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HOW TO CITE:
Glassom D, Scharler UM, Macdonald AHH. Society's needs cannot be met by applied science alone: A response to Cochrane et al. (2019). S Afr J Sci. 2019;115(7/8), Art. #6294, 3 pages. https://doi.org/10.17159/sajs.2019/6294

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
basic research; pure science; actionable research; societal benefit; interdisciplinary

PUBLISHED:
30 July 2019

Society's needs cannot be met by applied science alone: A response to Cochrane et al. (2019)

In their article 'Science in the service of society: Is marine and coastal science addressing South Africa's needs', Cochrane et al.[1] express concern, based on an analysis of abstracts from a single South African Marine Science Symposium (SAMSS 2017) that too little research is either interdisciplinary or 'actionable' – defined as science whose results translate easily to policies, management actions or industry.

They argue that science is disconnected from the needs of society, may not adequately benefit society and, therefore, that the science risks losing support and credibility. To remedy such drawbacks, they propose funding actionable science as a priority, including in the tertiary education arena, and emphasising interdisciplinary research. In conclusion, they offer eight recommendations for future funding of marine science. Because their article may substantially influence the policies of funding agencies and thus the trajectory of marine science in South Africa, it is important that their claims are examined in the wider context of how science benefits society.

Cochrane et al.[1]'s arguments are built on four premises which do not stand up to scrutiny. Firstly, they assume a clear distinction between pure, basic and applied (or actionable) research. Secondly, they underestimate, to the point of discounting, the value of 'pure' science in advancing the goals and imperatives that, in their opinion, should be urgently addressed. Thirdly, they assume an unrealistic linearity in the way that science translates to policy and management. Finally, they do not account for the manner in which the funding system already addresses many of their concerns.

Pure versus applied science

The distinction between pure and applied science has always been vague, notwithstanding more than a century of debate – for example in the second volume of the journal *Science* published in 1883.[2]

Louis Pasteur wrote:

> *No category of sciences exists to which one could give the name of applied sciences. There are science and the applications of science, linked together as fruit is to the tree that has borne it.*[3]

Even if we disagree with Pasteur, the distinction between the spheres is much less clear than Cochrane et al.[1] assume, with a case being made for a continuum from pure to applied research[4-6], for example, with the idea of 'Pasteur's quadrant' (Figure 1).[4] Interestingly, Bohr was chosen as an example of a pure scientist in the quadrant, yet his work on quantum physics is universally applied in modern electronics, emphasising the merging of the boundaries. On such boundaries, Marie Curie was explicit:

> *We must not forget that when radium was discovered no one knew that it would prove useful in hospitals. The work was one of pure science. And this is a proof that scientific work must not be considered from the point of view of the direct usefulness of it.*

It is now widely acknowledged that the differences between pure and applied science and the various other formulations (such as fundamental research and basic research) are political and social constructs that are not philosophically justifiable as much as they are actual distinctions.[5,6] The superiority of pure over applied science thus cannot be considered a widely held contemporary view, as claimed by Cochrane et al.[1], although this may have been so in the past.[5]

Should basic (or pure) research be curtailed?

There is strong evidence that basic science makes large contributions to societal well-being almost irrespective of its subject matter. However, the magnitude of the contributions is often underestimated. Basic research may provide a return on investment of 20–60% per year, because it benefits from a positive feedback loop – research creates knowledge, leading to wealth, leading to more investment in research and more wealth.[7] Thus, while Cochrane et al.[1] refer to the Department of Science and Technology (DST)'s mission of 'increased well-being and prosperity through science, technology and innovation', innovation is far more likely to come from basic research than from applied or actionable research.[8] The benefits of basic research are more objective, less politicised and less focused on specific stakeholders than those arising from targeted research. They are thus less ephemeral and wider ranging.

We have cited the example of quantum physics, which led to the invention of all of modern electronics[9] over the following century. Similarly, MRI scanners would not exist today without previous pure research into superconducting magnets.[10] Examples from biology also abound. Watson and Crick could hardly have imagined the application of genomics to personalised medicine when they described the DNA double helix.[11] The evolutionary history of coral species is emerging as a major influence on their resilience to climate change and this information is being used to 'enhance' evolution of corals in the face of climate change. Thus research on evolution, typically considered a field of pure science, may have practical outcomes for species conservation.

The notion that basic research should be eliminated or substantially curtailed is thus untenable. Ignoring the likely return on investment in basic research risks trapping South African science and the economy in a quagmire of low innovation and growth. Because the benefit of basic science is not directly appropriable by industry, investment from industry is low and governments traditionally have to provide it.[7]

Actionable science is inextricably linked to basic science

The use of conference abstracts by Cochrane et al.[1] to assess the 'actionability' of South African marine science, provides, by their own admission, a limited view. However, even then, the results may be misleading because there is no assessment of whether such actionability was successful. This assessment requires a retroactive view of whether science funded at some time in the past turned out to be actionable or not, and conference abstracts do not provide such information.

