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Invited Viewpoint

Balancing Hyperbole and Impact in Research Communications Related to Lead-Free Piezoelectric Materials

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Imagine a meeting with a member of your group, an early career researcher, to review a draft of their first publication. It concerns some interesting work on a class of novel functional materials. In one section, the paper compares an application figure of merit for one of the new materials with that of conventional materials. The new material exhibits a value approximately half that of the conventional material, but the draft paper concludes that the new material exhibits *excellent* properties. When asked why this statement was included, having clearly demonstrated the new material showed inferior properties, the researcher is somewhat perplexed, but eventually explains that the new material may have some cost advantages.

Is the researcher justified in making that claim? In our opinion, the answer is no. Certainly, one should signpost the link to potential applications for the material, but without undertaking a more detailed cost-benefit analysis, accounting for production costs and the trade-off against materials performance, the claim of "excellent properties" is unjustified. Although the researcher was not in a position to undertake that analysis, it does not excuse the misrepresentation.

But why did it happen ? It is evident that the researcher was following the example set in countless papers published by career scientists. In an academic world in which job appointments, promotions and pay-rises are governed by impact factors and citation counts, it is difficult, even for those with the highest integrity, not to indulge in a little hyperbole concerning the potential socio-economic impact of their results. To do so will help justify publication of the research in the leading journals and increase its academic impact. Qualitative claims of excellence and industrial importance are an easy and almost unverifiable way of adding more "substance" to an abstract or a conclusions section. To do any less would be tantamount to an admission that several man-years of valuable resource have been wasted. It is also in the Universities' interests to maximize the apparent impact of their research outputs. With a keen eye on their position in national and international league tables, many institutions encourage their employees by advising on how to maximize the alleged impact potential of their work via press releases and social media.

It seems it is also a practice that journal editors may tacitly encourage. In order to maintain their editorial policies, many top journals reject submissions, even manuscripts reporting excellence science, at the pre-refereeing stage, if they consider that the paper will have insufficient impact. Moreover, referees are mainly concerned with monitoring scientific rigor, and unless specifically selected for their industrial credentials, will seldom reject based on the non-scientific claims in the manuscript.

So, everyone appears to concur with the practice, therefore it must be OK.

Or is it? Can the exaggerated claims for the application potential of a material be detrimental? Surely, industrial scientists know their stuff and are capable of reading between the lines to make up their own minds about the potential of a piece of academic work? Yes, they can; but that is not where the problem lies. Where hyperbole becomes an issue is when non-experts are making decisions or recommendations based on information they read in the scientific literature. There are many recent, high-profile cases in which a large body of stakeholders lose trust in the opinions of scientists or experts. Examples for which significant fractions of public opinion differ from those of experts include climate change, nuclear power and MMR vaccines. In the run up to the 2016 UK BREXIT referendum, a cabinet minister often noted for his intellectual rigor, when faced with the accusation that there were no expert opinions to support his pro-BREXIT stance, seriously remarked “people in this country have had enough of experts….” [1]. In the US, the acceptance of “alternative facts” also appears to have originated in the popular distrust of expert opinion.

Our exemplar case is an issue that is outside of public debate, but is topical in materials science. It is one in which those with very limited understanding of the science may use the scientific literature to aid their decision making. The decisions they make concern potentially serious public health issues in specific locations in the developing world, but will have implications for jobs and local economies in the industrial world. The example is the search for new, lead-free, piezoelectric materials.

In 2000, the EU’s Restriction of Hazardous Substances (RoHS) directive came into force [2]. RoHS, as it is known, limits the content of a number of elements and organic substances in electrical and electronic equipment for sale in the EU. RoHS has served as a model for similar legislation in other areas of the world including Japan, China, Korea, central Asia and the Gulf states. Hence, the influence of RoHS is effectively worldwide. The directive restricts the use of component materials in which the lead content exceeds 0.1% by mass. It is important to understand that the directive was motivated not by any perceived risks in the manufacture or usage of components and equipment containing lead, but by the uncertainties of the disposal routes for such equipment at the end of life. So-called e-waste currently amounts to more than 50 million tons a year, a majority of which, despite other legislation to the contrary, is believed to be disposed of informally in land-fill sites in the developing world [3]. Such sites are hosts to hundreds of informal recyclers, who aim to extract metals in commercially viable quantities, often with the aid of child labor. The pernicious nature of lead-poisoning and its worryingly high incidence in the vicinity of such sites led to the inclusion of lead in the RoHS directive. Given the difficulties in policing end-of-life disposal, the directive seeks to limit the most dangerous elements at the source, by preventing their incorporation into products for sale in the EU. Since the introduction of RoHS, the lead content of electronics, as typified by the ubiquitous mobile phone has fallen from >1% to <0.015%, mainly through the replacement of SnPb solder by lead-free alloys. The abandonment of cathode ray tubes as the visual display of choice for computers has also helped reduce the overall lead content of the e-waste stream. These reductions in lead content have been made despite the continued employment of lead in certain classes of use allowed by RoHS exemptions. These were established to allow for electrical and electronic functions that could not be achieved without lead at concentrations > 0.1%.

