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RESEARCH ARTICLE

SCIENTIFIC RESEARCH CROSSROADS. WHICH WAY TO GO?

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Abstract

Scientific Research (SciRes) can and should be a platform for mankind's progress by tackling previously unsolved problems and new ones arising each day. However, for SciRes to succeed in this role, it must be properly aimed. This paper presents a systematic analysis of the diverging crossroads SciRes has reached, discusses the right way to go at each in order to pursue quality and examines the implications of taking the wrong way in each case. The most critical crossroads or dilemmas for SciRes at present demand choosing between true or only apparent innovation; publication or usefulness; opacity or transparency; isolation or interdisciplinarity; social responsibility or no social commitment and proper or spurious assessment of research. The paper ends with a summative discussion of the right and wrong ways that can be taken at SciRes crossroads now and in the future.

Introduction:-

Contextualization:-

Mankind's challenges have evolved enormously for centuries but especially markedly over the last few decades. Formerly well-established paradigms have been swept away by others in response to new, increasingly demanding problems. *Scientific research* (SciRes) has and should continue two play two central roles in the process. First, as a driving force for the material and immaterial challenges and second as a means for consolidating proven solutions and predicting new challenges to be met. As stated in the 2009 Lund Declaration and refined in its 2015 revision (Lund Declaration, 2015), SciRes should evolve in parallel with mankind's *grand challenges*. Such challenges include global warning, universal healthcare, population ageing, pandemics, security, and tightening global supplies of energy, water and food.

SciRes should have external and internal targets. The former include mankind's grand challenges and the latter various concepts that can be jointly designated "quality". Quality in SciRes is the subject matter of this paper.

Research & Development & Transfer:-

The word "innovation" has lately aroused much confusion and often purposely sought misinterpretation (Valcárcel, 2017). Very frequently, it is associated to the last step of scientific and technological processes: Research, Development and Innovation (R&D&I). Quite often, however, it is misused to refer to the transfer of scientific and technical advances to industry or the population at large, for example. Rather than R&D&I, however, the sequence should be referred to as R&D&T, the T in which stands for "Transfer", a word akin to Translational Medicine in the healthcare realm, for example. Innovation is a transversal concept also reaching the other two terms in the acronym

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(Research & Development) as well as other human activities such as education, business or management. The interesting booklet *Mission-oriented research and innovation in the EU*, recently published by the European Union (Mazzucato, 2018), fails to accurately distinguish between "research" and "innovation" because the I in R&D&I influences the R. The Glossary of Terms for EU's Horizon 2020 program excludes R&D&I. In fact, "research" does not always mean or necessarily leads to "innovation" and, as shown below, innovative SciRes rests heavily on making the right decision (i.e., choosing the right way) when reaching a crossroads.

Crossroads:

The word "crossroads" is a singular and plural noun ubiquitous in book, film and TV serial titles for which renowned English dictionaries essentially provide two meanings. The first meaning arises from the combination of its component words ("road" and "cross") and hence refers to a junction of two or more ways (e.g., a point where two or more streets or roads intersect one another). A crossroads is thus a point of convergence and divergence. Figure 1 illustrates the three choices typically available from among several divergent ways at a crossroads. Obviously, the difficulty of choosing well at the decision point increases with increasing number of choices.

Fig. 1 :-. Range of available choices at divergent crossroads depending on the number of new directions that can be taken.

The second meaning of "crossroads" has to do with a decision or critical choice from among a few. Hence, the word is for example used to refer to a crucial point where a very important decision should be made; a critical situation or point in time when a choice is mandatory; or a time when important changes occur and a decision is very necessary.

Crossroads in SciRes essentially represent directional bifurcations leading to a right or wrong end. SciRes crossroads can also obviously facilitate a positive or negative change of direction (from a wrong way to the right one or vice versa). Taking the right way is obviously essential with a view to ensuring quality in scientific research.

Basic, oriented basic and applied research:-

The blurry conceptual boundaries between these now classical adjectives are most probably at the heart of their increasing fall into disuse in the scientific literature. In some cases, basic, oriented basic and applied research are identified with the three components of the R&D&T triad.

The difference between *basic* and *oriented basic research* is elusive owing to the difficulty of defining very basic research in isolation. In fact, only research aimed at true innovation, identifying new paradigms and probing new

approaches —whether experimental or otherwise— can be deemed "pure" or "blue-sky" research. Eventually, however, basic research inevitably becomes oriented basic research.

The difference between *basic* (or *oriented basic*) *research* and *applied research* is somewhat clearer. Thus, applied research is research aimed at solving economic or social problems by exploiting well-established material or immaterial advances in basic or oriented basic research. Some regard oriented basic research as the unavoidable link between basic and applied research, but this is not quite correct.

Although basic, oriented basic and applied research occasionally converge, it is more common to conduct stepwise oriented research based on existing basic research in order to find some new use for the outcome (applied research).

In the XX century it was quite usual to save the word "quality" for the most "pure" type of research (that is, basic research). This was clearly unwarranted because applied research can also be high-quality research. Quality is usually assessed in terms of dedicated indicators and the usual indicators for basic research (e.g., journal impact factor, number of citations by other authors) differ markedly from those for applied research (e.g., patent type, product sales, level of investment).

