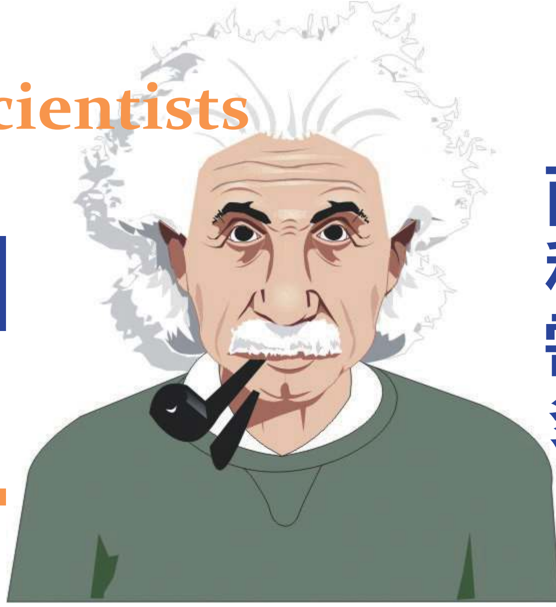
Two Views: How Much Math Do Scientists Need?



两种观点：科学家需要多少数学？

E. O. Wilson , E. Frenkel / 文　　丁 玖 / 译

2013 年 4 月 5 日的《华尔街邮报》发表了哈佛生物学家 E. O. 威尔逊（E. O. Wilson）的一篇随笔：《好科学家≠数学好》。2013 年 4 月 9 日，伯克利数学家爱德华 • 弗兰克尔（Edward Frenkel）在 Slate 上回应了此文。《华尔街邮报》和 Slate 允许我们如下转载这两篇随笔。

On April 5, 2013, The Wall Street Journal published an essay by the Harvard biologist E. O. Wilson, "Great Scientist ≠ Good at Math". Berkeley mathematician Edward Frenkel responded to it in Slate on April 9, 2013. We reprint the two essays below, with permission from The Wall Street Journal and Slate.

好科学家≠数学好

E. O. 威尔逊揭秘：发现源于想法，而不是数字运算

对于许多立志成为科学家的年轻人，大感头疼的是数学。没有高级的数学，科学上你怎能做出严肃的工作？好吧，我有一个职业秘密与您分享：当今世界上许多最成功的科学家，在数学上差不多是半文盲。

在我哈佛几十年的生物学教学生涯中，我伤心地目睹大有前途的本科生转身离开可以跻身其中的科学职业生涯，只因担心如果数学能力不强而会导致失败。这种错误的假设已经从科学界里夺走了不可估量的急需人才。它已经产生了要急需止住的脑力大出血。

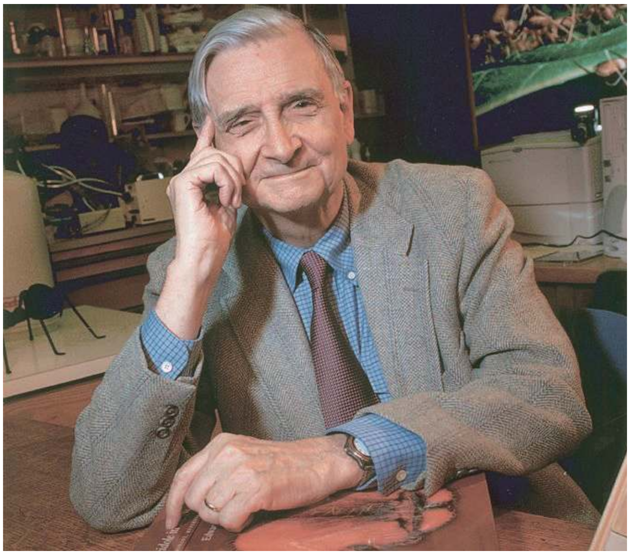
就这个论题而言我可以一个权威的身份说话，因为我

Great Scientist ≠ Good at Math

E. O. Wilson Shares a Secret: Discoveries Emerge from Ideas, Not Number-Crunching

For many young people who aspire to be scientists, the great bugbear is mathematics. Without advanced math, how can you do serious work in the sciences? Well, I have a professional secret to share: Many of the most successful scientists in the world today are mathematically no more than semiliterate.

