, applicable knowledge, that is, knowledge which is applicable inside and outside of school context; and (3) to transmit content knowledge accumulated and organised according to the values of the sciences (Csapó & Szabó, 2012). In modern societies these three dimensions of learning should be present simultaneously, reinforce and interact with each other, and not compete for teaching time. However, most digital games in the sciences develop scientific knowledge/concepts, and less than one-third facilitate students' thinking skills and scientific reasoning skills[7].

The development of the eDia system by the Research Group on Learning and Instruction at the University of Szeged addresses this issue (Csapó & Molnár, 2019). The aim of the technology-based assessment system is to identify students' developmental deficiencies in the domains of reading, mathematics and science and to provide diagnostic feedback, based on an empirically validated three-dimensional model of knowledge (Molnár & Csapó, 2019, 2020) with objective reference points for teachers on their students' development.

Scientific reasoning tasks, that is, tasks from the reasoning dimension of scientific knowledge (see Figure 1), are the most universal across cultures and school systems.

Tasks in the application dimension of knowledge are embedded in relevant situations, and real life-like context illustrated by pictures, videos or simulations, which can be manipulated. In the first tasks presented in Figure 2 students can interact with an authentic problem environment using online technology. The second task presented in Figure 2 uses an item format, which it is impossible to realise with traditional techniques.

The disciplinary dimension of knowledge is measured in the eDia diagnostic system via tasks assessing the acquisition of concepts and procedures which are part of the curriculum. Figure 3 presents an example, in which pupils' disciplinary scientific knowledge is assessed in the area of Earth science.

At present, the eDia system contains more than 25,000 innovative (multimedia-supported), empirically scaled tasks – one-third of these tasks are science tasks – and provides students and teachers regular feedback from the beginning of schooling to the end of the six years of primary education. Beyond student-level achievement and national standards, teachers receive feedback on their class- and school-level results in comparison to regional and state-level achievement. At present, the system is used during the whole school year in more than 1000 elementary schools (approx. one-third of the primary schools in Hungary). Our future plan is to administer the task on an adaptive level and make better use of the impact of visualization in feedback, that is, offer teachers an interactive feedback module with highly integrated visualization techniques.

At the very beginning of the school closures caused by COVID-19, we launched a new module of the eDia system, the eDia kindergarten test module, and made the eDia teacher test module available to everyone. Both are free and available to all. The kindergarten module

[6] Flow is a mental state of being fully immersed and focused, the optimal experience, based on the classic work of Mihály Csíkszentmihályi.

[7] Scientific reasoning encompasses reasoning skills involved in generating, testing and revising hypotheses and theories.

(see ovi.edia.hu with tasks in Hungarian) contains more than 2000 innovative reading, counting and science tasks developed for kindergarten-aged children, while the teacher test module contains all the 20,000 tasks used in the diagnostic assessments (test.edia.hu). The tasks can be filtered by domain, topic, sub-topic, grade and difficulty level. Then online tests or mini-developmental training can be generated from the selected tasks with prompt feedback. All the students need to do the test is a technological device (*e.g.* a personal computer, tablet or smartphone) with an Internet connection.

Recent research findings offer a promising basis for further integration of game-based approaches to science education to enhance students' factual knowledge, its applicability and students' reasoning skills through active participation and interaction, thus finding the balance between digital learning and working with appropriate challenges. ■

Acknowledgements

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About the Author

Gyöngyvér Molnár is a full professor and the head of Institue of Education and the deputy head of the Doctoral School of Education at the University of Szeged, Hungary. She earned her PhD in 2004. Her main areas of interest include: technology-based assessment, improving cognitive skills, and the potential for using ICT in education.

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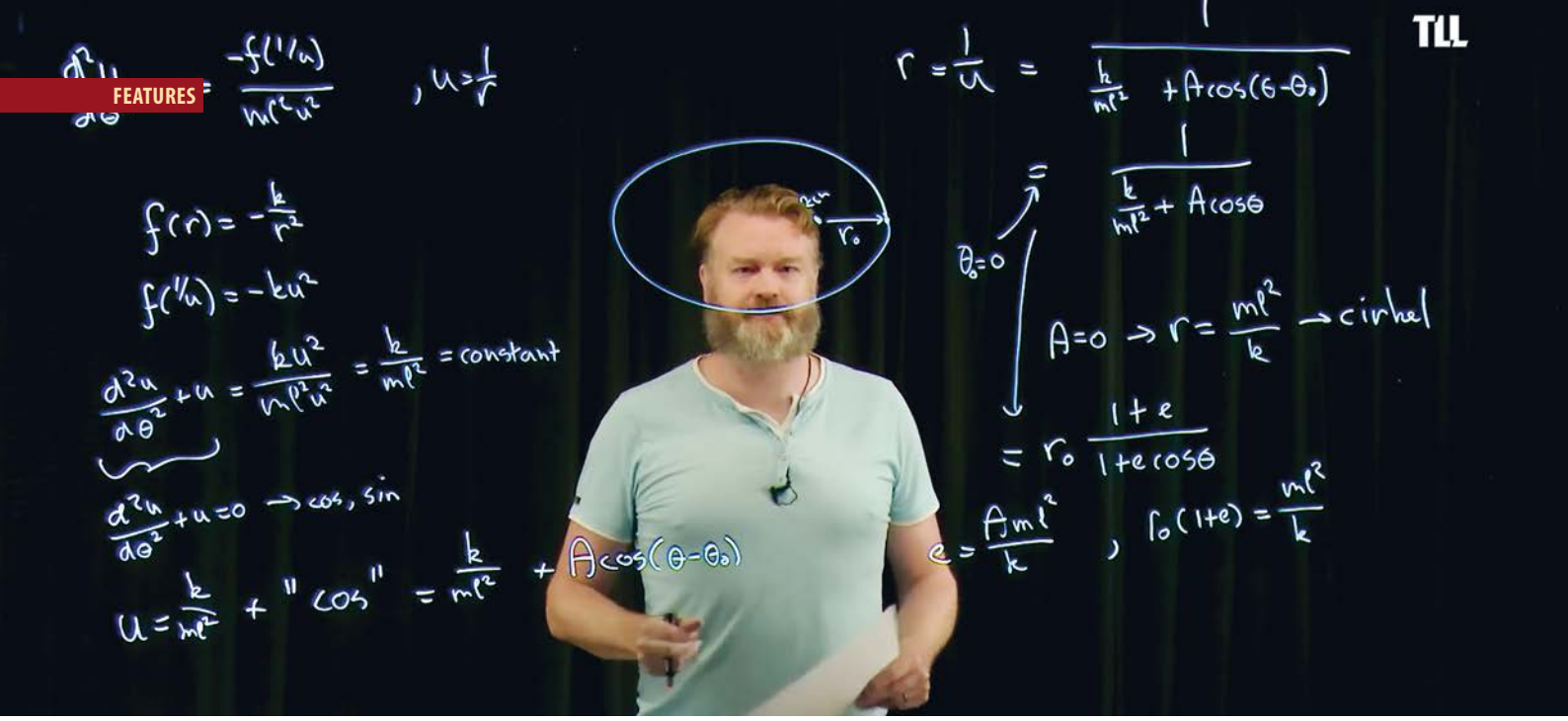