According to Valcárcel et al. (2007), one of the still unfulfilled goals of SciRes is *bridging the gap* between basic and applied research. Aiming in this direction is certainly warranted for a number of reasons including the need to repay research investments or enhance the reputation of the originating research center or group —the tangible results of applied research are typically more appreciated by politicians, society and other stakeholders than are the intangible results of basic research.

The following sections discuss the most salient three-way crossroads SciRes can face today and may reach tomorrow; also, they highlight their mutual relationships. All are depicted in Fig 2, where the directions leading to a predictably good outcome point to the center, which is where quality in SciRes should converge.

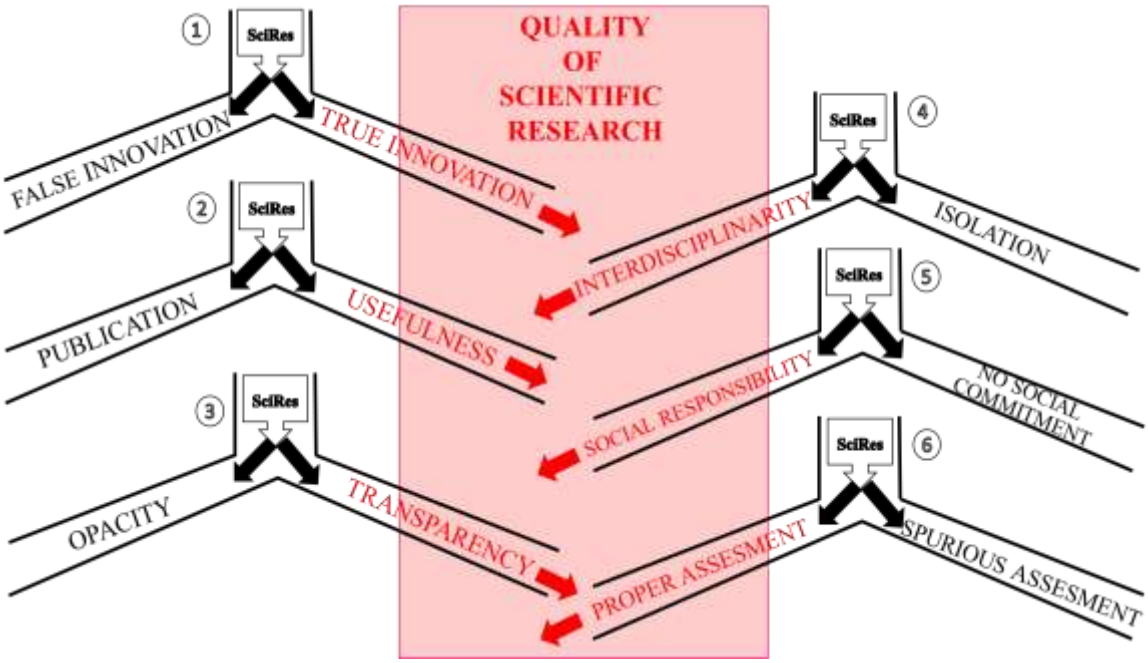

Fig. 2:- Present and potential future SciRes crossroads. Positive directions converge on the center, which represents quality in research.

Crossroads 1. True innovation and merely apparent innovation

One critical point in SciRes progress is choosing the degree of innovation to be targeted (see Fig. 2). As originally conceived by Einstein (2011) and later elaborated upon by Kuhn (1970), true innovation involves breaking mental and technical barriers, creating new paradigms, braving the risk of failure, avoiding unnecessary repetitions on a

well-worn topic such as Ravel's bolero in the musical realm and adding up net value —in summary, true innovation is akin to creativity and imagination. True innovation has a transversal nature reaching far beyond scientific research —so far as knowledge transfer, education, construction, economy or commerce, among other areas of human activity. In fact, the "open innovation" paradigm deems R&D an open system where valuable ideas can come from inside or outside researchers' circles to provide added value (Chesbrough, 2006). Figure 3 depicts true innovation and illustrates how it can be transversally approached SciRes, both basic and applied, should always take the road leading to true innovation.

