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Buckyballs, nanotubes and graphene: On the hunt for the next big thing

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Balanced voice

Scientists need to work towards resolving this uncomfortable relationship with the media; openness is required to maintain trust, and the public appreciates lively debate. For this to be effective, however, scientists need to be able to express themselves freely and without risk of libel – a threat that could cause scientists to self-censor some of their most progressive ideas. At the same time, scientists must balance reported articles with their own communications, through interviews and opinion pieces. After all, those who actually develop and test new ideas are best placed to understand the logic and subtleties of a scientific argument and thus communicate their work accurately.

Useful link:

Sense About Science

References:

(1) Singh, S. (2008) "Beware the spinal trap", *Guardian*.
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(3) Pearce, F. (2010) "Climategate inquiry points finger at university", *New Scientist*.
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Research trends

Buckyballs, nanotubes and graphene: On the hunt for the next big thing

ANDREW PLUME

The current focus on graphene owes its legacy to the foundations of nanoscience laid down with the discovery of buckminsterfullerene (named in homage to the geodesic domes of architect Richard Buckminster Fuller) in 1985. *(1)* This sparked the search for other fullerenes, complex carbon nanostructures typically occurring as spheres (similar in appearance to a soccer ball, and colloquially known as "buckyballs") or cylinders. The first cylindrical structures, quickly dubbed nanotubes, were isolated in 1991. *(2)* Graphene can be considered as an unzipped and flattened-out nanotube, and has been shown to have unique electronic properties under certain conditions. *(3)*

Explosive growth

The growth of the peer-reviewed journal literature on nanotubes and graphene is nothing short of remarkable. While articles on fullerenes have appeared in steadily increasing numbers annually since 1985 (see Figure 1), massive (and so far sustained) growth has been observed for both nanotubes and graphene. Early response to the "discovery" of each of these materials shows very different trends (see Figure 2). While fullerene and nanotube research expanded rapidly, graphene research has grown exponentially (at a rate of 58% per year) since the publication of Novoselov *et al.* *(4)*, a landmark paper describing a new method for isolating stable graphene sheets. The citation impact of this paper is visualized in Figure 3, giving a clear sense of the citation ripples emanating from this paper out into the literature, like those from a brick dropped in a pond.

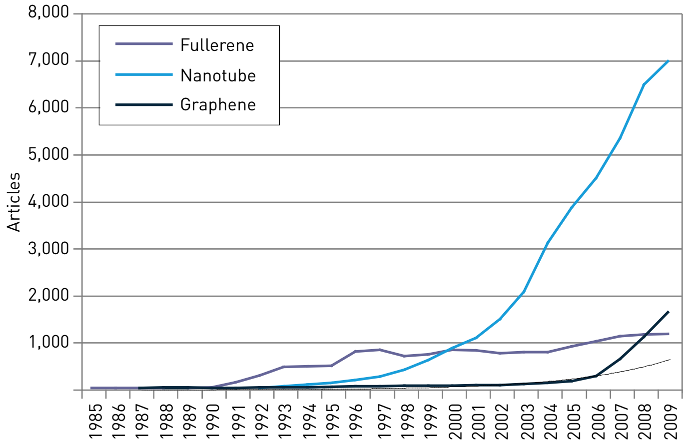

Figure 1. English-language research articles published in journals in the period 1985–2009. Keyword searches were conducted for fullerenes (*fullerene), nanotubes (nanotube*) and graphene (graphene*).
Source: Scopus.

