Thoughts on an education

Eight students from across the world discuss their own nanoscience education.

Research in nanoscience and nanotechnology has grown rapidly in recent years and has provided numerous scientific and technological breakthroughs. The field has also, in some sense, changed the way in which a research topic can be tackled, unconstrained by traditional scientific disciplines. However, what effect have the developments in research had on the curriculum being taught in universities? And what sort of education do the nanotechnologists of the future need to succeed? *Nature Nanotechnology* asked a range of current, or recently graduated, masters and PhD students about their own experiences, and what, if anything, they would change about the current education system.

A decade ago, I was a high school student in Apopka, Florida and my physics teacher secured a grant for a pioneering experiment in science education. He had designed a course in which high school students could experience what it was like to have a career in scientific research. For the final class of each school day, we would commute to a nearby university campus that had a fully equipped wet-chemistry lab and would work on independent research projects related to nanotechnology. The course gave me the chance to learn what it would be like to be a practicing research scientist and was one of the reasons why I chose to attend a university where I would have the opportunity to participate in nanotechnology research early in my degree.

During my undergraduate studies in chemical engineering, I discovered that although none of the classes dealt directly with nanotechnology the lessons in matter and energy-transport phenomena were universal and highly applicable to nanotechnology research. I spent my summers enrolled in extra courses and worked as an undergraduate research assistant in a colloidal and interfacial science group. By the end of those four years, thanks to the encouragement of my professors, I was able to publish my first scientific paper and graduate with a joint bachelor's and master's degree.

By the time I started my PhD, topical seminar classes in nanotechnology were just being implemented. Only now, as I near the end of my PhD studies and a decade after my high school class, is nanotechnology beginning to be integrated into the academic curriculum. The field has, I believe, finally reached a critical mass of knowledge and now has its own distinct history of discoveries and advancements. That being said, my studies in nanotechnology were the result of my mentors who created a unique personal research experience for me. Although formal classes are critical to retain the groundwork that has been laid in the subject, it is important to remember that it is the responsibility of the scientific community to mentor students and to guide them towards the future forefronts of scientific research. Classes cannot teach what has yet to be discovered.

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I ended up in nanoscience quite by accident. It was only after being allocated a research project in the final year of my undergraduate chemistry degree that I started to really learn about it and become interested in the area. The project was a one-off idea from my supervisor and by chance looked at the synthesis and characterization of nanoparticles. At that time, there were no opportunities in my undergraduate degree course to specifically study modules in nanoscience. Since then, nanoscience has evolved into a real buzzword of twenty-first-century research and governs a significant proportion of scientific news stories. Given this prominence, the subject should perhaps feature not only in our university degree curricula, but also our schools.

Would I have benefited from a nanoscience module in my chemistry degree? Yes, but I could say the same for every optional module that I did not take. These modules are equally valuable, but undertaking them all would double the length of your degree. I think the key point is that nanoscience research benefits hugely from a collaborative team of scientists. I work in a research group that includes students and postdoctoral researchers from a variety of backgrounds, and I am always fascinated how, for example, a chemist can approach a problem in such a different way to a physicist. It is this combination of different expertise that is necessary to completely understand the subject and has been integral to its success as a research field.

In my opinion, researchers in nanoscience need to retain a basic grounding in physics, chemistry and materials science. However, I think the general awareness of nanoscience and nanotechnology could be improved. Researchers in the field are working towards solving a vast number of problems, and have already achieved a number of amazing things. It is therefore becoming more important that non-scientists have a taste of what 'nano' really means. At degree level, educating young, intelligent minds about nanoscience and its potential could recruit some of the brightest thinkers into this fast-expanding area. In schools, I have found when giving informal talks and introducing the topic to 16–18-year-old students, it is incredibly well received. This is because nanoscience is both current and encompasses such a broad range of science that most students can find an area to relate to. Raising the awareness of nanoscience in education, even just to introduce the capabilities of the field, alongside the key sciences, could engage new researchers and spark new ideas from the scientists of the future.

Jude Britton is a DPhil student at the Department of Materials, University of Oxford, UK. She has an undergraduate degree from the University of Leicester, UK.

Since my undergraduate studies, I have been fascinated by the interplay between nanoscience and quantum information. Motivated by this, I decided to join a research group for my PhD that studies a broad range of related topics including entangled photons, cold atoms and solid states. This diversity means that the group brings together researchers with different expertise and this combination can often lead to the generation of interesting new ideas or novel solutions to technical problems in experiments.

