Exploring 'Flatland's' Future during Materials Week at Warwick

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Abstract *Materials have been at the heart of humankind's development since our beginning. Recently, a new family of materials have emerged that promise to revolutionise our technologies. These are materials that are only one atom thick, truly two-dimensional. From 1 to 5 of February 2016, Warwick hosted Materials Week, which brought together students, researchers, and the public to discuss materials research at Warwick. This critical reflection piece looks at the events in Materials Week that focused on the emerging field of 2D materials: a workshop to discuss 2D materials in composites and electrochemistry; a colloquium by Professor Jonathan Coleman, a leader in the production of 2D materials; and finally a lecture from Professor Sir Konstantin Novoselov, one of the two researchers who won the Nobel Prize in Physics for having started the 2D revolution.*

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Since the dawn of humankind, we have been experimenting with materials. This research is so fundamental to our development that they define our technological eras: from the Stone Age to the Atomic Age. Most recently, we are in the Information Age, where, since the Digital Revolution in the 1970s, our society is built on data. Yet it is still the understanding of materials that facilitate progress. As an example, the miniaturisation of silicon is at the heart of the dramatic changes in information processing we have witnessed over the past 50 years.

Despite its clear importance, materials science itself was moving out of fashion at the turn of the millennium. I spoke to Professor Robert Young, a fellow of the Royal Society and a professor within the School of Materials at the University of Manchester. He saw this decline in popularity in the admission numbers for the School. In fact, extrapolating the reducing numbers suggested that the School would not be needed after 2005. In a perhaps related way, the University of Warwick has never had a materials department, despite flourishing science and engineering departments.

However, materials science is now returning to the forefront. The School of Materials at the University of Manchester is now oversubscribed. It was around 2004 that numbers started to increase. Similarly, Warwick recognised the increasing interest in materials science. In 2013, Warwick introduced a series of Global Research Priorities (GRP) to tackle problems in areas such as energy and food. Included was a Materials GRP.

One cause for the increase in numbers could be attributed to a recent revolution in materials science: the isolation of materials that are only one atom thick. The groundbreaking experiments in graphene, a single-atom-thick sheet of carbon atoms, earned Konstantin Novoselov and Andrei Geim the Nobel Prize in Physics in 2010, and launched whole new fields, techniques, and journals. Further to this, they captured the imagination of the public. When I am asked what I research, I can say 'graphene' and people have heard of it. Moreover, they often know some of its superlative properties: it is extremely strong; it is a great conductor; and it is the thinnest material possible. Graphene, and related nano-materials, have invigorated materials science, much like the Large Hadron Collider did for particle physics, or the Mars Rover for space exploration.

In the first week of February 2016, the Materials GRP at Warwick hosted 'Materials Week', a series of events to celebrate, advertise, and coordinate materials research at Warwick. In this reflection I review my experience of Materials Week, in particular the three events that attracted most of my attention: the first, a workshop reviewing 2D materials in composites and electrochemistry; the second, a colloquium by Professor Jonathan Coleman; and finally a talk by one of the pair that were recognised with Nobel Prizes for causing the 2D revolution, Professor Sir Konstantin Novoselov.

On 4th February, Warwick hosted a workshop to discuss recent progress and direction for graphene (and related 2D materials) in electrochemistry and composites (combined materials). Speakers included Professor Pat Unwin, Professor Milo Schaffer, and Professor Robert Young. Interesting talks were also presented by Professor Robert Dryfe and Dr Mark Bissett from the University of Manchester, and Dr Chaoying Wan from Warwick Manufacturing Group. Along with the speakers, there were 12 posters presented, some of which came from undergraduate students who had worked on materials projects over the summer. It was particularly encouraging to see undergraduates engaging in materials science projects.

First to speak at the workshop was Professor Pat Unwin from the Chemistry Department at Warwick. His talk outlined his work on the electrochemistry of graphite (stacked layers of graphene), focusing on whether the electrochemistry occurs at the edges of the sheets, or on the sheets themselves. The consensus was that the sheet surface - the basal planes - contributed little. Unwin demonstrated how he had used graphite that contained different ratios of edges to basal planes, along with microscopical control of the electrochemistry, to show that the basal planes do contribute. Graphene was then used as an ideal system to further investigate these effects.

Next to speak was Professor Milo Schaffer from the Imperial College London. Schaffer specialises in making large amounts of nanomaterials and using them in novel applications. The most intriguing amongst these is 'nanotubide': a solution of carbon nanotubes that can be painted onto surfaces to make them conductive.

Concluding the talks for the workshop was Professor Robert Young from the University of Manchester. Young investigates polymer reinforcement by nanomaterials, including carbon fibres and nanotubes. These rod-like materials reinforce depending on their orientation, with a stronger reinforcement with increased alignment. In his talk he explained how this extended to sheet-like materials, like graphene. The key result is that randomly orientated sheets should reinforce better than randomly aligned rods. This gives promise to graphene as a reinforcing material because controlling the alignment is a challenge.