During my decades of teaching biology at Harvard, I watched sadly as bright undergraduates turned away from the possibility of a scientific career, fearing that, without strong math skills, they would fail. This mistaken assumption has deprived science of an immeasurable amount of sorely needed talent. It has



E. O. 威尔逊

自己就是一个极端的例子。在相对较差的一所南方学校度过了我几年的大学预科后，直到在阿拉巴马大学上大一时我才修了代数课。作为一个 32 岁有终身教职的哈佛教授，我终于和微积分面对面了，和比我岁数的一半只大一点点的那些本科生坐在同一个课堂里，我是那么地不舒服。他们中的几个是我教的进化生物学课上的学生。我吞下了我的自尊心，学会了微积分。

在迎头赶上期间，我从未是一个 C 以上的学生，但我以此发现感到安心：卓越的数学功底和流利的外语能力是相似的。经过更大努力及与内行人多交谈，我可能会更流利，但沉浸于野外和实验室的研究，让我只有少量的进步。

幸运的是，出色的数学才华只在少数几个学科中需要，如粒子物理、天体物理和信息论。整个科学其余部分更为重要的是形成概念的能力，在此期间，研究者以图形想象，凭直觉行事。每个人有时都像科学家那样浮想。立足而起且训练有素，幻想是创造性思维的源泉。牛顿梦想过，达尔文梦想过，你也梦想。其诱发的图像在开始时是模糊不清的。它们在形式上可以转移，淡入或淡出。当在纸上勾勒出图形时，它们会变得更坚实一点，而当寻找真实的例子并有发现后，它们便活生生起来。

科学先驱者鲜有从纯数学的想法中提取发现。大部分在黑板上研究成行方程的科学家的刻板照片上，展示的是解释已作出的发现的教师。真正的进展出现在充满笔记的现场，堆积乱涂乱画纸张的办公室，向朋友奋力解释的走廊上，或独自吃午饭之时。灵光一现需要努力工作和全身心的投入。

当出于自身需要而对世界的某些领域进行研究之时，

created a hemorrhage of brain power we need to stanch.

I speak as an authority on this subject because I myself am an extreme case. Having spent my precollege years in relatively poor Southern schools, I didn’t take algebra until my freshman year at the University of Alabama. I finally got around to calculus as a thirty-two-year-old tenured professor at Harvard, where I sat uncomfortably in classes with undergraduate students only a bit more than half my age. A couple of them were students in a course on evolutionary biology I was teaching. I swallowed my pride and learned calculus.

I was never more than a C student while catching up, but I was reassured by the discovery that superior mathematical ability is similar to fluency in foreign languages. I might have become fluent with more effort and sessions talking with the natives, but being swept up with field and laboratory research, I advanced only by a small amount.

Fortunately, exceptional mathematical fluency is required in only a few disciplines, such as particle physics, astrophysics and information theory. Far more important throughout the rest of science is the ability to form concepts, during which the researcher conjures images and processes by intuition.

Everyone sometimes daydreams like a scientist. Ramped up and disciplined, fantasies are the fountainhead of all creative thinking. Newton dreamed, Darwin dreamed, you dream. The images evoked are at first vague. They may shift in form and fade in and out. They grow a bit firmer when sketched as diagrams on pads of paper, and they take on life as real examples are sought and found.

Pioneers in science only rarely make discoveries by extracting ideas from pure mathematics. Most of the stereotypical photographs of scientists studying rows of equations on a blackboard are instructors explaining discoveries already made. Real progress comes in the field writing notes, at the office amid a litter of doodled paper, in the hallway struggling to explain something to a friend, or eating lunch alone. Eureka moments require hard work. And focus.

Ideas in science emerge most readily when some part of the world is studied for its own sake. They follow from thorough, well-organized knowledge of all that is known or can be imagined of real entities and processes within that fragment of existence. When something new is encountered, the follow-up steps usually require mathematical and statistical methods to move the analysis forward. If that step proves too technically difficult for the person who made the discovery, a mathematician

最容易产生科学的想法。这些想法源于严谨而有序的知识。而所有这些知识或是已知的，或是能由真正的实体以及尚不完整的现实进程所勾画。遇到新的东西时，后续步骤通常需要数学和统计方法来将分析向前推进。如果对发现者而言该步骤证明技术上太困难，数学家和统计学家可以加进来成为合作者。

20 世纪 70 年代末，我与数学理论家乔治 • 奥斯特 (George Oster) 一道研究社会性昆虫的等级制度原则及其劳动分工。我提供了已在自然界和实验室中发现的细节，而他用其定理和假设的工具库来捕捉这些现象。即便没有这样的信息，奥斯特先生也许能开发出一个一般理论，但他不会有任何的方式来推断出可能排列中的哪些在地球上实际存在。

多年来，我曾和数学家及统计学家共同撰写多篇论文，所以我有信心提供下面的原理。这叫威尔逊第一原理：科学家从数学家和统计学家获得所需合作远比数学家和统计学家找到科学家能够运用他们的方程更加容易。

这种不平衡在生物学中尤其如此，在那里现实生活中的现象经常被误解，或未摆在首要位置而被注意。理论生物学的编年史塞满了数学模型，而它们要么可以放心地忽略，或测试时失败。当中超过 90% 的可能没有任何持久的价值。只有那些与活生生的系统知识有扎实联系的模型才有许多被用的机会。

如果你的数学竞争力级别低，规划提升它，但同时应知道你现有的知识也能做出优秀的科学工作。不过，对于专攻需要实验和定量分析密切更替的那些领域，要三思而后行。这些包括：大部分的物理和化学，以及分子生物学中的一些专业。

牛顿为了给他的想象力实质内容而发明了微积分。达尔文几乎没有什么数学能力，但由于积累了大量的信息，他能够构想出一种过程，后来才用到了数学。

对于有抱负的科学家，关键的第一步是要找到一个他们极感兴趣并专注于此的学科。这样做的话，他们应该记住威尔逊第二原理：对于每一位科学家，存在一门学科，在当中他或她的数学能力足以使其走向辉煌。

——E. O. 威尔逊，哈佛大学荣休教授

or statistician can be added as a collaborator.