▲ Still from one of the clips showing Dries van Oosten, author of this article

ACADEMIC TEACHING DURING A PANDEMIC:

CLASSICAL MECHANICS AND SPECIAL RELATIVITY AT A DISTANCE

Dries van Oosten – Utrecht University, the Netherlands – DOI: https://doi.org/10.1051/epn/2021203

In the spring of 2020, the schools and universities in the Netherlands were closed for the first time. Urgently and unexpectedly, teaching had to be organised differently. At the time, our students at Utrecht University were well in their third quarter already.

For that reason the time left to properly prepare for online teaching was minimal. Personally, I knew that a few months later in September it would be my turn to teach my students online and I started to think about a teaching model that could work. Here, I report how I planned and implemented that model.

I teach a first-year course on Mechanics and Relativity Theory. A larger number of students than usual were expected, because many of them could not take the final national school exams, since these were cancelled due to corona measures. Moreover, it was already clear that after the summer, the restrictive measures would come back again. It was crucial to choose an educational model that could withstand regular staff downtime and technical difficulties; that makes most effectively use of the time on campus that we were granted; that will teach students to work independently as quickly as possible; and that allows students to motivate each other in small groups. It was essential that the structure and working method would be clear from the start, so that I could immediately offer students structure and regularity. The teaching structure I chose comprised:

- Only once per week on-campus tutorial in a fixed workgroup of four students (three hours per week + three hours per week for other courses).
- One permanent assistant per mentor group of twelve to sixteen students (*i.e.*, three to four workgroups) that together form a team.
- Online tutorials with the same workgroups in the mentor group.
- Core of the lectures to be pre-recorded in short knowledge clips.
- Watching the knowledge clips is scheduled and mandatory, during this time assistance is available online.

What is still lacking in this structure is the possibility of giving students some say in the type of examples being discussed through plenary questions. For this I introduced the "Friday question". Each mentor group could submit a question on Thursday before 17:00, on the basis of which I gave a lecture on Friday morning during a live stream. These questions were often about details in the material, but also about how you see the material in current affairs.

Knowledge clips

For recording knowledge clips I used the Lightboard, a facility for which the Freudenthal Institute of Utrecht University has set up a studio, complete with technical support [1]. A Lightboard is a light-framed glass plate that is written on with fluorescent markers (see introduction figure). By using the Lightboard, I structured the lecture in suitable blocks of about ten minutes. Wiping out in between is not possible on a Lightboard, so care had to be taken that one board would be enough to work everything out. In total I recorded 64 clips, in four sessions of fourteen hours in total. I left minor mistakes and redid only two or three clips . The idea was that I would also make mistakes during a live lecture and perfectionism would simply have taken too much time. A risk in offering the material in the form of knowledge •••

STUDENT INGMAR

It was amazing how smoothly and naturally online education runs. Especially the lectures can easily be followed online. Clips have the advantage that you can choose when and at what speed you get the material explained. In addition, they remain available, making it easier to refresh your knowledge. It is a pity that the lectures have now mainly become an individual affair. When in a lecture hall, you would exchange meaningful glances or comments, people usually turn off the microphone and webcam online to focus on the material. Tutorials are a bit more difficult online. Talking to each other is generally more difficult when you don't see each other; so is asking questions, consulting or explaining each other. Anyone who has ever tried to read a math equation knows what I'm talking about. In addition, in my experience, online you tend to wait longer to ask help from an assistant. Since I am a fresh first year student in 2020, I know no better than home lectures in corona time. But still: if you walk through those empty corridors of the university buildings on campus twice a week, you realise how much you actually miss. - Ingmar Degroote, student of a double bachelor's degree in physics and mathematics.

▲ FIG. 1: Picture of the setting in which the online course was given.

clips is that students experience viewing the clips as non-binding. After all, in online lectures social control is lacking and for students it is tempting to think that they can always watch those clips later. Certainly there would be students who did not watch the clips or only watched them when they could not solve the tutorial exercises.

In order to have some social control, I explicitly put the viewing of the clips in the schedule. As an extra incentive, direct online help with the clips was only available during these scheduled times. In addition, watching the clips was a workgroup activity. So the students were present in a meeting with their workgroup while watching in MS Teams. The students also made interim assignments (together) to promote further discussion about the clips. If workgroups were not online, I could see that in MS Teams and I could address students about it.

STUDENT LISA

I appreciated how the Mechanics and Relativity course in MS Teams was organised. For each workgroup of four students a channel was created. We usually viewed Dries' knowledge clips together and helped each other during the online seminar. This small-scale set-up made me dare to ask my questions and to enter into discussions with my fellow students. In another channel we could ask for the help of our assistants. This worked very well. It was annoying that it is difficult to share worked-out solutions in MS Teams. In the program it is possible to use a whiteboard, but writing with a mouse is difficult. I also found the tutorials (twice three hours) a bit on the long side. I am very satisfied with the knowledge clips. There was not one long recording per week, but always eight shorter clips well connected to each other with the iconic phrase: "But what if ...? We will see that in the next video." The Friday questions often went deeper. As a result, the answers were not always part of the material we had to master for the exams. However, they did give the opportunity to look at a subject in a cross-curricular way, which was very valuable. It certainly helped that Dries was able to turn it into a well-coherent story every time. All in all, I think the approach is successful, although of course I cannot compare: unfortunately I do not know what"normal" is like. - Lisa van Eij, student of the double bachelor's degree in Physics and Chemistry.

Tutorials

In the tutorials the students must work with the material and learn to solve problems independently. Students sat on campus in groups of four, of course keeping a proper distance within the group. Four of these groups together with one larger mentor group fit in a (large) room. An assistant was linked to the mentor group, which allowed them to bond with the students. Because the students worked together intensively during the tutorial on campus and quickly realised what they could achieve together, they could also work together effectively during the online tutorial. The configuration also made up for funny scenes. If, for whatever reason, a student could not come to the tutorial session, a fellow student simply placed a laptop on the empty space of the student, so that they could participate via MS Teams.