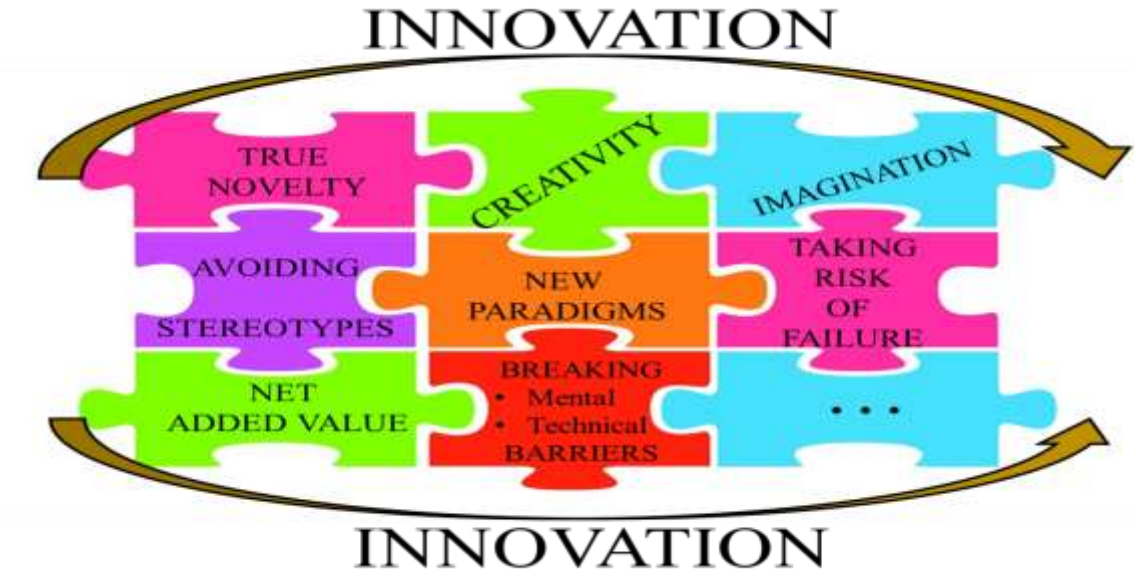

Fig. 3:- Approaching true innovation through the right ways.

Apparent or fake innovation in SciRes seeks no usefulness or added value to the state of the art in a scientific discipline or area. Rather, its actual aim has nothing to do with authentic innovation. Also, it takes little risk of failure and anticipates a predictable or certain outcome. Although a simple, smooth change in a previously published paper by even the same group should never be the driving force for "new" SciRes, this deviant approach can be highly appealing to individual scientists, and research groups or centers, under great pressure to publish whatever. Doctoral students are frequently misled into conducting mistakenly innovative work to obtain their PhD degree.

As we shall see, this crossroads is closely connected to the next.

Crossroads 2. Publishing not to perish or contributing actual socioeconomic value

This has been one of the greatest dilemmas for SciRes in recent decades; one in need of a more rational approach. This crossroads is connected to several others (see Fig. 2) and, interestingly, includes a fourth way where all others should converge.

Why, as stated by Ioannidis (2016) for clinical research and Valcárcel (2017) for analytical chemical research, is publication increasingly divorced from usefulness? According to these authors, most clinical and analytical research is useless because publication has become too strong a driving force for the two. A thorough reform is thus urgently needed according to Ioannidis and rethinking R&D&T activities according to Valcárcel.

Accurately defining *usefulness of research* requires considering how the research work is to be designed and whether the initial objectives are to be fulfilled in the short, medium or long term. Thus, because research is often assessed in the wrong manner (see Crossroads 6) and many would-be scientists have little interest in true innovation, their main short-term objective is often publication of as many papers as possible in order to engross their CVs for professional or academic promotion —or simply to justify investments.

On the other hand, long-term objectives aim at a well-defined target and those pursuing them seek true innovation and social usefulness rather than mere publication. If a "hot" target is chosen (e.g., developing a simple, efficient method for preventing cancer or VIH infection, or devising a reliable nanosensor for monitoring Alzheimer's disease from a very early stage), then these social considerations come into play and should be carefully taken into account (see Crossroads 5).

So-called "blue-sky research" also aims at true innovation (see Crossroads 1) because it often provides interesting opportunities for oriented basic and applied SciRes. These opportunities can be taken by other research groups more knowledgeable in bringing new paradigms closer to actual needs (e.g., biomedical institutes serving hospitals in the context of translational medicine).

The other way one can go at Crossroads 2 is *publication* of articles, books, reports, etc., which is a customary activity for scientific researchers. Why can publication be antagonistic with usefulness? In our opinion, the main aim of publishing should be sharing SciRes results with peers and society. However, the well-known phrase "publish or perish" has caused the emergence of other, distorting driving forces for publication that have very often led to a drop in scientific paper quality. In fact, a vast amount of literature reporting scientific research has little added value. Also, it is not uncommon to encounter glittering titles that have little to do with what was actually done or achieved but succeed in arousing the interest of rapid-publication or pay-per-page journals (see Fig 4).

An enlightening article recently published by the British newspaper *The Guardian* (Burannyi, 2017) posed a tough question in its title: "Is the staggeringly business of scientific publishing bad for science?". The journalist's answer was a categorical "yes". He compared the business of scientific publishing with that of big companies such as Google and warned scientists that they were being "exploited". In fact, giant publishers do not share enough of their profits with authors, reviewers, editors or editorial board members in exchange for their hard work. Why do authors have to pay to make their papers available online? Why do reviewers receive an average of 2 to 6 articles per week to be reviewed within short notice and for free? Why do scientific journals advertise through cookies in on-line dailies? Why are book authors paid a ridiculously low proportion of editorial turnovers? Why are web sites intended to help authors publish their research free of charge (e.g. Sci-Hub) inevitably disappearing? Why do some countries pay a vast sum of money each year to maintain on-line libraries at universities and research centers? Fortunately, science publishers affiliated with scientific societies such as ACS and RSC are being more respectful of author's rights.