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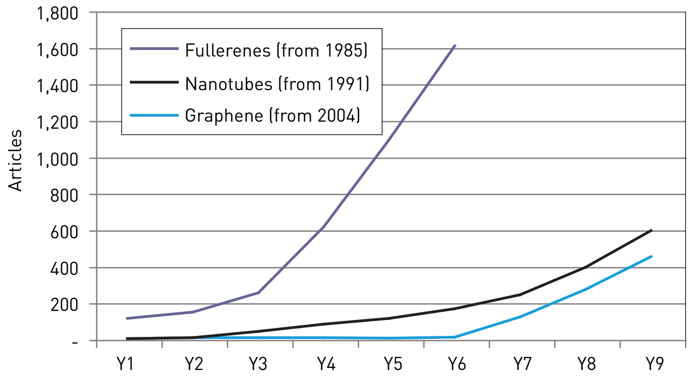

Figure 2. English-language research articles published in journals from the year indicated (i.e. for fullerenes, Y1 is 1985). Keyword searches were conducted for fullerenes (*fullerene), nanotubes (nanotube*) and graphene (graphene*).
Source: Scopus.

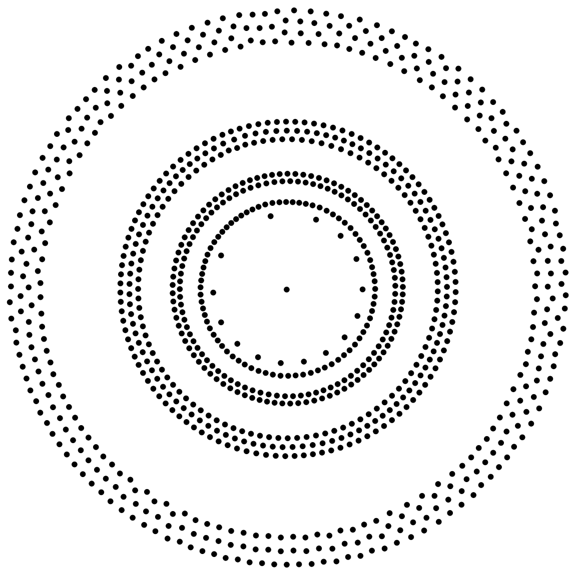

Figure 3. All documents citing Novoselov *et al.* (2004; shown at the centre of the figure). Each concentric ring of citing documents were published in 2005 through 2009 respectively and are identified by their first author – note how their number increases with each year, just like the broadening of the ripples in a pond.
Source: Scopus.

This paper effectively opened up research on the characterization and exploitation of the unique properties of graphene to a new field of scientists, many of whom had previously been working on carbon nanotubes. Indeed, the 100 most prolific authors on graphene to date have shown a recent decline in their share of publication output on nanotubes in favor of graphene, with the latter exceeding the former since 2008. These top 100 authors appear to have a low and decreasing output on fullerenes, perhaps a carryover from the origins of the nanotube and graphene research fields.

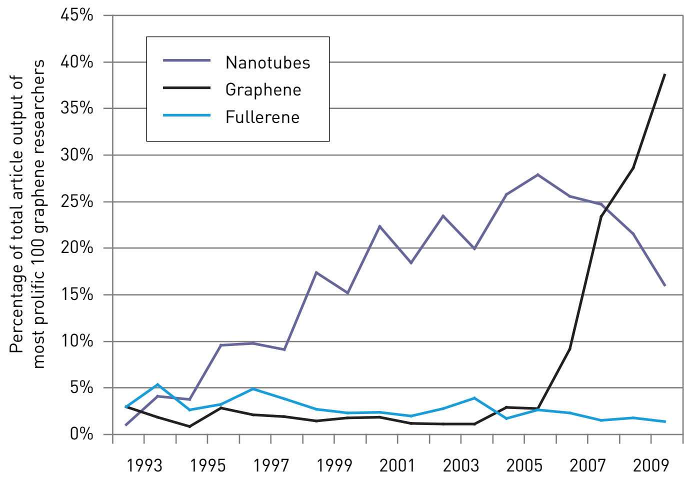

Figure 4. Percentage shares of total article output of most prolific 100 graphene researchers on fullerenes, nanotubes or graphene. Keyword searches were conducted for fullerenes (*fullerene), nanotubes (nanotube*) and graphene (graphene*).
Source: Scopus.