The Friday-question livestream

Every Thursday evening at 17:00 PM, the preparation for Friday morning's lecture started. It turned out to be quite a challenge to put together a coherent 45-minute lecture on the basis of about twenty individual questions. However, I made a solemn promise to the students that every question would be answered. If a question really didn't fit the rest of the story, I answered it in the chat on MS Teams, but in general a lot of questions went the same way. What was discussed on Friday was not exam material, so everyone who attended was there purely out of interest. The questions went quite deeply, and I often had to bring in general relativity, quantum mechanics or fluid dynamics on Friday. For the live stream, owe use the system shown in Figure 1. A camera that can be aimed at various boards using foot switches and a monitor large enough to read the chat and see some of the students.

Back to the old normal?

We all assume that one day we will be able to offer education without restrictions again. Then the question will arise: how would I organise my education if it is allowed to be "normal" again? Do I still want to go back to the situation of the past? The students are very enthusiastic about the clips; they can pause a video, but they cannot pause me. The added advantage is that I have more time during the course to speak to students individually. In any case, the students find me much more accessible this year than in previous years. My office was always open to students, but especially first year students normally do not easily come in. Since the online course they don't know any better: post a question on MS Teams and the teacher will respond. Working in small groups also generally worked very well; the only question is whether I will get so many student assistants to help organise my course without this emergency. Of course, the students prefer to see each other more often on location, but perhaps offering an online component is a way to stimulate

working in smaller groups and above all to make it easier to approach the teacher. ■

Acknowledgments

I like to thank Fridolin van der Lecq, Robin van Damme and Arjen Vredenberg.

About the author

Dries van Oosten is associated professor at University Utrecht, the Netherlands. In 2004, he obtained his PhD at the same university. His group conducts research into Bose-Einstein condensation of light and extremely nonlinear optics.

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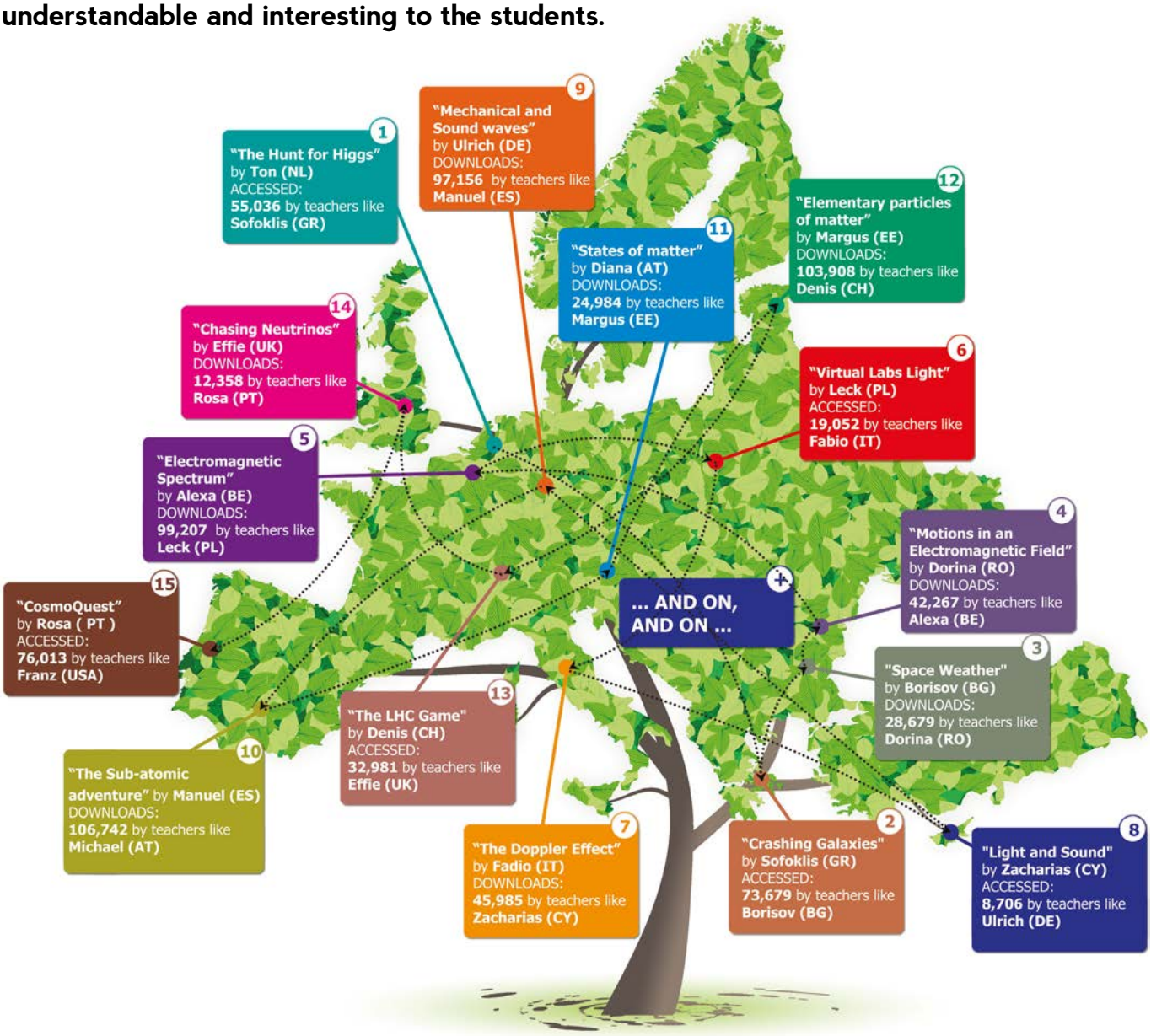
DIRECTOR OF EDUCATION PETER

In the spring of 2020, physical education in universities was stopped overnight and all lectures were offered online. Before the summer it soon became clear that this situation will not change for a long time. In Utrecht, we 'sat around the table' with various teachers to further assess the implications. We discussed questions such as: How can we offer the material to the students as optimally as possible? How do we keep the students actively involved in a course? How can we provide feedback to the students as clearly as possible, but also as efficiently as possible? How we can provide students with possibly making the transition from high school to university thinking, came into a different light and forced us to come up with new answers. In this article, one of our teachers explains how he dealt with this in his course, which for the students is their first introduction to physics and astronomy. - Peter van der Straten, Education Director Physics and Astronomy.