My PhD research looks at, in particular, the optical control of quantum dots, and combines semiconductor nanosystems with quantum information. The first year of the degree was mainly focused on attending graduate courses such as advanced quantum mechanics and quantum optics. After that, I received a systematic training in the laboratory, from basic vacuum and cryogenic techniques to high-resolution laser spectroscopy, single-photon and single-spin manipulation. In addition, biweekly seminars or meetings were arranged that had an emphasis on the discussion of the latest results, the exchange of ideas, and training for writing papers and giving presentations. I expect these skills to be very helpful in my future career.

In recent years, I think an increasing number of Chinese students have benefited from the government's recruitment programme of overseas talents. Both my PhD supervisors (Jian-Wei Pan and Chao-Yang Lu) were educated abroad (at the University of Vienna and the University of Cambridge, respectively). As a result, they have developed the ideas, methods and style of the western system, and have an international vision. For instance, the importance of critical thinking is emphasized, authority is routinely challenged, and students are given considerable freedom and flexibility to conduct research. I think this is important in promoting a harmonious student–supervisor relationship and a healthy group dynamic.

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A science degree is endlessly fascinating. It provides an opportunity to step back and appreciate the confusing, complicated and truly awe-inspiring nature of the physical systems that compose our world. Undoubtedly, some days can be filled with laborious proofs or frustrating experimentation, but these are worth it for those 'eureka' moments: moments germinated from a feeling that you are beginning to understand the immensity of our reality. I came to nanotechnology from a theoretical background in natural sciences. However, I became much more interested in research that had direct applications and could significantly improve the quality of peoples' lives.

Nanoscience has the potential to affect deep and profound changes to the circumstances of people around the world, from all socioeconomic backgrounds, because it can be related to such a wide range of industries. I would argue it is becoming increasingly difficult to identify an industry in which the field of nanoscience has not already exerted some influence. My master's course — an MPhil in Micro and Nanotechnology — bridged the borders between the natural sciences, material science and engineering. I believe such a multidisciplinary approach is vital to tackle a field with such a broad reach. The research components help to reinforce the teaching material and allow students to find a specialized area of interest.

I feel that this could have been aided further by a regular 'journal club', which could have provided a platform for discussing the latest advancements in the field and helped us gain a deeper understanding of best practice in scientific experimentation. Such a journal club for master's students would have complemented the existing framework, which does, I feel, produce scientists prepared for careers in academic or a related industry, but lacks an appreciation of the trials of research.

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The nanoscale is a length scale at which the immutable properties of atoms give way to configurable materials and devices that are both useful to society and exciting for science. This intersection of utility and fundamental scientific curiosity is what led me to pursue research in nanoscience and nanotechnology. A personal bonus of being a researcher in this area is finding that non-specialists often show interest in my work because I can provide concrete examples of how research in this field can benefit their life. In my involvement with several outreach events, I have observed a similar reception when engaging intermediate and high school students. This leads me to believe that motivating school children through discussions and, moreover, hands-on demonstrations is crucial; our increasing understanding of the way in which nature harnesses nanoscale design seems to especially pique the curiosity of children of this age. On the other hand, summer research experiences seem to hold the attention of undergraduate students by immersing them in sustained research activities.

During the course of my own education and research, I have been constantly reminded about the multidisciplinary nature of nanoscience. Having transitioned from engineering to applied physics, I have come to appreciate the rigorous fundamental training I received in the basic science subject areas of physics, chemistry, mathematics and biology during my undergraduate degree in India. Until recently many of my compatriots chose to pursue graduate education in other countries due to the availability of better opportunities to conduct high-calibre nanoscience research. However, in my recent interactions with the Indian diaspora research community through such nascent forums as the volunteer-organized Young Investigator Meeting in Boston, Massachusetts, it seems that this trend might be changing. These developments will bring about a local emphasis on nanoscale research, helping its benefits reach populations globally.

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During my childhood, my father would explain to me some of the great discoveries and achievements in physics. He used to motivate me by simply explaining how modern scientists could miniaturize entire factories to the size of a matchbox. This was my first insight into the world of nanotechnology and was a strong inspiration for my decision to study physics at university. I did my undergraduate degree in Armenia. Unfortunately, there are no specialized master's programmes or modern laboratories in nanoscience and nanotechnology in the country. I therefore applied to do a master's degree in France, where I am currently in my second year of study.