Graphene research boom

How does the graphene revolution feel to those working in the field? Dr Jamie Warner, Glasstone Research Fellow in Science at the Department of Materials, Brasenose College, University of Oxford comments: "The main thing I see when visiting other research groups is the massive uptake of graphene-focused research. Everyone wants to get on board the graphene revolution. Laboratories that have facilities for examining carbon nanotubes are suitable for graphene as well. So there is no real investment cost required to expand the research into graphene. […] When combined with the ease with which graphene can be obtained from scotch (sticky) tape, it is evident why output in graphene research has boomed in such a short time.

"It's clear that many researchers are riding the graphene wave in the hope of high-impact papers. The quest for all scientists is to be among those leading the field. But there are few who are setting the trend for others to follow. In such a fast-moving field, it may be hard to stay ahead."

Contribution to the carbon community

How has this fundamental shift in research direction affected the communities of physicists (interested in graphene's electronic properties), materials scientists (seeking potential applications in new carbon materials) and chemists and surface scientists working on its large-scale synthesis?

Dr Warner continues: "The coalescence of nano-carbon communities hasn't really changed that much. Groups have always collaborated worldwide; that is the nature of science. More interesting is how established groups have shifted focus or expanded. Research groups that were previously working on nanotubes are now entering the graphene field.

"Groups with established expertise in examining carbon nanotubes with high-resolution transmission electron

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microscopy – such as Kazu Suenaga and Sumio Iijima at the National Institute of Advanced Industrial Science and Technology (AIST) in Japan, and Alex Zettl at UC Berkeley – were able to translate their expertise directly to graphene. The large-scale growth of graphene using chemical vapor deposition (CVD) was a similar case: groups with experience and apparatus set up for CVD of nanotubes – such as Rodney Ruoff at the University of Texas at Austin – were able to modify the catalyst structure to grow graphene. Surprisingly, it was two scientists with no background in carbon nanotubes or fullerenes, Kostya Novoselov and Andre Geim, who made the biggest contribution to the field of graphene. This highlights how people from outside the immediate field can make a massive impact.

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Reporting back

Metric mad: the future of scholarly evaluation indicators

ASHLEA HIGGS

In mid-December 2009, around 50 science colleagues assembled for what was tipped to be a veritable bibliometric wonderland. Attended by George Hirsch and Henry Small among others, the event offered a practical workshop rather than one-way theoretical presentations.

Jumping on the interdisciplinary bandwagon, the speakers and attendees represented many differing points of view: government vs. academic vs. corporate; evaluator vs. proposer; funding vs. policy vs. scientist; metric theorists vs. practitioners. But while debates were spirited, discussions were collegial and focused on advancing work on new metrics.

Two particular questions occupied participants, to which all discussions of new metrics circled back. Herbert van de Sompel of Los Alamos National Laboratory, the first speaker and one of the event organizers, asked attendees: "What are the qualities which make a metric acceptable to all stakeholders? And how do we move from conception to acceptance?" The workshop centered on projects investigating or proposing new metrics, including the MESUR project, Eigenfactor, h-bar index, and PLoS ONE's article-level metrics. Many of these new metrics center on usage data.

New usage metrics: recurring themes, fresh challenges

Small beginnings: it took centuries for citation structure to develop; technologies are only now available to make new metrics possible.

Incentives work both ways: people need incentives to adopt new metrics, while metrics incentivize both positive and negative behavior.

Availability of raw data: usage data can be proprietary, fragmented, and not overtly displayed.

Metrics are only part of the answer: peer review continues to play a role.

Usage-based versus article-level metrics

Metrics based on usage data are central to the MESUR (MEtrics from Scholarly Usage of Resources) project. Johan Bollen from Indiana University, and principal investigator for the MESUR project, presented his findings to date. When comparing traditional citation-based metrics with usage-based metrics, he observed that usage data are very good indicators of prestige, but that evaluating scholars solely on rate metrics and total citations is "like saying Britney Spears is the most important artist who ever existed because she's sold 50 million records."

In contrast, Peter Binfield of PLoS ONE presented the journal's work on article-level metrics. In PLoS ONE, article views, downloads, star ratings, bookmarks and comments join

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