One such exemption is 7(c)-I, which covers the category of electroceramics exemplified by “piezoelectronic” devices. This exemption was introduced mainly because there was no available replacement for the class-leading piezoelectric material $Pb(Zr,Ti)O_3$, known as PZT. Exemptions are reviewed periodically by Expert Groups appointed by the EU and aided by consultants who administer and report on stakeholder consultations that contribute to the review. In the case of exemption 7(c)-I, the Expert Group comprises environmental experts and civil servants rather than technology experts. Their reviews have taken place at 5 yearly intervals and have so far not recommended lifting of the exemption. However, continuation of the exemption is dependent upon the stakeholder industries engaging in research to identify alternative materials or technologies to replace the subjects of the exemption. In the case of piezoelectric materials there has been a vigorous search for viable lead-free piezoelectric materials that could replace PZT. This has been an overwhelmingly academic activity, rather than industry led. An indicator of the level of activity is that since 2000, over 4000 journal and conference papers have been published on the topic of lead-free piezoelectrics and in 2018 over half the scientific publications on piezoelectric materials and devices included the keyword “lead-free” [4]. Naturally, a large number of these papers make unverifiable claims for the industrial significance of the reported research, and typically refer to how the reported material is an excellent candidate to replace PZT. These claims may be driven as much by a genuine ignorance of industrial needs as they are by the motive of creating or demonstrating impact.

Despite the significant expenditure and resource required to maintain this level of research, there are currently very few examples of commercially available lead-free piezoelectric materials. Sales of PZT are still orders of magnitude greater than those of the very small number of commercially available lead-free materials. There is a complex combination of factors that have inhibited the widespread industrial adoption of lead-free piezoelectric materials. However, the simplest conclusion is that no lead-free material has yet been demonstrated that can match the full set of required material specifications for major applications. There are certainly lead-free examples that can match or exceed one or two of the high profile performance criteria of PZT (e.g. the piezoelectric charge coefficient), but when the full set of requirements are examined, these have either not been evaluated or do not make a sufficient case for replacement of PZT in the target applications. Any one of a score of factors might prohibit the use of such new materials on purely technical grounds, including processability, reproducibility and reliability – factors seldom assessed in academic research. Moreover, one should not underestimate the cost of approving a new material for a given application. This most probably involves the redesign and test the of devices to adapt to the change of material specification. Unproven material sources and a complex intellectual property landscape are also inhibiting factors.

An issue which is only recently coming to light is that a lead-free material is not automatically environmentally benign. Increasing activity in life-cycle analysis and sustainability assessment is demonstrating that a number of the leading lead-free candidates have poorer environmental credentials than PZT [5,6]. Whilst researchers may not have been aware of this for most of the last 20 years, it is now something they need to assimilate into their research. With this in consideration, the inclusion of elements such as niobium and antimony may preclude compositions being considered by the Expert Group as suitable replacements for PZT.

Notwithstanding the comparatively small levels of lead in the current e-waste stream from piezoceramics, the next consultation on exemption 7(c)-I will start in 2020. The group of industry stakeholders will almost certainly argue in favor of a continuation of the exemption on the basis that there are no suitable replacement materials. The Expert Group and the associated consultants will have to examine that argument critically and no doubt will consult the scientific literature to determine its veracity. Of course, they will find hundreds of claims concerning how research on particular lead-free piezoelectric materials has resulted in materials ripe for commercial application. How will the group manage the apparent discrepancy between the industry arguments and the scientific literature? Suspicious of industry's motives, but more confident of academic integrity, they may conclude that the industry is guilty of misrepresentation and therefore recommend modification of the exemption to exclude certain categories of piezoelectric use. At best, this will accelerate both the uptake of lead-free materials and alternative, non-piezoelectric technologies, but at the expense of loss of performance and at significant cost to the end-users. At worst it could result in a loss of products of high socio-economic value from the marketplace and create job losses and adverse impacts in a number of local economies in the developed world. These factors should be tensioned against potential reductions in risks to public health due to e-waste landfill and informal recycling (which may be negligible given the small lead content currently in the e-waste stream). However, that balance will not be debated by the Expert Group; their brief is to review exemptions, with the goal of achieving maximum compliance with the existing RoHS directive, not to question the relevance and scope of RoHS 20 years after its introduction.

Whatever the recommendation of the Expert Group, those affected by it should be convinced that the decisions were reached in the light of accurate information, free from the possible distortions of hyperbole and misapprehension. It is our public duty as scientists to ensure that this is always the case. Decisions of public interest may be made on the basis of our publications without our prior knowledge. Even the lowest level of habitual hyperbole that has become the norm to self-validate our work, may not be without wider consequence and may contribute to the continued erosion of public trust in publicly-funded science.

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