INQUIRY-BASED SCIENCE EDUCATION AND E-LEARNING

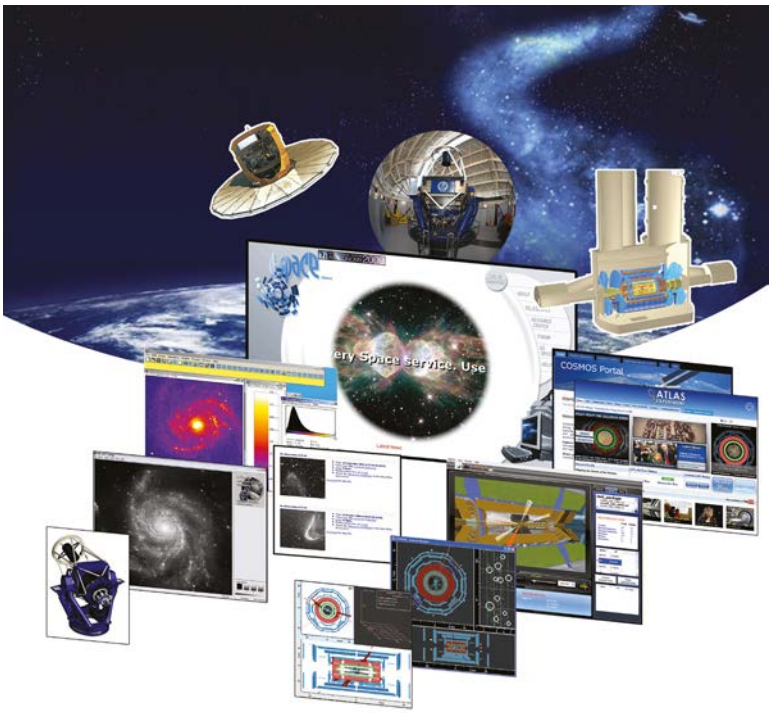
Sofoklis A. Sotiriou – DOI: https://doi.org/10.1051/epn/2021204
Research and Development Department, Ellinogermaniki Agogi, Greece

Science classrooms (even in the time of the pandemic) should provide more challenging, inquiry-based, authentic and higher-order learning experiences allowing students to participate in scientific practices and tasks. Rich scientific databases, e-Learning tools and digital educational resources can serve as a catalyst for science learning. They can offer a better understanding of complex scientific research, making science understandable and interesting to the students.



Science Education and Inquiry Approaches

Science education methods (project-based, collaborative, and hands-on) are highly affected by the current restrictions that have been implemented in schools due to the COVID-19 pandemic. Even in a hybrid scheme of delivery of education services, the restrictions posed are creating a rather problematic framework for the implementation of *inquiry-based* projects and activities. On the other hand, the introduction of *inquiry-based* approaches into school curricula is a major priority in most EU Member States. *Inquiry* is seen as the catalyst for the development of students' deeper learning competence (academic knowledge, problem-solving skills, cooperation and creativity, development of academic mindset). *Inquiry* holds great potential for increasing the enrolment and academic success of students, addressing gender segregation and producing a well-qualified and diverse workforce with the right Science Technology Engineering and Mathematics (STEM) skills [1]. How can we safeguard the continuation of such initiatives? Are there tools and applications that could facilitate the implementation of *inquiry-based*, collaborative and creative activities while schools are closed? Are teachers and schools ready to deploy such innovative approaches to keep delivering high-quality services to their students?



▲ **FIG. 1:** e-Science programmes that reinforce the cooperation of leading researchers provide a solid framework for bringing new instruments and opportunities into modern education, thereby providing learners with better opportunities to build their knowledge for the future. e-Science programmes provide an appropriate framework for reinforcing a participatory learning approach and developing instruments for authentic assessment in science education at all levels. Discover the COSMOS Portal [2] offers access to such programmes related to High Energy Physics, Space and Astronomy.

The unique potential of e-Learning

E-learning represents an appropriate vehicle to overcome these barriers and to offer high-quality science education, while at the same time safeguarding the key characteristics of physical learning through the *inquiry* experience. The orchestrated use of digital resources, applications and tools can facilitate the development of innovative learning experiences that do not merely simulate the school lab environment. They can offer much more than that: access to virtual labs and online experiments that cannot be performed in school labs, e-Science programmes for schools that include virtual visits to research infrastructures (see Figure 1) [2], virtual pathways to science centres and museums located all around the world. Furthermore, the introduction of innovative digital tools that enhance experimentation, *e.g.*, the development of digital storylines, enriched with 3D digitization and AR/VR applications for the students, tap into the creative potential of technology to offer transformative experiences for schools (see Figure 2) [3].

Such experiences focus heavily on skills development, deepen conceptual understanding and succeed in introducing concepts within their real context. The real key to future developments in learning is personalization: of interpretation to significantly enhance social and intellectual inclusion; of technology to free both schools, teachers and students from many of the current constraints; of learning to finally facilitate an escape from the deficit models so prevalent in schools and release untold potential, as the individual learner is able to use technologies to exercise choice and to take responsibility for his/her own learning. For example, students can navigate the finest digital collections at European science centres and museums, guided by attractive educational pathways connecting objects to discoveries. Digital collections at science centres and museums can form interactive storylines, interconnecting the school curricula with different exhibits, beyond time and location limitations. E-learning provides innovative ways to explore the world: not simply to automate processes but to inspire, to engage, and to connect. It offers a powerful framework for teachers and students to engage, discuss and explore how schools need to evolve, transform and reinvent; how schools can facilitate open, more effective and efficient co-design, co-creation, and use of educational content (both from formal and informal providers), tools and services for personalized learning and teaching; how schools can become innovation incubators and accelerators.

Effective introduction of *inquiry-based* approaches into educational settings to promote learning outcomes

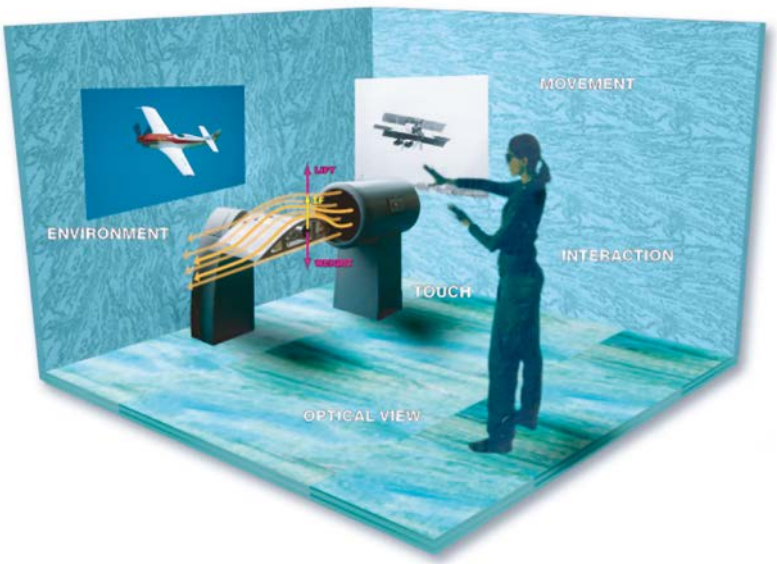
Inquiry-based approaches in science lessons have produced positive educational outcomes even over the long term [5], [6], [7]. Although the process itself is time-consuming and the current curricular structure too often fails to support opportunities for such interventions, digital tools and resources offer an effective way to decrease the time needed and ● ● ●

