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Review

What makes a good scientist? Karl Fent as an example

John P. Sumpter

Institute of Environment, Health and Societies, Department of Life Sciences, Brunel University London, Uxbridge, Middlesex, UB8 3PH, UK

A B S T R A C T

Despite the undoubted interest in assessing the performance and impact of scientists, there appears to be no generally accepted way of doing so. Their research papers can be assessed by various metrics, but these cover only one aspect of the activities of a scientist. In this paper I provide my own thoughts on many of the aspects I consider make up a good research scientist. However, these are my opinions only; they are often not supported by available quantitative, or even qualitative, evidence. I have then applied these criteria to one individual scientist, the ecotoxicologist Karl Fent. I show that he has contributed significantly to his chosen discipline in a number of distinct ways, through both his teaching and his research. I therefore conclude that he must be considered a very good scientist. In the current era of attempting to quantify and hence rank almost everything, an approach often driven by lack of trust, it is very clear that there is substantial scope in attempting to develop, then utilize appropriately, objective criteria that are informative of a scientist's contributions. Those criteria need to be much broader than the metrics currently available.

1. Introduction

The question in the title of this paper is a very simple one and, therefore, a question that many people, especially existing scientists, might think they could answer with ease. But can they? If you asked scientists to name exceptional scientists, then names such as Albert Einstein, Charles Darwin, Marie Curie and Galileo Galilei would probably be forthcoming. If then asked why these people were considered the greatest scientists, they would probably say things like "their discoveries changed the world". However, if you then said "put aside the really great; what characterises a good scientist?", then these same scientists may struggle to provide the criteria that make a good scientist. I certainly did, so I resorted to the World Wide Web (the invention of another exceptional scientist, Tim Berners-Lee) for help. Using the Web of Science Core Collection database and the search term 'what makes a good scientist' as a title, I was very surprised to obtain only 4 references published since 1970, none of which seemed to answer my question. Widening the number of journals searched from the Core Collection of the Web of Science to all journals in the Web of Science database yielded only 3 additional papers, albeit one very important one (see below). Then I broadened my search term to simply 'good scientist' in the title, which gave me 225 references. Yet none of these papers appeared particularly relevant to my quest; most just had the words 'good' and 'scientist' in their titles, and not always together. Hence it appears that either the question in the title of this paper is of no interest to scientists – which I strongly doubt – or it is not as easy to answer as intuition might have one believe.

The question posed by the title of this paper is really a social science question; and I am an experimental (eco)toxicologist, and hence probably not the best person to attempt an answer to that question. In fact, the study most relevant to the topic of this paper that I am aware of [10] is published in a social science journal. That paper reports the results of a relatively small survey intended to identify the factors senior scientists use when judging the C.V.'s of junior scientists. Once the senior scientists had rated the junior scientists, the author then assessed how strongly a range of factors (e.g. number of papers published per year, impact factors of journals, position of junior scientist on the authorship lists, prestige of institution, etc) correlated with the ratings provided by the senior scientists. Of the various factors investigated, annual publication productivity (i.e. average number of papers per year) was most strongly correlated with the ratings [10]. Put another way, the senior scientists considered that the number of papers published by the young scientists they rated was the best indicator of how good those scientists were: quantity trumped all other factors. That finding was supported by the finding of another study [2]. Are we any better at judging scientists now, more than 30 years later?

In contrast to those two studies [2,10], I have not conducted a study to address the topic of this paper. However, having spent my entire career (over 40 years to date) as a scientist, I have gained a considerable amount of experience in judging the quality of science, and hence scientists. I have reviewed many hundreds of papers submitted by other scientists for possible publication in scientific journals, and also reviewed a lot of research grants. I have read the opinions of other scientists when they have reviewed my papers and my grant applications. I have attended many scientific conferences, during which I must have listened to thousands of talks and read thousands of posters. And I have been asked to judge the merits of many applications by scientists for promotion. Hence, whether consciously or not, I have been judging

E-mail address: john.sumpter@brunel.ac.uk.

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scientists and their science for many years. Here I use that experience to reflect on the characteristics of a good scientist, then apply those characteristics to one particular scientist, namely the ecotoxicologist Karl Fent.

2. How can we judge how good a scientist is?

2.1. Subjective opinions

There has never been any shortage of subjective opinions along the lines of 'he/she is an excellent scientist' and 'he/she does really good research'. However, these were opinions, not facts supported by evidence, and hence they suffered from bias.