In fact, the notion of actionable science implies a linearity between the goals, execution and implementation of scientific research that seldom exists, partly because research outcomes are often unpredictable. Even with positive outcomes, successful management and adequate policies are not guaranteed. While there are, no doubt, examples of directed, actionable science producing usable results, there are also many examples of where such results have not been achieved. Further, actionable science is invariably based on results emerging from basic science. Lewis Thomas[12] wrote:

> *When you are organized to apply knowledge, set up targets, produce a usable product, you require a high degree of certainty from the outset. All the facts on which you base protocols must be reasonably hard facts with unambiguous meaning .... But most of all you need the intelligible basic facts to begin with, and these must come from basic research. There is no other source.*

Fisheries science is surely considered actionable research. Yet for more than half a century it failed to substantially improve management of fish stocks.[13] A recent bitter dispute between two globally renowned fisheries scientists on the state and management of the world's fisheries[14] illustrates the point. Examples of the failure of actionable science from fields as varied as aquaculture, conservation and nutrition are numerous.

Additionally, while Cochrane et al.[1] argue that research priorities should be stakeholder-driven, undue prominence given to stakeholder interests may be a major problem, again evident in fisheries management.[13] This conflict is to some extent intuitive. Stakeholders are, by definition, self-interested. The scope and scale of the research driven by them is likely to reflect this self-interest. It seems to have eluded Cochrane et al.[1] that stakeholders effectively constitute 'sectoral and vested interests' whose influence their eighth recommendation calls for government to renounce.

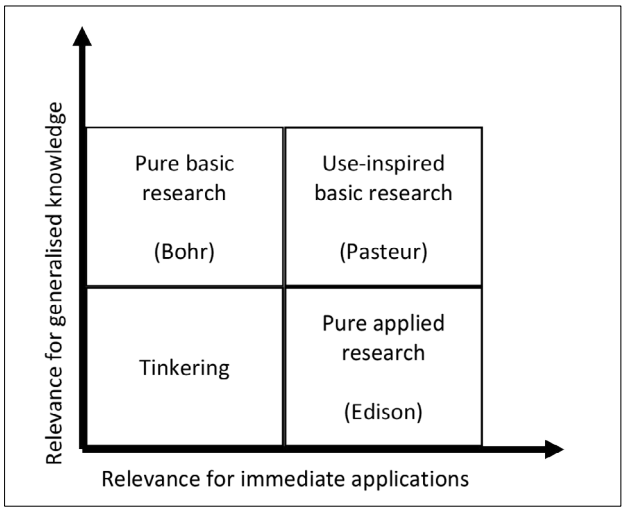

Figure 1: Pasteur's quadrant (from Stokes[4]).

Inter- and transdisciplinarity

Cochrane et al.[1] consider that 'reductionist' science cannot consider the full scope of complex socio-ecological problems. However, it is difficult to see how stakeholder-driven, interdisciplinary science can address complex challenges without a solid foundation of discipline-based, basic research. The knowledge which constitutes the building blocks for inter- and transdisciplinary applicable science must originate from discipline-specific basic research. Reductionist science is inextricably linked to the modern scientific method, and provides many benefits to society. For example, the success of molecular and genetic research and their societal benefits rest on a foundation of reductionist biology at the cellular and molecular level.[15] Although we strive to understand systems as a whole, the benefits of 'reductionist' science can thus not be discounted. Although Cochrane et al.[1] affirm that basic research or 'reductionist' science still has a role to play in South African marine science, the general gist of their article largely negates this sentiment, sometimes to the extent of misquoting other views on the subject. For example, they cite McQuaid[16] in support of their view that more science in South Africa should be 'actionable'. But although McQuaid[16] did allow that society is entitled to make demands of science, the point of his paper, stated in the conclusion, was that 'over-managing science in the interests of political imperatives, past or present, can be detrimental to both the science and eventually to society at large'. The recommendations by Cochrane et al.[1] fall squarely into the category of over-management and should be repudiated.

We agree on the need for scientists of different disciplines to work together. However, not all research is interdisciplinary, and not all interdisciplinary research need involve the humanities. It makes no sense to sacrifice strong disciplinary research because of a perceived imperative for interdisciplinary work[15], particularly that involving the social sciences. Where natural scientists do engage with social scientists, methodological differences need to be reconciled. This process is not as simple as Cochrane et al.[1] imply. Twenty years of structured interactions achieved only incomplete integration of natural and human sciences in climate change programmes[17] and a Rural Economy and Land Use programme showed similar difficulties[18], leading a participant to comment:

> *Often it is assumed that interdisciplinarity will simply happen if you put enough motivated people from different disciplines in the same project together. In reality, there are many barriers . . . and successful interdisciplinary collaboration must be planned for explicitly to overcome these barriers.*

Rather than demanding interdisciplinarity as a condition of funding, South African science would therefore do well to develop appropriate collaborations through structured, extended interactions that reconcile different research methods, ideologies and epistemologies among research fields.