Immediately after the workshop was a colloquium by Professor Jonathan Coleman from Trinity College Dublin. Coleman's lab was the first to show the advantages of high-shear exfoliation. In this process, you can take a layered material like graphite, place it in a solvent, and then mix it up with a high-shear mixer. These mixers tear the layers of the material apart, leaving individual sheets in solution. In this way they have managed to produce high quality sheets of graphene in unprecedented amounts: hundreds of litres solutions packed with graphene flakes. This research also charms the public because most people own a high shear mixer in their kitchen - a blender (**Van Noorden, 2014**).

The talk then moved on to the uses for these litres of graphene flakes in solution. One astounding option is to put silly putty into the solution. The solution's solvent causes the putty's rubber to relax and allow the graphene flakes to penetrate throughout the material. Once out of the solution and dried, you have a flexible rubber composite that is also a conducting network due to the touching graphene flakes. Any deformation of the putty causes a measurable change in the resistance of the network. Further, this change is sensitive enough to detect the movement of a spider walking over the surface. The applications of a material like this are vast, with Coleman's example being a breathing monitor built into a baby's cot mattress.

What struck me the most about Coleman's talk was his ability to make his findings compelling. The details were not laboured over so that the audience could be fascinated by the fun of what the research involved.

The final event I wish to review here was a colloquium presented by one of the Nobel Prize winners, Professor Sir Konstantin Novoselov. Novoselov's lecture was titled 'Materials in the Flatland' in reference to the ultimate flatness of materials that are one atom thick. The lecture theatre was packed as many turned up for the rare occasion of a Nobel Prize winning speaker, with even the stairs used for seating.

Novoselov began his talk with his key scientific point. In the beginning, graphene was the only 2D material, but since its isolation a whole family of them have been found. At the moment graphene is the most illustrious, but it is not the only 2D material. Each of this collection, from boron nitride to the assortment of transition metal dichalcogenides, has its own unique properties.

Once we had understood that graphene was not alone, Novoselov went on to discuss the main scientific idea. Now that we have a list of 2D materials, what would we get if we stacked them together? The principle of making these heterostructures is quite straightforward. You start with one layered material like graphite. Single (or sometimes a few) layers are pulled off (in a process called exfoliation) and placed onto a base. Then, layers are pulled off a different layered material, which can then be placed precisely on the first. This process is then repeated until the final heterostructure is complete. Novoselov explained how future devices could be designed in this manner: the top layers could be chosen to function as a display, the layers below as data processing, and those below that as data storage, for example.

He then showed us some real results of doing this. One of the examples displayed was a transistor – the solid state switch on which all of our electronics is founded — made from 2D materials. By stacking layers of boron nitride, graphene, and tungsten diselenide, they had managed to make a transistor that performed better than any graphene-based device so far, all while being only a few atoms thick. This thinness makes these structure ideal for transparent applications like touchscreens (**Georgiou et al., 2012**).

Finally, the talk highlighted that graphene's isolation had opened doors for other 2D materials. This was emphasised again during the final questions. An audience member asked whether graphene was as good as the hype suggested. The answer was that, while you cannot deny the remarkable properties of graphene, the future work is in combining all the different 2D materials. And these different 2D materials are everywhere. One of the most recent discoveries is that cat litter can be exfoliated into 2D sheets (and as Novoselov pointed out in his talk, it is important to do the exfoliation before it has been used).

Overall, Novoselov did an excellent job of outlining this exciting field. As someone who works in this field, there was little that I had not heard before (although exfoliated cat litter was one), but on reflection, that is a good thing. There is so much research in this area, and it is moving so fast, that providing an entertaining overview in 45 minutes is a challenge. Others I spoke to after the event felt that they had enjoyed it, and no one felt bogged down with minutiae.

The events above were just a sample of what happened during Materials Week. Alongside these were an evening outreach lecture given by Nick Barker and his colleagues; an egg drop challenge, where teams designed and tested protection for an egg to survive a drop; and a workshop on bringing 3D printing and biomedical engineering closer together, hosted by Andrew Dove.

In conclusion, Materials Week at Warwick highlighted some of the excellent work already taking place at Warwick, as well as showcasing collaborations with universities across the UK. The inclusion of the presentations by undergraduate students who have just begun their own research on materials also points to a bright future in this field. Events like Materials Week and the work of the Materials GRP will encourage an increased focus on materials research at the University, and start to involve Warwick in this fascinating and evolving field.

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References

Georgiou, T. et al. (2012), 'Vertical field-effect transistor based on graphene–WS2 heterostructures for flexible and transparent electronics', *Nature Nanotechnology*, 8(2), 100–03

Van Noorden, R. (2014), 'How to make graphene in a kitchen blender', http://blogs.nature.com/news/2014/04/how-to-make-graphene-in-a-kitchen-blender.html, accessed 30 March 2016

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