This situation was radically transformed in the 1970's, when the Institute of Scientific Information (ISI) began, first manually, then electronically, compiling list not only of most scientific publications (all those published in what were considered reputable journals, albeit with a very strong English language bias), but also, uniquely at the time, the frequency that those publications were referred to (that is, cited) by scientists in subsequent publications: citation analysis was born.

2.2. The use of metrics

It now takes only a few minutes to find out what any individual scientist has published during his or her career, using databases such as the Web of Science, Scopus or Google Scholar. Thus the number of papers published by a scientist is easily obtained, allowing raw productivity to be compared between scientists. It is equally easy to obtain the number of times each of those papers has been cited, both by the scientist himself/herself in their subsequent papers (self-citation) and by other unconnected scientists. These data can be analysed in various ways, to obtain an objective view on the degree of interest to any scientist's research. However, great care needs to be taken when assessing the outputs of scientists in this way. One of the biggest problems is being certain that the listed papers or citations do belong to the scientist of interest and not to another scientist with a similar or identical name. For example, an author search (conducted on 14 January 2019) on the name Jones, A.B. yielded 259 papers from the Web of Science Core Collection database. As these papers covered a number of different scientific fields, I suspect that they were published by more than one scientist with the name Jones, A.B. When the search was broadened to the name Jones, A., it yielded 17,026 papers, which I am very confident were written by very many different scientists.

In an attempt to incorporate both productivity (number of papers) and their citation frequency (their apparent impact) in one number, the Hirsch Index (or h-index) was developed [6]. A scientist with an h-index of 40, meaning that he or she had published 40 papers that had received 40 or more citations, is considered a very good scientist. Hirsch himself suggested that an "outstanding scientist" would have an h-index of 40 or more, and a "truly unique" individual would have an h-index of 60 or more, although Hirsch noted that h-indices would vary between different fields of science. As a consequence of environmental science being a relatively small field, with fewer scientists, fewer papers, and hence fewer citations than fields such as medicine, h-indices of environmental scientists are likely to be lower than those in some other disciplines.

Many of the problems associated with the use of metrics to gauge the quality of scientists are illustrated by the data in Table 1. It is clear that the Retired Professor was, and probably still is, a good scientist. However, judging if the Ph.D. student, post-doctoral fellow and Assistant Professor are good scientists is difficult, if not impossible, due to a paucity of data: only time will tell. There are currently no widely accepted methods capable of judging whether or not scientists at early stages of their careers will become good scientists, although some approaches that could be used to assess the quality of young scientists have been proposed [6,7].

Various refinements of raw citation data are possible. One is to exclude self-citation, so that judgements are made only on the number of citations provided by other scientists. Another is to exclude citations to review articles (these can be highly cited), so that judgements are made only on original research. Both these refinements are easily conducted using the Web of Science database.

2.3. Research impact

It has become fashionable recently to try to estimate the impact of someone's research as a measure of their 'quality' as a scientist. For example, a scientist whose research led to a major beneficial change in society would be considered a better scientist than someone whose esoteric research appeared to be of very little interest or relevance to anyone.

Research impact is often considered to be the effect research has beyond academia; on society and the economy. However, whereas it is undoubtedly true that research can have economic and societal benefits, these are notoriously challenging to evaluate and quantify, especially as impact can take years, or even decades, to become apparent. Despite these difficulties, it has become very important politically to demonstrate that society obtains value from the research that it supports, and hence impact evaluation methodology itself has become an active and dynamic field of study.

2.4. Other outputs

There are other ways of disseminating research findings besides publication in scientific papers. These ways include contributing to articles in newspapers and magazines, and appearing on television and radio. Activities such as these have the potential to reach a far larger audience than a research paper in a journal is likely to reach. However, measuring the success of activities such as these is not presently possible, although search engines such as Google can alert huge numbers of people to the existence of some of these outputs.

Social media also provide ways of disseminating research findings to potentially large audiences, and these platforms are increasing used by scientists both to make others aware of research and to discuss that research with other interested researchers, or even people more generally. Although to some extent it is possible to determine the effectiveness of dissemination via social media – by, for example, knowing the number of people reading the blog, reading your tweets on Twitter, etc – assessing whether or not those numbers are related to the quality of the scientist is quite another issue. In fact a reverse correlation might occur: an outrageous scientific claim might cause a social media 'storm', but be based on fabricated evidence, or no evidence at all.