to encourage teachers to adopt the *inquiry* process in their daily lessons [7]. Organising and delivering digital resources during a normal school lesson is quite a demanding task for teachers and prevents many of them from following such an approach. Technology-supported, teacher-generated lessons enriched with high-quality educational resources could bolster such interventions in a variety of classroom settings, meeting the needs of both students and teachers [7]. Such interventions could be effective in building bridges to real life experiences, but also lead students to a lifelong learning experience, and inspire students – even those with limited interest in science and math subjects [8]. The teachers' role concentrates on organizing learning resources to run collaborative activities amongst student peers and make use of existing lessons [9]. It is exactly this competence-oriented, *inquiry-based* lifelong learning experience that facilitates teachers' and students' interaction with 'knowledge scaffolds' in their peer communities by sharing (knowledge) domain- and (education) grade-specific practices and solutions.

Creating Deeper Learning Experiences

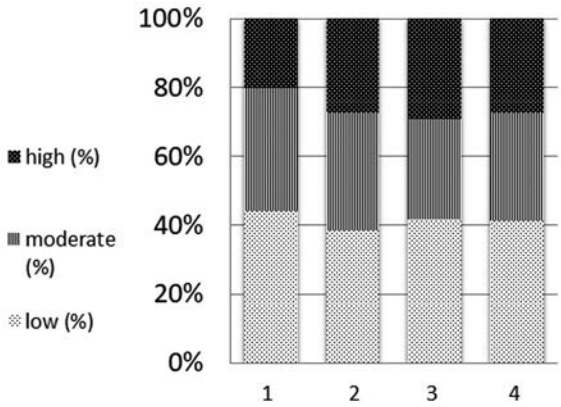
Advanced e-Learning tools are making assessment more efficient and effective, incorporating the added capability of administering dynamic and interactive problems, engaging students' interest more fully and capturing more information about the problem-solving process. This result also is definable as deeper learning, which is regarded as sustained retention of successfully acquired cognitive knowledge. ICT-based assessment tasks can make it possible to record data about the type, frequency, length and sequence of actions performed by students in responding to items. The organisation of *inquiry* activities in lab work provides the opportunity to analyse the effects of advanced scenarios that foster complex problem-solving abilities. The different steps performed by the students in the *inquiry* process (*e.g.*, understanding and characterising the problem, representing the problem, solving the problem, and reflecting and communicating the solution) can be included in the educational design process: in this way, the system allows for the mapping of changes in these partial abilities during the problem-solving process. The assessment permits the analysis of solution paths or strengths and weaknesses at an individual student level. The Inspiring Science Education EU Policy Support Action [3] has performed such a study with the involvement of more than 12,000 secondary school students (14-15 years old) in *inquiry-based* science lessons using an advanced e-Learning platform for their delivery. The analysis of the data demonstrates a significant increase in high achievers (20-29%, compared to the 10% OECD average) while a significant impact on low achievers is also recorded (see Figure 3) [10]. The potential to overcome the usual barrier to implementing *inquiry-based* lessons in classrooms is shown by the substantial increase of the proficiency level within complex problem-solving tasks. Conclusions regarding the domain-specific characteristics of the curricular content may be drawn; for instance, whether a student has attained a certain competence level after a specific science activity. The acquisition of increased levels of problem-solving competence provides a basis for future learning, for effective participation in society and for performing personal activities. Students need to be able to apply what they have learned to new situations. The study of individual problem-solving strengths provides a window on their abilities to employ basic thinking and other general cognitive approaches needed to confront life challenges.

▼ **FIG. 2: Visualizing the invisible at science centres and museums: The visualization of natural phenomena could support conceptual change. Immersive interfaces can foster educational experiences that draw on a powerful pedagogy: Situated learning requires authentic contexts, activities and assessment coupled with guidance and mentoring [4].**



Re-imagining Science Education

A wide range of innovative ideas has emerged in science education over the last few decades. While progress has been made in implementing them, much opportunity remains, especially as the needs of our economy, our insights into pedagogy and the emergence of affordances such as e-Learning have evolved. However, innovations also have side-effects, if they are not widely propagated, of widening achievement gaps. We must ensure that the tide of innovation 'lifts all boats'. The fact is that the COVID-19 pandemic has accelerated matters dramatically. Schools and educational institutions with the wherewithal to respond to COVID-19 – be it through e-Learning or hybrid teaching – have been forced to accelerate their innovation. It is important, as society limps back from an extended abnormal, to reflect on what has worked and what has not, and to ensure that the overall outcome of this difficult period in human history is a set of practices that are better suited to serve overall progress rather than jury-rigged solutions that live on because they are convenient. The COVID-19 era has offered us opportunities to re-imagine science education. ■



▲ **FIG. 3:** The graph presents classroom profiles as far as the students' proficiency in problem-solving competence is concerned. The study includes data from 12,000 secondary school students (14-15 years old) who were involved in inquiry-based science lessons using the Inspiring Science Education platform for their delivery. The average pattern of high, moderate and low performers per phase of all students, for all implementations in the pilots. Phases: 1 = understanding and characterising the problem; 2 = presenting the problem; 3 = solving the problem; 4 = reflecting and communicating the solution. The analysis of the data demonstrates a significant increase in high achievers (20-29%, compared to the 10% OECD average) and significant impact on low achievers (decrease from 45% [OECD Average] to 40%) after their involvement in the inquiry lessons.

About the Author

Sofoklis Sotiriou is the Head of Research and Development Department of Ellinogermaniki Agogi since 1998. His main field of research is the modernization of science education using the *inquiry-based* approach. His work is focusing on the design, application, and evaluation of virtual and digital media environments that bridge the gap between formal and informal science learning. He is the author of the Science Textbooks that are used in Greek primary schools.