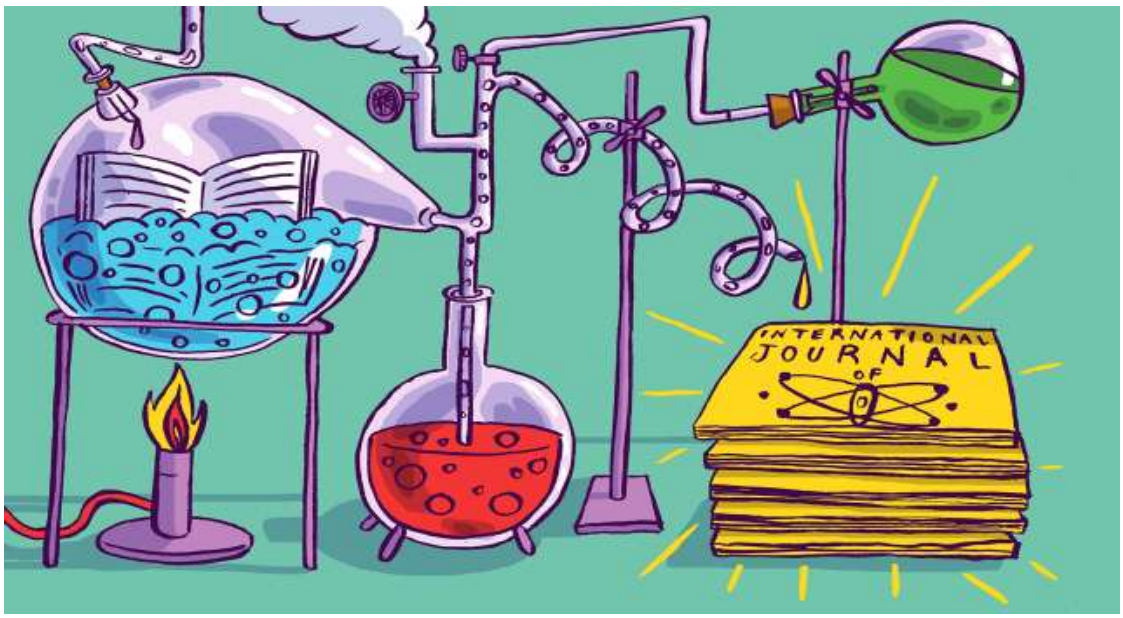

Fig. 4:- Humorous depiction of a laboratory as a high-throughput paper production machine. Reproduced from reference 8, with permission.

Publishers should be fully aware that, without scientists, who produce and buy the literature they publish, they would probably not exist —or most of their profits would likely vanish. An urgent need for a substantial change here therefore exists, but not in the direction most of the on-line journals that have recently appeared as mushrooms in forests have taken, which is charging authors for publishing their work and subjecting papers to unrigorous review. How can they possibly expect to have a high impact factor by acting so selfishly?

The *pressure to publish* has grown steadily under the combined effect of publishers' greed and the use of spurious merit assessment measures (see Crossroads 6 and Fig 5). Many are unable to admit that overpublishing has nothing to do with good science. An urgent need therefore exists to have these apparently contradictory ways converge at this crossroads. This can be accomplished by dropping journals with a very low impact factor, promoting scientific innovation, having publishers better support scientists (especially those involved in editing tasks) by sharing their profits in a fairer way or increasing the rigor of the paper reviewing process. In our opinion, Science will progress better if the amount of research published each year is reduced by 20–30% while clearly raising the quality standards (e.g., innovativeness) of published papers.