Some scientists write books, and these can still be very influential and be a mechanism of both informing and enthusing other scientists, as well as the public, depending on the level of detail of the book. Although there is as yet no single source that contains information on both all scientific books published and the sales figures for those books (as a measure of the impact of the book), in the way that various databases provide comprehensive information on published scientific research papers (see above), it is possible to search databases such as Amazon's 'Bestsellers' list to find out if a scientist has authored a book, and if so whether or not it appears to be selling well (although many caveats apply to that last statement).

2.5. Teaching

Teaching can be a very significant component of the job of many, but not all, research scientists, although it can be argued that all research scientists teach, albeit in different ways. Scientists based in universities are likely to do considerable amounts of formal teaching. Even if they taught only two or three classes a year – and many will teach much more than this – during their careers they will teach many

Table 1
Who is the best research scientist? These are possible, not actual, metrics, but they are probably representative of productive scientists at different stages of their careers.

Position	Age (years)	Length of publishing career (years)	Number of papers	Number of citations	Average number of citations per paper	H-Index
PhD student	28	2	2	6	3	2
Post – doctoral fellow	34	8	9	54	6	4
Assistant Professor	38	12	15	225	15	11
Associate Professor	52	26	48	1,152	24	20
Full Professor	58	32	150	3,000	20	30
Retired Professor	66	40	220	8,360	38	46

thousands of students. Even if only a small proportion of those students is enthused enough to follow a science-based career, that still adds up to a substantial number of scientists. Later in this article I provide a specific example of the impact of a good teacher on the undergraduate students he taught.

Although I know of no supporting evidence, I expect that most well-established scientists can look back to when they themselves were students and easily recall the names of one or more of their teachers who inspired them and played a major role in them becoming scientists. My own experience is probably typical. As a 20-year old zoology undergraduate I took a course on animal reproduction. It was taught extremely well by a relatively young and obviously knowledgeable lecturer, Brian Follett. His enthusiasm for his subject was obvious, and that enthusiasm transferred readily to many of the students taking the course. A number of us went on to do our Ph.D.'s in the field of animal reproduction, some of whom subsequently obtained permanent scientific jobs in which they were able to develop their own independent research careers within the general area of animal reproduction. And they, in turn, taught and inspired the next generation of scientists. Hence a whole 'family' of scientists spread out, internationally, as a consequence of the excellent teaching of one individual.

It would not surprise me if the teaching component of the jobs of many scientists, especially academic scientists, contributed more to their legacy than the research they did and published. It is unfortunate that no simple – or even complex – metric has been developed yet that can identify and quantify the importance of teaching.

2.6. Supervision and mentoring of junior scientists

Supervision and mentoring of junior scientists could easily be considered a form of teaching, the only substantial difference being that whereas 'traditional' teaching is usually delivered to groups of students, supervision and mentoring are nearly always one-to-one activities. Also unlike traditional teaching, supervision and mentoring are explicitly forms of training; more experienced, often older, scientists train the next generation of scientists. Much of this training occurs when young scientists are doing their Ph.D's. This is an absolutely crucial phase in the development of a scientist, with the most important factor being the 'quality' of the supervisor. There is ample evidence that this phase in the development of a scientist does not always go as well as it might; often but not always because the supervision is not as good as it could, and should, be. To try to help young scientists fulfil their full potentials as scientists, many organisations have established formal training programmes, and written advice is also available (e.g. [8]).

I would consider the ability to be a good supervisor a key component of a good scientist; it ensures that the next generation of scientists will be well trained. However, I accept that some excellent research scientists are not particularly good supervisors, and that some excellent supervisors are not particularly good research scientists. Yet the best scientists are both.