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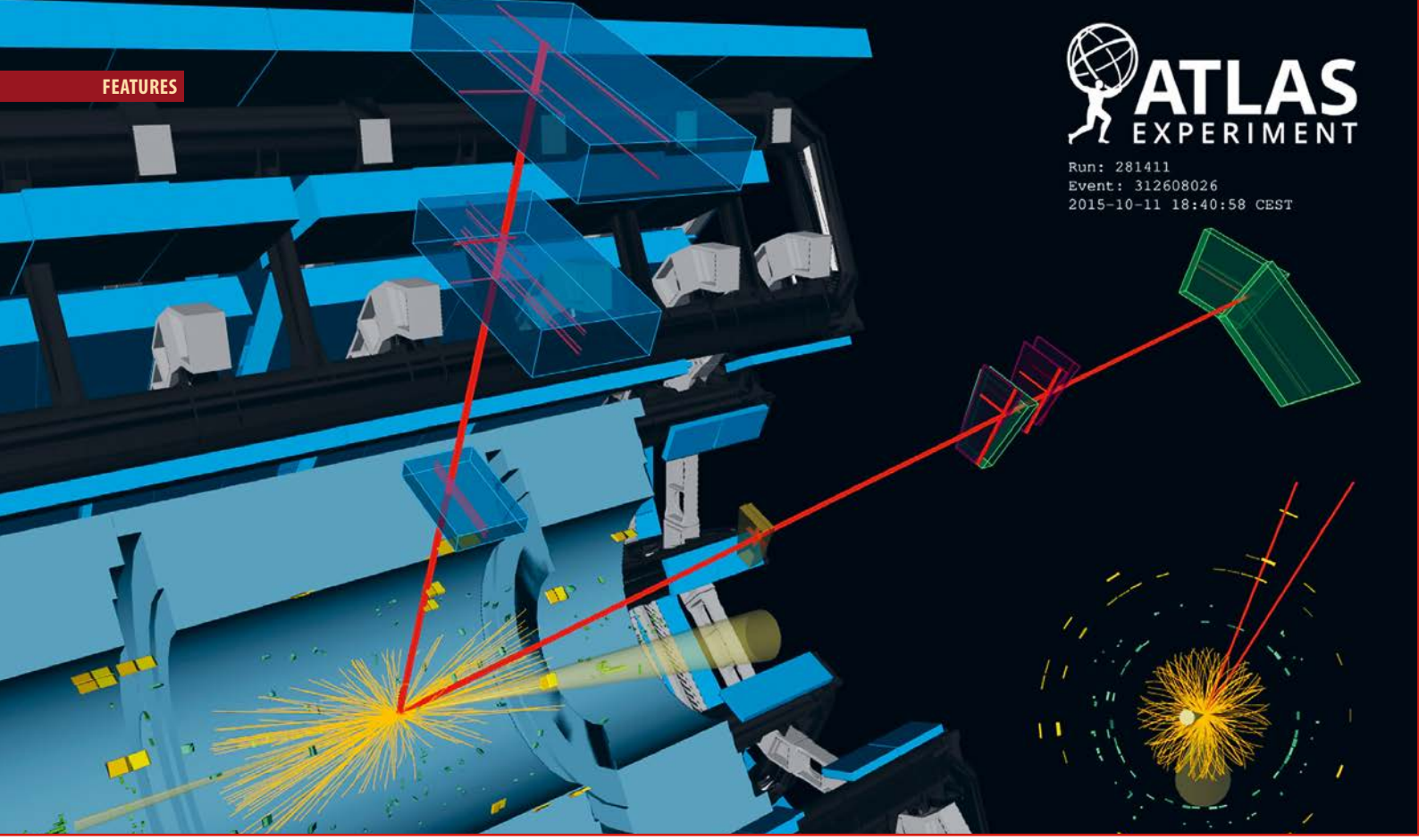


▲ Candidate event for a Higgs boson decay to two muons, produced together with two hadronic jets in the ATLAS detector.

MASS MATTERS: LATEST HIGGS BOSON RESULTS FROM THE LHC

The Higgs boson was discovered at the Large Hadron Collider in 2012. Since then, a comprehensive program has been ongoing to characterize it as precisely as possible. Can this particle help us solve some of the big open questions in physics?

Sarah Heim – DESY, Germany – DOI: https://doi.org/10.1051/epn/2021205

As particle physicists, our goal is to understand the fundamental building blocks of the universe by studying their properties and their interactions with each other. Our dream is to have a consistent and complete mathematical model of the elementary world, relying on as few input parameters as possible.

Our current best description of elementary particles and their interactions is called the Standard Model of particle physics. As an integral part of this model, the so-called Higgs mechanism describes a scalar field which permeates the universe, and gives mass to elementary particles by interacting with them. Furthermore, the quantum excitation of this field produces a scalar particle. In 2012, the ATLAS and CMS Collaborations at the Large Hadron Collider (LHC) discovered such a particle, the Higgs boson.

The Standard Model predicts neither the Higgs boson mass nor the mass of the matter particles, the fermions, so these need to be measured. By now, the ATLAS and CMS experiments have determined the Higgs boson mass with a stunning accuracy of 1-2 permille [1,2]. Knowing the masses, all other expected Higgs boson properties can be calculated, at least up to a certain precision. Measurements that do not agree with those predictions could point us towards a different mass-generation mechanism, perhaps as part of a theory that can explain some of the questions the Standard Model cannot answer, like the nature of dark matter or the origin of the matter-antimatter asymmetry in the universe.

Interacting with the Higgs boson

Arguably the most interesting property of the Higgs boson is its interaction with other fundamental particles (and also with itself), as the strengths of these interactions are directly related to the particles' masses: the stronger the coupling, the larger the mass. The Standard Model does not explain why some particles, like electrons, have very small coupling strengths and are therefore extremely light, while others, like the top quark, weigh about as much as a gold atom. Measuring the strength of the Higgs boson interactions could possibly help us understand what lies behind the very different mass values found in the elementary world. The couplings between the Higgs boson and other particles can be extracted by measuring how exactly the Higgs boson is produced in the proton-proton collisions at the LHC and, since the Higgs boson has a very short lifetime, how it decays to other, lighter particles. Figure 1 shows the Standard Model predictions for Higgs boson production and decays.