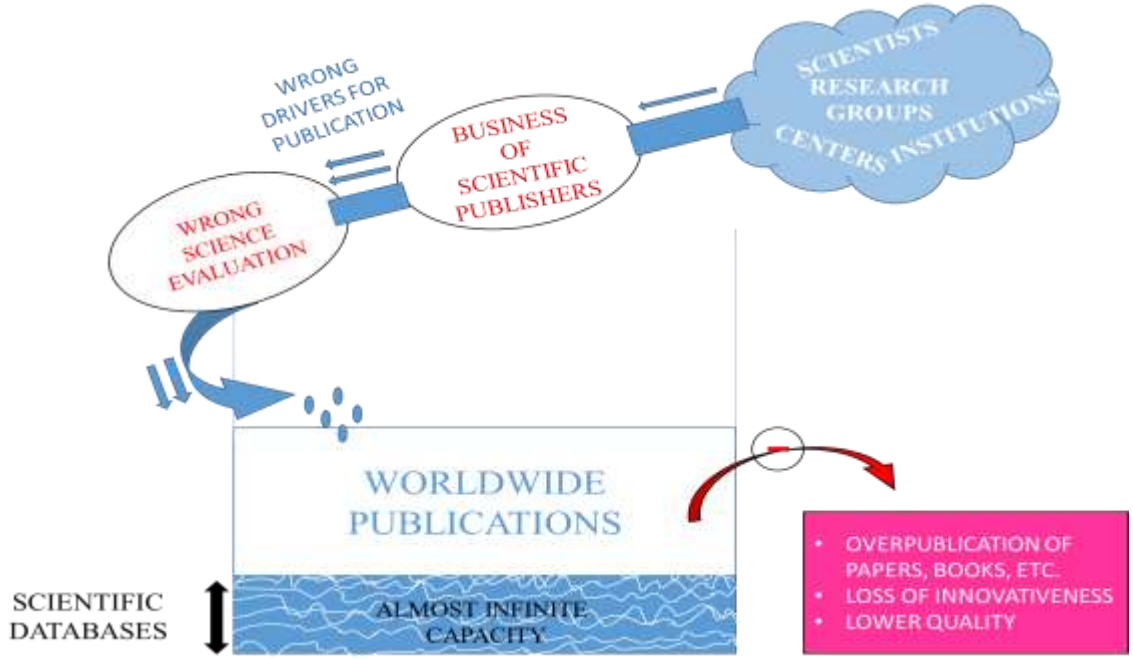

Fig. 5:- Driving forces for publication of an unjustifiably large number of papers and its regrettable consequences.

Crossroads 3. Transparency or opacity

The word "transparency" as applied to an object means that the object allows light to pass through and that other objects behind it can also be seen. However, "transparency" has other meanings such as "ease of detection or perception" when referring to openness in people, processes, information, institutions, etc., and is equivalent to "crystal-clearness" when applied to activities. On the other hand, "opacity" defines the extent of impenetrability (i.e., lack of transparency) of an object to light, but also has alternative acceptations such as "obscurity of meaning" or "the quality of being obscure or incomprehensible".

Crossroads 3 can be identified with the intangible side of transparency and opacity rather than with their light-related meanings. The two terms can be applied to institutions, centers, scientists, publications, etc., where the transparency/opacity pair can have slightly different but related connotations. Here, we focus on scientific papers, which are mostly concerned with experimental work.

Transparency and research reproducibility (Goodman et al., 2016), which are also mutually related, should be two key attributes of experimental scientific work (Collins and Tabak, 2014; Gorgolewski and Poldrack, 2016). Thus, transparency in a paper means that the claimed merit can be evaluated on the basis of evidence, while reproducibility is the degree of feasibility of other scientists reproducing the reported findings if provided with the original data.

Reproducibility can also refer to the production of new data with another methodology leading to the same conclusions. An opaque paper is one that is unclearly written and/or incomprehensible; whose objectives are blurry or loose; the experimental section in which cannot by easily replicated (under the "repeatability" and "reproducibility" statistical conditions); or one where the origin of the materials is obscure, or the methods used are poorly explained or even intentionally described in a distorted manner (e.g., by stating that some reaction took place under nitrogen rather than in an open atmosphere) in order to make them irreproducible. It is usually quite difficult to reproduce a published experimental section in another laboratory. For example, Errington et al. (2014) believe that "data" of growing interest such as those from bioimaging should be replicated a number of times and an "average picture" rather than a single instance reported. Rejecting opaque papers is a great challenge for editors and reviewers, who, as noted in discussing Crossroads 2, necessitate better support from publishers to properly fulfil their duties.

Crossroads 4. Isolation or interdisciplinarity

Interdisciplinary studies integrate two or more academic disciplines (Repko and Szostak, 2016) into a single activity in search of cross-fertilization, complementariness and synergy. Combining theoretical and practical knowledge from various fields can no doubt considerably enrich SciRes (Repko et al., 2012). The farther apart the areas brought together are, the greater will be the degree of innovation achieved in the form of new understanding or meaning, a novel product or a new paradigm. Although managing interdisciplinary work is costlier and more complicated, it repays investments with more added value than individualistic work does.

Although isolated SciRes is easier to manage, it is restricted to a single area of knowledge or specialty. Interdisciplinary SciRes requires a clear leadership, strong internal organization, high transparency in the participating research groups and respect for the different idiosyncrasies involved.

The future of transversal and enabling areas such as Chemistry is definitely bound to interdisciplinarity (Martin et al., 2015), that is, to expanding its traditional boundaries and seeking integration with other areas. The classic triangle of Chemistry (theory, synthesis and analysis) has evolved first to a tetrahedron including applications at the new the vertex and then to a pentahedron including interdisciplinarity at the fifth (Valcárcel et al., 2017) (see Fig. 6).

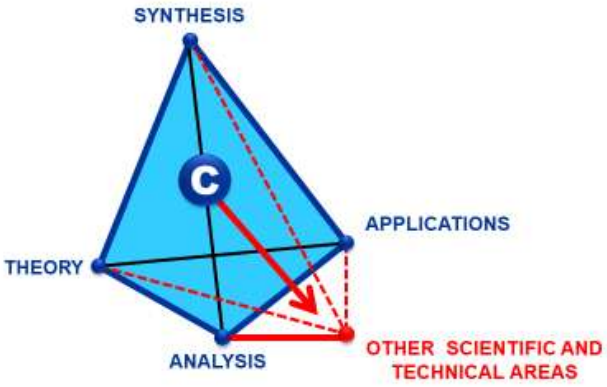

Fig. 6:- Evolution of Chemistry from the original triangle (theory, synthesis and analysis) to a pentahedron. Reproduced from Valcárcel et al. (2017), with permission of Springer-Nature.