2.7. Leadership

In the past science was mainly an activity of individuals. Even today, most scientists pursue their research as individuals, even if they conduct that research within a team or organisation devoted to a particular scientific topic. Having stated that, those teams or organisations need to be directed by someone, and that someone is almost always another scientist. Leading a team, let alone a scientific organisation, is a very demanding, time-consuming activity. In a large research organisation the head of the organisation may have little, or even no, time for their own research; their entire time can be taken up with various forms of administration. A good administrator tries to protect his or her scientists from non-scientific issues, so that those scientists can devote most of their time to research. Thus, although leaders may not be actively involved in research, they undoubtedly contribute to research in a more indirect manner. They may, for example, be very effective at obtaining funding for their organisation; funding that is then spent on research by research scientists. The contribution that leadership makes to research should not be underestimated, and effective leaders can very definitely be good scientists, even if they are not especially active in research themselves. However, quantifying this aspect of the contribution a scientist makes to his or her discipline is only possible subjectively; there is no metric available for scientific leadership.

2.8. Appropriate mental characteristics

The exceptional scientists mentioned at the beginning of this article were characterised above all else by being able to think originally. They were undoubtedly also highly intelligent. But as I have argued above, it is possible to be a very good research scientist without changing the world to the extent that Einstein or Darwin did. Besides intelligence – which is undoubtedly a very useful trait to a scientist – other characteristics that can be useful include the following:

2.8.1. Objectivity

the ability to maintain an open mind instead of letting existing prejudices influence thinking. Objective scientists are unbiased: beware confirmation bias.

2.8.2. Curiosity

the desire to understand something of interest; to be inquisitive about the world.

2.8.3. Vision

the ability to identify important new research topics, rather than follow fashionable topics, and then have the courage to initiate research on those novel topics.

2.8.4. Finishing something

knowing when 'enough is enough' on a topic, hence completing that project, then moving on to the next topic.

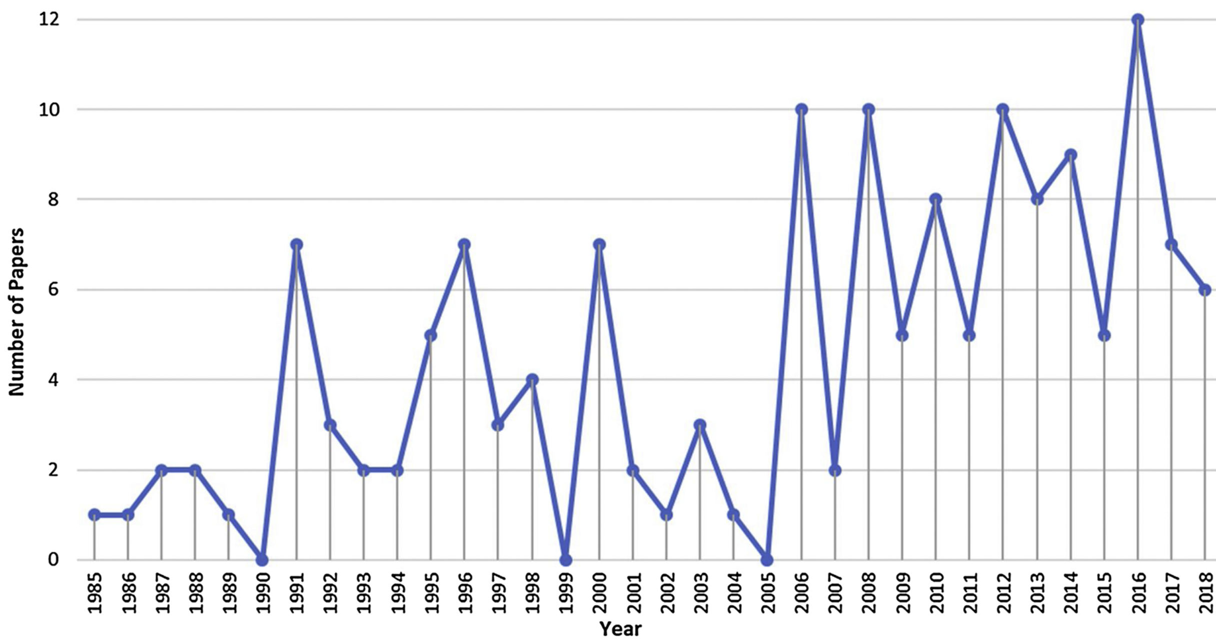

Fig. 1. The number of papers published each year by the ecotoxicologist Karl Fent, based on data from the Web of Science.

2.8.5. Communication skills

the ability to deliver public talks and publish scientific papers, in order to make others aware of research findings.

2.8.6. Coping with failure

it is inevitable that scientists will 'fail' at some stage: experiments may not work as expected, papers will be rejected and grant applications not funded. Persevering while regularly 'failing' is a prerequisite of any scientist.