Predicting and restricting research

Cochrane et al.[1] advise that the National Research Foundation (NRF) and DST should assess 'the current *and future* needs for scientific research' (our italics). It is difficult to conceive of a reliable model for predicting future research needs, as the future itself is increasingly unpredictable, with emergent problems arising more quickly than ever before. However, they go further, recommending that all tertiary education and research agencies should review their teaching and research in the context of the identified societal needs. It is short-sighted to suggest that the fundamentals of science taught at universities in South Africa should be revised to provide students with skills applicable only to perceived contemporary societal priorities.

Tertiary education is vital to ensure that foundational knowledge and a range of research skills are retained in the research community.[19] The restructuring of both teaching and research proposed by Cochrane et al.[1] would almost certainly hinder this goal. Further, a few highly cited papers, generated by a relatively small proportion of scientists, drive scientific innovation, progress and productivity.[20] However, because it cannot be known which scientists or papers will form the nucleus of progress, a 'surplus' of both is necessary to retain and increase the number of students and scientists the country needs for scientific innovation.

Constraining research and teaching to conform to a narrow, short-term political or social agenda will result in the loss of much foundational

knowledge and important skills, and risk degrading scientific capacity to address the problems that Cochrane et al.[1] say should be prioritised. Such constraints on research and teaching are characteristic of autocratic and closed societies and should not be embraced in South Africa. Whether changes proposed by Cochrane et al.[1] will bring about societal benefits (Recommendation 5), given increased funding for actionable research, is dubious. It has been recently demonstrated, for example by the partial opening of the Tsitsikamma National Park to fishing, and by failed conservation efforts[21] as well as examples in Cochrane et al.[1], that there is a considerable gap between actionable research, sensible policy and effective management, especially where political considerations come into play. One of the reasons that there is a cry for more actionable science in South Africa is because of political interference, inefficient management, and poor skill sets within the implementing agencies to deal with complex governance problems, rather than too much basic science.

The conclusions of Cochrane et al.[1] are thus almost entirely unjustified. But even if we agreed with the conclusions, their recommendations are largely redundant. They failed to note conditions already imposed on funding applications. In the scoring system by which the NRF adjudicates funding applications, 10% is allocated to 'the wider impact of the study on society', 10% to collaborations among institutions and 5% to scientific engagement (informing the public, managers or policymakers about the significance of your work). The scoring system implies that a 'pure' or basic research application outside of the Blue Skies funding call must demonstrate considerably more scientific merit than an 'actionable' application to be competitive for funding. Thus, despite statements to the contrary by Cochrane et al.[1], the requirement for research, including in the marine sciences, to be interdisciplinary and 'actionable' is already well embedded in the funding system. It should concern all marine scientists if a scientifically sound proposal can be rejected unless the social aspects score well, especially if, as argued above, reducing basic research in favour of actionable research impedes economic development and the societal goals that government funding of research is meant to promote.

The model for funding marine science in South Africa should be constantly debated and updated. Unfortunately, this has rarely happened, with many marine scientists willing to tailor their research to the priorities of the NRF and government departments. This approach, along with the inclination of governments to view issues over short terms of office, may impede South African science and the benefits it brings to the population. Any changes should be made following a deeper and less subjective analysis than is contained in Cochrane et al.[1] We should bear in mind this dictum:

> *To feed applied science by starving basic science is like economising on the foundations of a building so that it may be built higher. It is only a matter of time before the whole edifice crumbles.*[22]

In this light, we urge that the debate around science in South Africa and its funding model should centre around how the benefits of local research**,** applied or basic, can accrue to South Africans, rather than about constraining the nature of research that is conducted.

We agree with Cochrane et al.[1] on some points, particularly that more collaboration among disciplines would yield benefits. We concur increased funding is needed for marine science, but not only for actionable science. We note that there are already several national research organisations, facilities and government departments devoted entirely or primarily to applied or actionable research. There are, however, few refugia for basic research.

We propose a comprehensive discussion among marine scientists and government funders to refine recommendations for future marine and coastal research to avoid potential damage to marine science for years to come. As Cochrane et al.[1] began their critique with an assessment of presentations at SAMSS 2017, perhaps a suitable forum for a full and structured discussion would be the upcoming SAMSS 2020.

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