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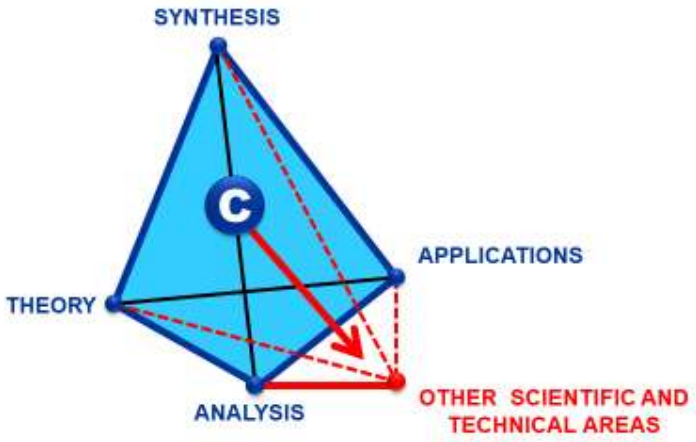

Crossroads 5. Social responsibility or no social commitment

The undeniable divorce of science and society is a subject of growing concern. So much so that, according to Krogsgaard-Larsen et al. (2011), a call to arms is needed if scientists are to regain society's trust. Succeeding in this endeavor will require profound attitudinal changes on both sides. The problem was envisaged as early as the 1950s, when a new management model called "Corporate Social Responsibility" (CSR) was developed to narrow the widening gap between corporations and society. The CSR model can be easily applied to the science–society pair. In fact, a number of written standards already exist to help implement CSR systems especially prominent among which is ISO-26000 (ISO, 2010). This standard can be easily adapted to specific SciRes fields such as Analytical Chemistry (Valcárcel and Lucena, 2012; Valcárcel et al., 2013) or Environmental Science and Technology (Valcárcel and Lucena, 2014). Social Responsibility in Science means full awareness on the part of scientists of the social impact of their activities on all stakeholders and rests on pillars such as fulfilment of stakeholders' needs, accountability, transparency (Crossroads 3), ethical conduct (honesty), respect of human rights (UN) and abidance by national legislations.

Krogsgaard-Larsen et al. (2011) have defined Scientific Social Responsibility as the responsibility of scientists to position and define their research activities in a context where they can contribute to the betterment of society and to meeting the Grand Challenges of our time as stated in the 2015 Lund Declaration. This complementary approach is consistent with the ways to go at Crossroads 1 and 2.

Turning their backs on society is a gross error scientists should avoid at any rate; an obsolete attitude bound to remind people of crazy scientists working on their own in dark laboratories. Instead, scientists should connect themselves to society through a solid bridge resting on firm pillars on both sides and on Social Responsibility of Science in the middle.

Crossroads 6. Proper or spurious assessment

This is a crucial crossroads inasmuch as it is a transversal crossroads. In fact, properly assessing research is crucial because it influences researchers' careers and institutional progress by facilitating professional success and securing economic resources, for example.

SciRes grew enormously during the XX century and continues to grow at present. However, science assessment methods have changed little in the meantime. In fact, many evaluation systems have remained unaltered for a long time and necessitate profound revision by scientific assessment agencies.

Scientific evaluation can have a variety of targets including papers; individual scientists; research groups, centers or institutions; and scientific projects. Obviously, a research center cannot be evaluated merely by combining the assessment results for its research groups. Because discussing every possible way of assessing research is beyond the scope of this paper, in this section we focus on 10 factors that can be applied to individuals, groups and institutions. Ten factors that constitute a network of potential ways to go in SciRes assessment (see Fig 7).

Fig. 7:- Interrelated positive future directions (modules) for SciRes assessment.

1. *Devising new assessment methods* consistent with the new directions SciRes is to take in the future and with the need to deliver quality research and fulfil mankind's grand challenges as stated in the 2015 Lund Declaration. Using a spurious evaluation system can impair the quality of SciRes by inviting unambitious goals. For example, it is utterly wrong to select candidates to a scientific position in terms of the number of papers they have published. Under this criterion, many Nobel laureates would never have got a job in science.

2. Funding. Reliable assessment of SciRes requires economic resources for proper conduct of the evaluation process. However, investments in improving science assessment can be expected to be promptly repaid in the form of better scientific developments. Editors and reviewers of well-reputed journals should be incentivized with a fair remuneration for each review job (see Crossroads 2). Also, book authors should receive a greater portion of publishers' profits and careful peer reviewing should be rewarded somehow. Although computers have made the reviewing process easier, faster and more economical, nothing can replace dedicated work from conscientious peer reviewers that are reasonably remunerated for their help and allowed more time for each paper.