2.8.7. Hard work

good scientists are very passionate about their research and thus work hard; but it is not necessary to do nothing except work.

These are just some of the personal characteristics often found in good scientists. Many also have very balanced characters, enabling them to interact well with other scientists and allowing them both to lead scientific projects and collaborate with other scientists successfully.

2.9. Integrity

Integrity is a personal characteristic, and hence could have been considered in the section immediately above. However, it is now realised that scientific integrity is such a crucial factor in science that I have chosen to consider it separately from other personal characteristics often possessed by good scientists.

In the last few years it has become clear that a considerable proportion of all published research is of poor quality: much is probably irreproducible. There are many reasons for this 'reproducibility crisis', with the perverse incentives used to judge scientific 'success' – mainly the number of papers a scientist publishes, the number of citations those papers receive, and the amount of grant money a scientist wins – probably being the major ones. The pressure that many scientists are under has led to a wide range of unethical behaviours [9]. These range from relatively trivial indiscretions, such as not publishing negative results and/or exaggerating positive results, to major deviations from acceptable behaviour, such as fabricating results. Our chosen field of study, ecotoxicology, is not immune from unethical behaviour, even very serious unethical behaviour, as the fabrication of results in a paper published in the journal 'Science', then subsequently retracted, demonstrates [1].

Determining the degree of integrity demonstrated by a scientist is very difficult, if not impossible. There is no metric for integrity! However, it is not uncommon to hear comments from scientists such as "I don't believe that" or "that paper is very poor", or alternatively positive comments like "he/she does excellent research" or "that is a very robust study". Hence, scientists are regularly making judgements on the level of integrity shown by other scientists, even if they do so somewhat unconsciously. My own personal experience and opinions I have formed based on that experience are probably typical. As an example, I consider that over half of all the papers I review for journals (and I review a lot) illustrate unethical behaviour. These unethical behaviours include: bias in the interpretation of results; hype and exaggeration, especially in the title and abstract; figures that distort data, or do not display it fully; failure to cite relevant papers from other scientists; too much self-citation; failure to mention any limitations to the study; conflicting interests not mentioned; raw data not submitted as supplementary information; and failure to analyse the results appropriately and accurately. These unethical behaviours are often superimposed on poor scientific principles, such as no hypotheses, poor experimental design, use of techniques not fully validated, no evidence of repeatability of results, etc. (Harris et al., 2014). It is no surprise that much published research is not repeatable.

2.10. Final thoughts

I have no training in the topic of this paper; hence, my opinions on what makes a good scientist (and thus what does not) are personal opinions only. I cannot support them with much robust evidence. Yet I suspect that most scientists would agree with much of what I have written above. We should all aspire to being good research scientists, because only good research is of benefit to society. The advent of scientific metrics applied to the output of scientists has helped to add a degree of objectivity into the judging of scientists, but perversely it has also stimulated a range of poor scientific practices, as scientists try to 'play the game' to satisfy their paymasters, who often utilize metrics uncritically. Probably only further education and training can improve the current situation, and enable as many research scientists as possible to become good researchers.

3. Karl Fent as an example of a good scientist

Karl Fent has been a productive scientist: there were 154 publications of his on the Web of Science Core Collection database on 24 January 2019 (Fig. 1). He is the senior (first or last) author on the vast majority of these papers. Put another way, he has made major contributions to essentially all of the papers that he is an author of. You will not find Karl Fent's name sandwiched between 20, or more, authors on 'group papers'. His annual productivity has varied markedly; in a few years he did not publish even one paper, but in others he published 10 or more (Fig. 1). This very erratic publication rate is, perhaps surprisingly, not atypical: it means that scientists should not be judged on how many papers they produced in a particular year (as annual appraisals of performance usual do), but instead on their productivity over longer periods; perhaps 3, or even more, years. Fent's most productive period has been the last 10 years; in fact, nearly half of his papers have be published in that period. The message is clear: older scientist can be very productive. Some very good scientists even manage to publish almost as many papers after they officially retire (and hence no longer receive a salary) than they did when they were employed: Dr. A. P.Scott of Cefas Weymouth Laboratory, UK, is a particularly good example of impressive late productivity. Managers should probably take this finding into account more than they appear to do, as the founder of, first, Current Contents, then the Web of Science, realised many year ago [5].

