Advancements in sensor technology with innovative and significant research publications: how to write that perfect paper?

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The general immediate reaction to the question posed may be that it should not be different from writing any other scientific paper, and in general terms, this is true for all research seeking to develop new technologies. Significant scientific advancements are based on innovation, which is the driving force for moving any research beyond the state-of-the-art. For sensor research specifically, innovation or novelty is the creation, development, and implementation of a new sensing concept, interface, and/or sensing ligand. Its aim is to improve selectivity or sensitivity or to offer other competitive advantages. Innovative sensor papers should thus describe a new technology that differs from previous ones by a large extent and addresses notable, existing hurdles or drawbacks, and hence an unresolved problem in the sensing field. Its advantages should be demonstrated by comparison of the performance to other analytical techniques or sensors. Analytical metrics for comparison include sensitivity, selectivity, dynamic range, limit of detection, and response time, and also parameters such as shelf-life, stability, and reproducibility. A valuable contribution to science is not demonstrated simply by the statement:

“this has never been done before.” Many things have never been done before, but most of those also would not truly contribute to scientific knowledge, if they were to be carried out. Take the example of carbon quantum dot synthesis for enhanced biosensing: even though nobody has used yellow carrots in contrast to orange carrots for carbon dot synthesis, yellow carrot carbon dot synthesis alone is not sufficient to make an innovative sensor design, even though “it has never been done before to our knowledge.”

In recent years, *Analytical and Bioanalytical Chemistry* has been focusing on the publication of sensor-related papers, including the criteria of novelty, analytical improvements and expanding the state-of-the-art. This editorial, written for the 20th anniversary of ABC, takes the opportunity to highlight important guidance for writing excellent papers in this field of (bio)analytical chemistry. Our goal is for authors to improve their ability to present those relevant experiments and findings that are of greatest interest to the sensor community and the scientific community at-large, and hence participate best in the scientific discourse.

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We start by refocusing on novelty and relevance within the constraints of this field of research, where ease-of-use and applicability to real-world scenarios are mandatory characteristics. Rendering a sensor more sensitive via the addition of countless assay steps does not necessarily advance the field further, since reduction of assay steps enables ease-of-use and reproducibility. However, it could be valuable in select circumstances to add assay steps, if those elucidate mechanisms or point toward future solutions to a major existing challenge. Actual applicability of sensors to real-life situations is most often a requirement. Thus, is a sensor that has never seen a real-world sample and has only been used with pure buffer solutions relevant? It still could be, for example, if the sensor entails a truly novel concept. Keep in mind, scientific sensor papers should ensure an increase in scientific knowledge and be highly relevant to your peers.

Where is such scientific knowledge urgently needed? The following illustrate a few key examples. (i) Biosensors are chemical sensors in which the recognition system utilizes a biochemical mechanism for the interaction process in/at the recognition layer. Bioassays, in contrast, may use the same mechanism but do not have a direct connection with a transducer. Importantly, trends and developments of this interaction found in both biosensors and bioassays have opened new perspectives in the sensing field and are therefore also of great interest to the sensor community. One example is the use of intracellular markers that generate an analytical signal by direct interaction of the sample with the recognition element in solution or in situ. In this bioassay, signals are monitored using a small imaging device rather than an in situ transducer. (ii) A myriad of nanomaterials (e.g., metal, metal oxide, carbon or polymer nanoparticles) have enabled a considerable enhancement of the sensitivity and selectivity for chemical and biochemical species detection. Often neglected is their applicability to real-world samples, their reproducible (and potentially large-scale) production, and head-to-head comparison to bulk materials. Information is hence needed about their analytical performance and the availability of reproducible calibration methods in light of stability, fouling, signal drift, target separation, and interference effects. (iii) Considering the singular importance of (bio)recognition elements in sensors, the development of new molecular (bio)recognition elements (aptamers, peptides, antibodies, polymers, etc.) is of great interest including studies on their selectivity, affinity, solubility, stability, and immobilization.

Understanding the analytical performance of a technique is the bread and butter of any good paper. As a sensor is a miniature analytical device for measuring the concentration

of an analyte species, standard IUPAC protocols and definitions should be utilized, just as in any analytical publication. These include calibration characteristics (sensitivity, operational and linear concentration range, limit of detection (LOD), and/or limit of quantitation (LOQ)), selectivity, steady-state and transient response times, sample throughput, reproducibility/repeatability, stability, and lifetime (Orange Book, http://old.iupac.org/publications/analytical_compensum/). Keep in mind that sensitivity and specificity have different meanings in analytical chemistry compared with biomedical assays and their use should be clearly described in the “Methods” section of a paper. While reversibility and short response time can be achieved for most chemical sensors with low equilibrium constants, biosensors exhibit high selectivity due to their large equilibrium constants, with the consequence of small dissociation rate constants. Therefore, most biosensors are not reversible, requiring high-quality regeneration procedures or excellent batch-to-batch reproducibility/repeatability to facilitate standard protocols that require blank and replica concentration measurements. Thus, biosensor papers in particular also need information on the quality of regeneration, effects of the shielding layer on top of the transducer, working range, and stability of immobilized recognition elements. As biosensors are based on biomolecular interaction processes, they exhibit a non-linear, sigmoidal calibration curve in the usual semi-logarithmic plot. In order to determine the LOD and LOQ, the 95% confidence belt and associated minimum detectable concentration and reliable detection limit should be calculated for sigmoidal calibration curves [1]. A frequently updated resource from the US FDA offers further guidance on bioanalytical method validation (<https://www.fda.gov/files/drugs/published/Bioanalytical-Method-Validation-Guidance-for-Industry.pdf>).

The comparability of the new sensor to existing methodology can be addressed on a variety of levels. Where available, reference materials or alternative reference methods should be used to validate a new sensor. As a minimum, an objective analytical performance comparison should be given to related papers or even commercial systems. Keep in mind that editors, reviewers, and ABC readers will easily spot a biased comparison that ignores relevant prior work; therefore, please provide an honest discussion of comparability. If you want to highlight the convenience, cost, simplicity, etc., of a sensor, plan to use quantitative metrics (€, time, assay steps, etc.). These important details will make the sensor’s advantages clear to the editor, referees, and future readers. It is important to keep in mind that a sensor may still be significant if it is not better than

prior ones in every single metric; however, it should clearly improve over existing methodologies in important ways as discussed in the beginning of this editorial.

In the end, these guidelines for that “perfect sensor paper” offer reminders about things to be included that result in a high-quality manuscript and help avoid common roadblocks that could keep novel work from being published. Much of the general guidance given herein for sensor papers is also relevant for any paper submitted to ABC: be sure to state what is innovative and significant, and provide appropriate metrics for comparison. ABC is excited to consider and publish sensors papers that meet this guidance, along with other papers that provide major advances in the fields of analytical and bioanalytical chemistry.

Reference

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and environmental monitoring.

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