3. *The human factor*. Properly assessing SciRes requires specialists on specific topics that are versed in the evaluation system rather than mere accountants for numbers of papers and other figures on international databases. Also, SciRes reviewers should be properly trained if they are to deliver accurate, fair reports. The enormous growth of scientific literature in recent times (Crossroads 2) has required recruiting a massive army of paper and book reviewers whose work is rarely recognized. Some journals merely designate "experts" that they invite to perform nonblind reviews of papers to be published in their December issue each year —for good reason, many such experts decline the invitation. In fact, careful evaluation of scientific contributions often takes so long that it is incompatible with a scientist's daily duties —which often include teaching in addition to conducting research. Frequently, review work has to be done over the weekend, which is completely unacceptable since free time is as personally valuable as labor time can be or even more so. Going another way is clearly the right choice in this situation, and the change of direction should reach a wide range of stakeholders including assessment agencies.

4. *Assessment stages*. The SciRes assessment process involves three different stages that span the periods preceding (*ex-ante* stage), coinciding with (*intermediate* stage) and following assessment (*ex-post* stage). Not all assessment processes include the three stages, however. Thus, a call for project proposals will unavoidably require ex-ante and ex-post evaluation of the candidates; however, if the project is important enough, intermediate evaluation at some point may also be desirable.

Evaluating an individual scientist seeking a position or wishing to hold one or being promoted has special connotations. Thus, the process leading to assignation of a job in a research center usually involves ex-ante assessment. Subsequent, intermediate assessment of the researcher's performance through, for example, well-structured annual activity or achievement reports —a central element of the much needed culture of accountability— may be the basis for economic incentives, promotion and other benefits. Ex-post assessment may be needed or desired when the researcher's commitment to the engaging center (e.g., a contract) ends since favorable evaluation may allow him or her to find a new or better job. Finally, positive evaluation of research group and centers for specific periods of service (3 or 5 years, for example) should focus on innovativeness and on effective transfer of knowledge and technology in the form of patents, startup creation or corporate contracts rather than on the quantitative indicators currently used at large for this purpose.

5. *The culture of accountability*. Accountability is a crucial ingredient of proper SciRes assessment; one that is closely related to Crossroads 5 because it is a pillar for Social Responsibility in Science (Valcárcel and Lucena, 2012; Valcárcel et al., 2013; Valcárcel and Lucena, 2014) together with ethics and transparency (see Crossroads 3). In fact, accountability is connected with liability, responsibility, awareness and integrity, and ultimately leads to reliability. Accountability can be individual (e.g., that of a scientist) or collective (e.g., that of a research group, center, institution or project). Many scientists simply identify accountability with monitoring and controlling budgets when properly evaluating SciRes requires assessing efficacy (viz., the degree to which objectives are fulfilled) and efficiency (viz., efficacy in terms of time, costs, etc.); demanding justification for deviations from the original commitment or plan; considering unexpected achievements and opening up of new research lines; and appraising efforts to transfer the ensuing knowledge to scientific and technological outlets.

6. Qualitative and quantitative indicators. Scientific work is very frequently assessed in terms of quantitative measures (especially from information stored in international scientific databases). These data sources use direct indicators such as number of publications or journal impact factor and indirect indicators such as Hirsh index or average number of citations per year. There is a growing feeling that using quantitative indicators in isolation can have perverse effects such as SciRes being inaccurately represented or contextualized; true innovativeness being misjudged —not infrequently, true innovation leads to poor quantitative indicators owing to the additional effort needed to start a new research line—; and "inflated" indicators placing undue credit where no proportional merit exists. Also, quantitative indicators are assigned not by well-reputed peers but rather by trained administrative staff in assessment agencies following well-established protocols previously developed by scientific evaluators.

Assessing SciRes in qualitative terms involves examining other factors of scientists' work that numbers cannot measure. Some such factors, but particularly those that follow, are very important:

(a) Availability of a solid scientific, technical and administrative framework.
(b) Success in past and present projects.
(c) The ability to discriminate between close numbers. For example, if the four candidates topping the list for award of two prizes in recognition of scientific merit are given 43.23, 41.47, 41.46 points and 27.54 points, respectively…, it would be unfair to exclude the third on the grounds of score alone since his or hers was only one-hundredth lower than that of the second. Rather than relying on numbers alone, an expert panel should judge the candidates' merit to reach a well-grounded decision.
(d) Opting for innovative research lines.
(e) The ability to conduct SciRes (e.g., scientists tutoring PhD, master and graduate students).
(f) The ability to collaborate with groups from other countries.
(g) Interdisciplinarity.

Using a well-balanced combination of quantitative and qualitative indicators is usually a tough challenge unless a detailed protocol is previously established and subsequently strictly adhered to. Most often, a score from 1 to 5 is used to deem merits very poor, poor, acceptable, good and excellent, respectively, in qualitative terms. One alternative type of merit to be considered in this respect is how often a group undertakes a new research line. This type of merit, however, can only be properly assessed by scientists with expertise in sound assessment methods.

Numbers are often like individual trees hiding the view of the forest of Science; they are necessary —there can be no forest without trees— but not sufficient for assessment purposes.

7. A balance between bureaucracy and simplified processes

One of the main challenges assessment agencies typically face is efficiently managing vast amounts of often unnecessarily detailed information for its purposes. Usually, their "clients" are under heavy bureaucratic pressure and must complete the usually extensive nonscientific parts of their proposals under the added pressure of tight deadlines. Because most of the information an agency requires is stored in some database, it would probably suffice to ask the "client" to provide any data not directly accessible from an available source of information. Simplification (that is, simplifying processes, which is a growing trend in Science and Technology in addition to automation and miniaturization) continues to be one of the greatest challenges of SciRes assessment. To what extent assessment can be simplified is obviously limited by the need to lose no essential information in the process.