Fent's papers have been well cited by other scientists, indicating that they have had significant impact (Fig. 2). There had been 7799 citations (7203 not including self-citations) to those 154 papers at the time of my search. This produced an average of 50.64 citations per paper, and an h-index of 48. His papers are currently receiving around 750 citations per year, a number that is continuing to rise steadily (Fig. 3). This rising number of citations indicates that Fent's papers are still of considerable interest to other scientists. He has 17 papers currently cited more than 100 times, with the most-cited paper (Ecotoxicology of human pharmaceuticals. Aquatic Toxicology 76, 122–159) having been cited over 1500 times, making it an extremely influential paper. Together, these metrics indicate that Fent has been, and still is, a very impressive research scientist.

Besides his original research articles and reviews, Fent is unusual in at least two ways for how he has disseminated his research findings and knowledge of his subject. He wrote two lengthy, detailed articles for a major Swiss newspaper, one on his research on the effects of organotins on molluscs [3] and the other one on endocrine disrupting chemicals with hormonal properties [4]. It is extremely rare for research scientists to write detailed articles on research results and their implications in national newspapers: these lengthy articles were written by Fent, not by a journalist who had interviewed him.

Fent also wrote a textbook, in German, with the title Ökotoxikologie. The book has been very successful, and is presently in its 4th edition. Each edition has sold approximately 2000 copies, which is a very high number for a specialized academic book, particularly one not written in English. Although impossible to quantify, this book has probably done a great deal to help educate the existing and future ecotoxicologists of Switzerland and Germany in particular.

Fent has done a lot of teaching, at a few universities in Switzerland, in the last 15 years. It is usually very difficult for an outsider (i.e. me) to judge the quality and impact of someone's teaching, but in this case it proved to be surprisingly easy. When Fent delivered his plenary talk at the 15th International Symposium on Persistent Toxic Substances, I noticed a number of young people in the audience whom I had not seen previously at the conference. I spoke to some of them at the subsequent coffee break, and learnt that they were final-year undergraduates (i.e. students studying for their B.Sc.'s) who had recently attended a course taught by Fent. They spoke very highly of his teaching. In subsequent correspondence, one of them wrote to me the following:

> "Karl Fent was my professor in a small class about ecotoxicology, a subject that I hadn't known before. I got to know him as a very passionate teacher. His main gaol was not to make us memorize every line he taught, but to understand concepts and to develop an independent thinking where we would question things we saw and learned. His lectures would always cover environmentally and socially relevant topics and I very much enjoyed them, in particular when he was talking about his own research. I therefore asked him whether I could carry out my bachelor's thesis in his group, a decision which I would not regret later.
>
> For my thesis he prepared my own little research project on the molecular effects of plant protection products on honey bees. He