My master's programme includes both theoretical and practical training. The first year was mostly theoretical, teaching the basics of nanoscience. During the second year we have access to several laboratories in Paris to perform the experimental part of the degree. The practical courses we have are not simplified versions of contemporary research; they instead immerse students in the experiments that are currently being carried out in different research groups. We have advanced courses in microscopy techniques such as scanning electron microscopy and atomic force microscopy, and many hours of practical training in topics such as the synthesis and characterization of nanoparticles, and the fabrication of carbon nanotubes. It is compulsory to perform an internship in a research laboratory at the end of each academic year, which is the best way to put this knowledge into practice.

I think the training provided by my master's degree is entirely satisfactory because it provides both a deep knowledge of fundamental topics such as quantum theory, and advanced experimental skills in relevant techniques and approaches. This combination is excellent preparation for choosing a topic to pursue a PhD in and for its successful completion.

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My PhD research looks at the creation of bright upconversion nanocrystals, which are materials that can convert infrared radiation into visible luminescence, and has been inspired by their promising applications in areas such as bioimaging, biosensing and display technologies. During the four years of this degree, I have received comprehensive interdisciplinary training in nanoscience and nanotechnology. I have, for example, obtained knowledge of topics such as experimental physics, and nanomaterial synthesis, characterization and theoretical modelling. In applying this knowledge, I have also developed skills in the nanoscale manipulation of materials and interfacial chemistry.

I enjoy the learning process and I am particularly fascinated by the discoveries that can be made as you move from the macroscale to the nanoscale. From my PhD supervisor, Dayong Jin, I have learnt the importance of setting goals and staying focused on the rational design of experiments. My PhD has also provided me with skills that extend beyond science. I have taken the lead in a team and worked collaboratively with international and industry partners. From these experiences, I have learnt the importance of teamwork, which is essential for interdisciplinary research. For example, during my PhD I have worked closely with my colleague Yiqing Lu, whose research is focused on instrument development. This has been a stimulating experience for me and together we have been able to achieve significant success in the development and characterization of sensitive nanocrystals.

Jiangbo Zhao is a PhD student at the Advanced Cytometry Laboratories, Macquarie University, Sydney, Australia. He has a master's degree from the University of Science and Technology of China (USTC) and an undergraduate degree from Inner Mongolia University, China. He will shortly join the Institute for Photonics and Advanced Sensing at the University of Adelaide as a postdoctoral fellow.

My fascination for nanoscience began in 2002, while I was still in high school in Switzerland. At an outreach event organized by the University of Basel, they presented a new, and at the time ground-breaking, degree in 'nanoscience'. I was instantly captivated by the subject and that excitement has not vanished since. Discovering the building blocks of life, studying how the characteristics of materials change at the nanoscale, and exploring the multidisciplinarity of the topic are what drive my enthusiasm for doing nanoscience research every day.

In education, multidisciplinarity is challenging, because it is impossible to comprehensively teach all of the different disciplines that are important in nanoscience. My undergraduate studies in Basel comprised an overflowing schedule of predominantly physics, chemistry and biology courses, spiked with mathematics and information technology. Lectures spanned quantum mechanics, supramolecular chemistry, systems biology, epigenetics and computational simulations, to name just a few. These were complemented with laboratory practicals and industry placements, which taught us the basics of doing research in the field and the different discipline-specific languages and approaches.

However, the only way to excel in a course that consists of almost three full undergraduate curricula was by interconnecting with other students. Therefore, we created a 'nanostudy network' in which we benefited from each other's individual strengths. Through this we were able to acquire key transferable skills such as problem solving, knowledge acquisition, and building and nurturing a scientific network. Importantly, we recognized that knowledge gaps are nothing to fear, but rather to be sought with curiosity and an open mind, as overcoming them is essential for professional development. Furthermore, I sat on the education board of the university and helped to continually shape and improve the curriculum.

During my subsequent master's studies at Basel, moving to international research groups was encouraged. This ultimately led me to pursue my PhD in London, which tackles one of the greatest challenges to society — antibiotic resistance. I think my nanoscience education has been an excellent preparation for doing research in the field and has given me the confidence to fearlessly tackle interdisciplinary problems.

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