A number of corporate approaches to simplification (Frost, 2018) could be easily used in adapted forms by SciRes assessment agencies. Implementing a simplified evaluation management system can provide substantial advantages such as replacing stacks of documents with computer facilities, increasing productivity, saving time and minimizing potential mistakes. Despite the growing advances in this field, most existing assessment agencies are still in need for less bureaucratic management systems.

In a world handling an ever growing amount of information and transfer thereof, blockchain (Mearlan, 2018) has recently emerged as a powerful tool for ensuring document and transaction traceability; one that could help assessment agencies accomplish internal and external quality.

8. Support to authentic innovation

As noted earlier, assessment agencies must first be able to identify true innovation in SciRes, and then firmly and steadily support it. This is crucial because the decisions made in assessment processes can lead to new research lines being supported even if the proponent group's evaluation numbers remain modest while the novelty is being implemented. True innovation (Crossroads 1) can be identified by qualitative evaluation. This is an exception to number-based evaluation; one that should be justified and considered in future assessments within the framework of Crossroads 3 in order to assure transparency in the process.

9. International collaboration

As stated in connection with Crossroads 4, being open to collaboration with other research groups should be an asset for favorable assessment by agencies. If the groups concerned are from another country or their research interests pertain to other disciplines, the participants in the collaborative venture, both individual and collective, will benefit from a synergistic combination of interdisciplinarity and internationalization. International collaboration in SciRes can be assessed *qualitatively* (e.g., a commitment to work with others in a joint project under the umbrella of a well-reputed international organization, innovativeness, interdisciplinarity, scientific level of the countries and groups involved, how solidly the need for the collaborative action is justified) and *quantitatively* (e.g., the combined number of papers published by the stakeholders, the impact factors of the journals, the number of joint proposals put forward and the proportion of those approved, funding availability for the joint venture). Ideally, assessment agencies should develop a protocol integrating qualitative and quantitative indicators for this purpose, and use an international expert panel to assess candidate collaborators.

10. Meta-evaluation

Meta-evaluation is the process by which previous SciRes evaluations are reviewed (Bormmann et al., 2010; Ioannides et al., 2015). This is a central pillar of many current SciRes assessment programs and strategies as it imposes the ethical and scientific obligation to assure that the evaluation process will be properly implemented, reliable, unbiased, reproducible and, in summary, a quality process. Meta-evaluations usually focus on science assessment agencies but can also target other subjects such as research proposals or individual scientists.

Optimal meta-evaluation occurs when (*a*) the meta-evaluation procedure is carefully defined and made known to all stakeholders; (*b*) the evaluators duties are duly recognized by all; (*c*) a combination of qualitative indicators (e.g., complexity of the assessment procedure, document flowchart, difficulty of conducting the requested evaluation, where and when time is wasted) and quantitative indicators (e.g., average evaluation time for an object, average cost of evaluations, proportion of face-to-face peers involved) is used; (*d*) external (international) evaluation peers participate in the process; and (*e*) the agencies involved accept the results of one another.

One of the most widely recommended procedures for meta-evaluating SciRes assessment agencies uses a cyclic approach starting with autoevaluation of each agency, and following with external assessment —by international bodies if at all possible— and with discussion of the assessment results with agency officials to produce a consensus report. The report should contain specific and general quantitative data in order to facilitate subsequent periodic re-evaluation of the agencies, as well as recommendations for improvement and for avoiding bad practices.

Conclusion:-

This paper depicts the present and desirable future of SciRes by using a model of crossroads where taking the right or wrong way can lead to a better or worse outcome. The six crossroads discussed are depicted in Fig. 2. Although we have strived to cover all possible SciRes areas, each area has some peculiarities that could lead to a different map of crossroads.

Quality in SciRes, which falls in the center of Fig. 2, can be defined in terms of a combination of keywords such as innovativeness (trueness), economic and social usefulness, transparency, reproducibility, social responsibility, simplicity, interdisciplinarity, and proper, integral (external and internal) assessment and re-assessment.

Choosing the *wrong way* at each SciRes crossroads is easy if one is obsessed about publishing not to perish; content with conducting facile, scarcely innovative research; elusive of collaborative research (particularly with groups from other countries); willing to make experimental procedures obscure or difficult to replicate; or supportive of old-fashioned evaluation systems. Scientists of this kind should be flatly rejected by any self-respecting SciRes assessment agency.

The predictably somber destination of those inadvertently or purposely choosing the wrong way at a crossroads can be avoided by making the two divergent choices converge at some point. For example, reporting purely innovative research work of no apparent use at the time of publishing (Crossroads 2) may eventually help the same or another group find an outlet for it and continue to propagate the R&D&T chain.

This paper is basically intended to help others discriminate between true (genuine) innovation and merely apparent innovation, and also to accurately define “Transfer” as the last element of the R&D&T triad.

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