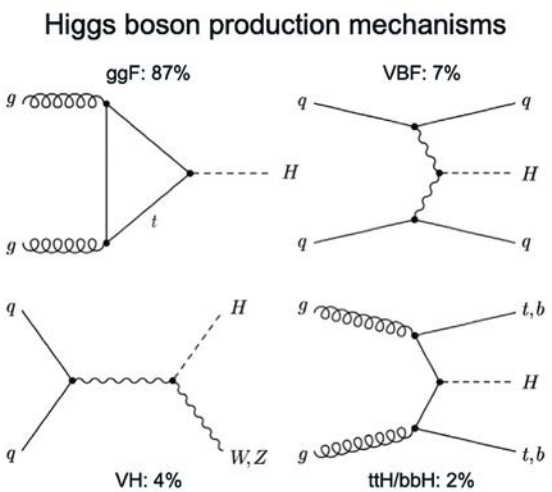
The Higgs boson was discovered by filtering for collisions that result in two force-carrying bosons, in particular two photons or two Z bosons. Their invariant mass, *i.e.* the mass of a possible mother particle, was scanned in the search for an excess. In the years following the discovery, more data was collected and physicists in the ATLAS and CMS Collaborations continued to improve their analysis techniques, incorporating for example more advanced machine learning algorithms. This led to the discovery of Higgs boson decays to fermions, which are as hard to find as needles in a haystack due to many background processes that leave similar detector signatures. By now, we have discovered Higgs boson decays to pairs of tau leptons (the heaviest known leptons) and pairs of bottom quarks (the second heaviest known quarks). Higgs boson decays to top quarks are not allowed kinematically, because the top quark is heavier than the Higgs boson. Fortunately, the coupling to these heaviest of all known elementary particles can still be probed directly by disentangling different Higgs boson production mechanisms, in particular the production of a Higgs boson in association with two top quarks.

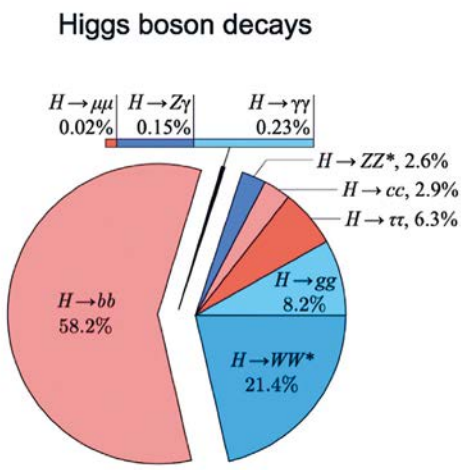
To understand whether all elementary particles receive their mass through the Higgs mechanism, it is now of utmost importance to probe the Higgs boson interactions also with lighter fermions. These couple more weakly to the Higgs boson, leading to extremely rare decays: For example, only 1 in 5000 Higgs bosons is expected to decay to two muons. It was possible last year to see first exciting hints of this decay at both the ATLAS and CMS experiments [3,4]. Thanks to the extremely strong magnetic field that allows the detector to determine the muon momentum with stunning precision, the CMS Collaboration found a signal consistent with the Higgs boson decaying to two muons, as shown in Figure 2, left. The significance of the signal is 3 sigma, which means the probability that it is due to a statistical fluctuation is less than 1 in 700. The combination of CMS and ATLAS results would increase the significance well above 3 sigma, providing strong evidence for this decay. For a discovery, a probability of 1 in 3.5 Mio is required - which we aim to achieve with more proton-proton collision data.

The best way to get a complete picture of Higgs boson interactions with other particles is to statistically combine measurements of all accessible Higgs boson production mechanisms and decays. With the assumption that the Standard Model describes the general structure of the interactions (see below for tests of the symmetry behaviour), one can then compare the measured coupling strengths to the Standard Model predictions. Figure 2, right, shows the results and achieved precision from the CMS experiment for the Higgs boson couplings to different particles - excellent agreement is found so far between all measurements and the Standard Model predictions [5,6].

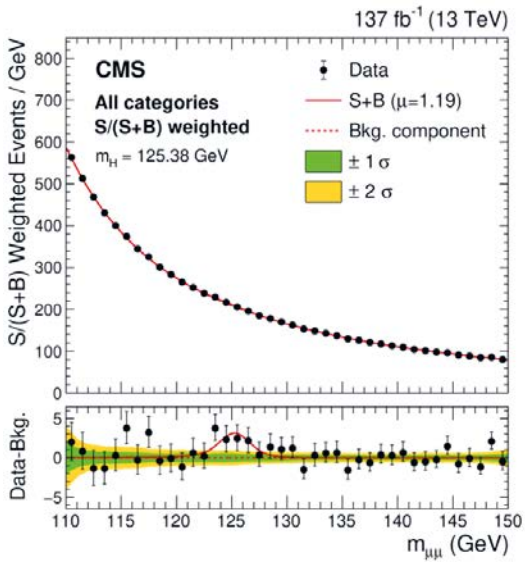
The Higgs boson and dark matter

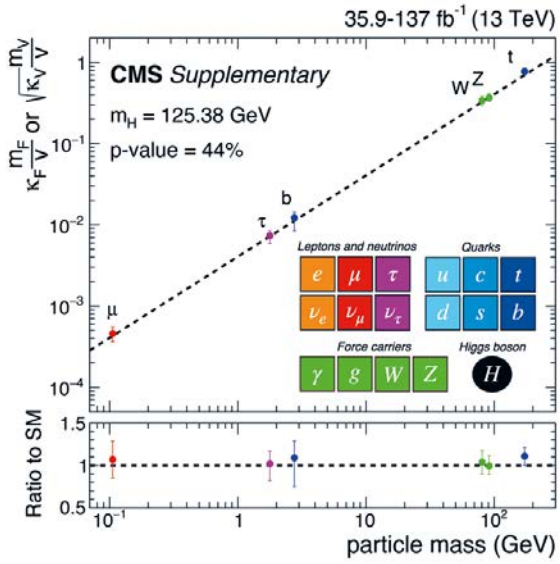
One of the biggest puzzles in physics today is the question of what constitutes the observed dark matter in the universe. Dark matter particles, if they exist, must be massive, but only interact very weakly with normal matter. Physicists attempt to track down these elusive particles with multiple ●●●





▾**FIG. 1: Left:** Higgs boson production mechanisms in proton-proton collisions at 13 TeV, according to the Standard Model of particle physics, assuming a Higgs boson mass of 125 GeV. The production mechanisms, from top left, clockwise, are: gluon-gluon fusion, vector-boson fusion, associated production with two top (or two bottom) quarks, and associated production with a Z or W boson. **Right:** Standard Model predictions for the fractions of Higgs boson decays to different particles, for a Higgs boson with a mass of 125 GeV. The fractions of the decays to fermions are shaded in red, and the fractions of decays to bosons are shaded in blue.