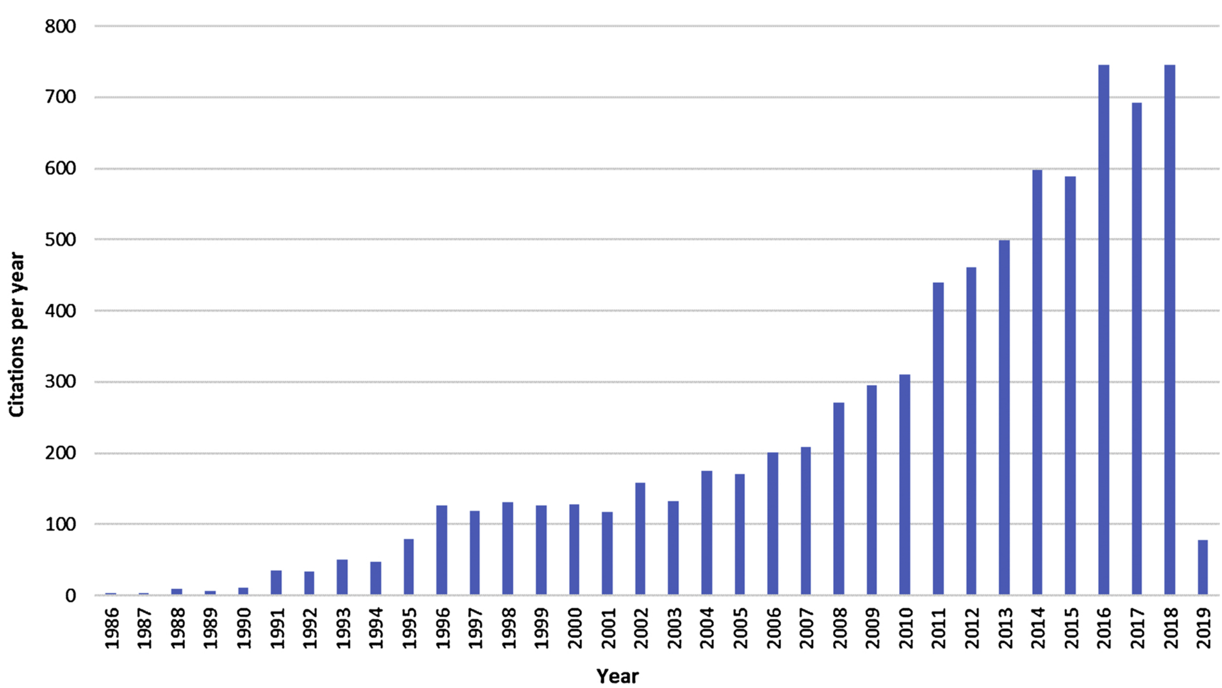

Fig. 2. The number of citations the papers authored by Karl Fent have received each year. Data from the Web of Science Core Collection database.

was very supportive of my work and whenever he had the time he would come and ask how things were going and would encourage me to keep going. When I was unsure about a concept or how to interpret data I collected, instead of giving a straight answer he asked several related questions until I found the answer myself. I learned a lot more during my thesis than in my classes and I was a little disappointed that I had only a short time to work on it.
In conclusion you would say that Karl Fent inspired me, by introducing me into scientific research and the field of ecotoxicology, which I now can imagine as my future career choice."
Elvira Rudin, 08 January 2019

I doubt those words can be improved upon; they say it all. Karl Fent obviously was an exceptionally good teacher. Anyone who influences and inspires the next generation of scientists has done a great service to his or her field.

Fent has also successfully supervised a number of Ph.D. students and post-doctoral fellows. Some of these ex-students of Fent's have written articles published in this special edition, so I will leave it to them to comment on how he supervised them and what they learnt from him. All I will say is that as many of them are still scientists, now building their own independent careers, he must have enthused and inspired them. They are surely a major part of his scientific legacy.

A characteristic I have always associated with Fent's research, but one that is rarely discussed, is his ability to pick the 'right' topic to research. He has shown considerable foresight and curiosity throughout his research career. He was, for example, the first scientist to raise the possibility that the presence of UV filters (used mainly in sunscreens) in the aquatc environment might pose a threat to aquatic organisms. His papers on these chemicals, most co-authored with one of his students, Petra Kunz, have had considerable impact; many environmental scientists across the world are now studying UV filters based on their pioneering research. An even more recent example is Fent's research with a colleague, Verena Christen, on the potential effects of pesticides on the brains of honey bees. The decision to study how pesticides affect gene expression in the nervous system of bees was both inspired and exciting. It has initiated a novel way of determining the effects of pesticides on a major group of pollinators and, potentially, other groups of insects. I anticipate that this research will have considerable impact. It could, for example, lead to the development of entirely new methods of assessing the safety of pesticides.

3.1. Concluding remarks

There is ample evidence, from many different avenues, that Karl Fent was, and still is of course, an extremely good scientist. He has contributed to his chosen discipline in a number of different ways: not only through his research, but also through his teaching and his willingness to engage and educate the wider public. In other words, he is a very well-rounded scientist. Good scientists leave a legacy of papers and/or people. Fent has left a substantial legacy of both.

Acknowledgements

First and foremost I thank Philippe Corvini for inviting me to write an article for this tribute issue, then allowing me to indulge myself on a topic that I am certainly no expert in. I also thank Walter Giger for making me aware of the newspaper articles I mention, and for sending me copies of them, Elvira Rudin for her very insightful thoughts on what makes a good teacher, to Tamsin Runnalls for preparation of the figures and support in many other ways, and Sue Masters of Thieme Publishers for the information on sales of Fent's textbook.

I am also extremely grateful to an anonymous reviewer of this paper who made me aware of the highly relevant paper by Sonnert [10], which encouraged me to conduct further literature searches.

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