▸ FIG. 2: Left: Reconstructed invariant mass distribution in collision events with two muons recorded by the CMS detector. The measured data points are shown in black. The events are weighted according to their probability to contain a Higgs boson decay to two muons. In the bottom panel, the expected background is subtracted and the excess around the Higgs boson mass is visible. **Right:** Coupling strengths of different elementary particles to the Higgs boson from CMS measurements, plotted vs the respective particle's mass. The Standard Model prediction is the dashed line. The bottom panel shows the ratio between measurements and prediction. Current measurement uncertainties are shown as error bars. It can be seen that the measurements agree very well with the linear prediction from the Standard Model.

• • • strategies: Trying to capture the extremely rare interactions of dark matter in gigantic detector volumes, or through strong magnetic fields; looking for cosmic radiation that could come from dark matter decays somewhere in the universe; and trying to produce dark matter in accelerators.

Given that we know dark matter is massive, it makes sense to assume that it interacts with the Higgs boson. If the dark matter particles are in the right mass range, there is even the possibility to find them in decays of the Higgs boson. Since dark matter does not interact with the ATLAS or CMS detectors, we search for these decays by selecting collisions with a momentum imbalance, where detected particles recoil against something invisible.

At both LHC experiments, no hint of Higgs bosons decaying to dark matter has been observed [7,8]. Combining a number of analyses with different search strategies, a recent ATLAS analysis managed to constrain the fraction of Higgs bosons decaying to dark matter to smaller than 11%, an impressive achievement, which nonetheless leaves plenty of space for the discovery of such decays in the future.

Is the Higgs boson symmetric?

The Standard Model predicts that the Higgs boson interactions with other particles should not change under various symmetries, in particular the case where the space coordinates are flipped (mirror symmetry) and the charges of the interacting particles are swapped simultaneously (for example a negative tau lepton vs its positive antiparticle). This symmetry is called Charge-Parity (CP) symmetry, and if it is fulfilled, as the Standard Model predicts, the Higgs boson coupling is called CP-even. Beyond the Standard Model, a coupling could also be CP-odd or a mixture containing an even and odd component.

For Higgs boson interactions with force-carrying bosons, it was already shown that the CP symmetry holds to a large extent. Last year, ATLAS and CMS also tested the symmetry properties of the Higgs boson coupling to top quarks and tau leptons [9,10,11]. In both cases, the data clearly favors the CP-even over the CP-odd hypothesis with a significance of more than 3 sigma. Large CP-odd admixtures are excluded as well. Other checks of the Higgs boson coupling structures have so far also solidly confirmed the Standard Model predictions.

Extending the Higgs family

Given all the successes and shortcomings of the Standard Model, it is natural that for a long time physicists have tried to find extensions to this model. Many of the new models predict more than one Higgs boson. In fact, one of the most popular classes of models, supersymmetry, states that there are at least five Higgs bosons, two of which are charged, and one of which violates CP symmetry. The additional Higgs bosons could be lighter or heavier than the Higgs boson we already found.

At the LHC, an intensive search is ongoing for additional Higgs bosons, similar to the original Higgs boson search. Furthermore, the interactions of the already-discovered Higgs boson could be affected by their existence; this means that precise measurements of Higgs boson properties - especially interaction strengths and structures - are also crucial in these investigations. In fact, it turns out that the sensitivity of the two approaches (search and measurement) is quite complementary, and, since nothing new has been found so far, they can exclude different areas of model parameter space, telling us at least where we do not have to search anymore [12].

Characterizing the Higgs boson - Is that it?

The landscape of Higgs boson physics remains interesting: Both ATLAS and CMS are still measuring Higgs boson properties and searching for additional Higgs bosons with the data set recorded between 2015 and 2018. Combined analyses of the collected data from the two experiments will push the precision even further.

The third LHC run starts in 2022 and the LHC Upgrade, the High-Luminosity LHC, is scheduled to go

into operation in 2027. The plan is to increase the recorded data set by about a factor of 20, allowing the hunt for even rarer processes and more precise measurements.

One goal will be the measurement of the Higgs boson couplings to other particles with precisions up to a few percent [13]. Another major goal will be to measure the self-interaction of the Higgs boson, which is sensitive to the energy potential of the scalar field, and therefore another important test of the Higgs mechanism and the structure of the vacuum.

The highlighted studies, both at the LHC and at future colliders, all have the purpose of stress-testing the Higgs sector of the Standard Model, as we are looking for tiny hints that could answer some of the big questions about our universe. ■

About the author

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Further reading

In general, the physics briefings of the ATLAS and CMS experiments give a good overview over recent results:
https://atlas.cern/updates/physics-briefing
https://cms.cern/tags/physics-briefing

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The challenges of online teaching

I am relatively new to on-line teaching. When the UK first entered lock down, I had already completed my teaching and retired from my full time position shortly afterwards. Now, as a visiting lecturer at another university, I have had to deliver a small number of lectures and offer the following opinion based on my, admittedly, limited experience.

▲ Hopefully we can return soon to physical teaching. © iStockPhoto

Recently, I reported on the experiences of several academics in the UK (Europhysics News 51/4, 2020 p.30-32) and it became clear to me that online teaching is very demanding of time. Even if the online time was used to deliver information in the manner of a normal lecture, time was spent afterwards offering students individual support. Important though the impact on staff might be, the impact on students is what really counts. As an old colleague of mine put it, learning is an activity: you have to do something to learn and for many students in an online environment, it is too easy to hide. Moreover, it has been my experience recently that increasing numbers of students are struggling to move beyond a view of physics teaching as the delivery of factual information which need only be learnt by rote.

Students will only do with knowledge what their assumptions will allow and a naïve view of physics is a serious impediment to their development. Discussion with peers is an effective way to challenge such assumptions, but I find this very difficult to do online. Interactivity drives engagement and whilst pretty much all on-line platforms now facilitate interactivity, not to mention the existence of web-based interactive polling platforms which enable both quizzes and rapid feedback from students, some students still just do not participate. If students are not inclined to interact with academic staff they are even less inclined to engage in open discussion with their peers.

Undoubtedly, the technology exists for highly effective interactive teaching if students are aware of their own responsibilities and are willing to participate. Perhaps it is my limited experience, but it sems to me that there is still a technological gap to be filled when this is not the case. Within a classroom setting I can create groups, give them media through which to interact (small whiteboards are very effective), move between the groups, pose questions and guide the discussion. If something arises that needs to be brought to the attention of the whole class, it is easy to do so. None of the platforms I have looked at make overseeing different groups in breakout rooms easy and on-line peer-to-peer discussion remains a challenge. However, peer-to-peer discussion not only helps students to restructure their knowledge, it is also essential for challenging limited assumptions about the nature of physics knowledge and learning and for developing complex skills like problem solving. Initiating this kind of interaction on-line is perhaps the next big challenge in educational technology. ■