In the late 1970s, I sat down with the mathematical theorist George Oster to work out the principles of caste and the division of labor in the social insects. I supplied the details of what had been discovered in nature and the lab, and he used theorems and hypotheses from his tool kit to capture these phenomena. Without such information, Mr. Oster might have developed a general theory, but he would not have had any way to deduce which of the possible permutations actually exist on earth.

Over the years, I have co-written many papers with mathematicians and statisticians, so I can offer the following principle with confidence. Call it Wilson's Principle No. 1: It is far easier for scientists to acquire needed collaboration from mathematicians and statisticians than it is for mathematicians and statisticians to find scientists able to make use of their equations.

This imbalance is especially the case in biology, where factors in a real-life phenomenon are often misunderstood or never noticed in the first place. The annals of theoretical biology are clogged with mathematical models that either can be safely ignored or, when tested, fail. Possibly no more than 10 percent have any lasting value. Only those linked solidly to knowledge of real living systems have much chance of being used.

If your level of mathematical competence is low, plan to raise it, but meanwhile, know that you can do outstanding scientific work with what you have. Think twice, though, about specializing in fields that require a close alternation of experiment and quantitative analysis. These include most of physics and chemistry, as well as a few specialties in molecular biology.

Newton invented calculus in order to give substance to his imagination. Darwin had little or no mathematical ability, but with the masses of information he had accumulated, he was able to conceive a process to which mathematics was later applied.

For aspiring scientists, a key first step is to find a subject that interests them deeply and focus on it. In doing so, they should keep in mind Wilson’s Principle No. 2: For every scientist, there exists a discipline for which his or her level of mathematical competence is enough to achieve excellence.

—E. O. Wilson

Harvard University, Emeritus

莫听 E. O. 威尔逊的

数学可以帮助你从事几乎任何职业，没有理由害怕它

E. O. 威尔逊是一位杰出的哈佛生物学家和畅销书作者。我为他的成就向他致敬。但他最近的一篇《华尔街邮报》短文（改编自他的新书《给一个年轻科学家的信》）是不能再错的了，其中他告诉那些满怀抱负的科学家，他们不需要数学就能茁壮成长。他以这样的话开始："当今世界上许多最成功的科学家，在数学上差不多是半文盲。……就这个论题而言我可以一个权威的身份说话，因为我自己就是一个极端的例子。"如果他接下来说："但是你，年轻的科学家，不必像我一样，所以让我们来看看我是否可以帮助你克服对于数学的恐惧"，那倒是很好。唉，这位年逾八旬的社会性昆虫权威却反其道而行之。原来他居然相信不仅恐惧是有道理的，而且大多数科学家并不需要数学。"我得到的，所以你也可以得到"是他的态度。可悲的是，从这篇文章清晰可见，威尔逊犯下这等错误的原因是，基于他自己有限的经验，他不明白什么是数学以及它如何用于科学。

倘若数学是美术的话，那么威尔逊对它的看法将是：这一切都是在你家的后院篱笆上涂油漆。当你可以雇人来做时，为什么要学习如何自己做呢？但是美术不是油漆围栏，而是大师的画作。同样，数学不是关于如同威尔逊的文章所指的"数字运算"。它是关于概念和想法，它们把我们武装起来描述现实，并发现世界是怎样工作的。伽利略的名言说："自然法则都是用数学语言书写的。"

数学代表着客观的知识，这使我们能够打破教条和偏见。正是通过数学，我们才了解到地球不是平的，它围绕太阳旋转，我们的宇宙是弯曲的、扩张的，充满了暗能量，并

爱德华·弗兰克尔

Don't Listen to E. O. Wilson

Math Can Help You in Almost Any Career. There's No Reason to Fear It

E. O. Wilson is an eminent Harvard biologist and bestselling author. I salute him for his accomplishments. But he couldn't be more wrong in his recent piece in *The Wall Street Journal* (adapted from his new book *Letters to a Young Scientist*), in which he tells aspiring scientists that they don't need mathematics to thrive. He starts out by saying: "Many of the most successful scientists in the world today are mathematically no more than semiliterate …… I speak as an authority on this subject because I myself am an extreme case." This would have been fine if he had followed with: "But you, young scientists, don't have to be like me, so let's see if I can help you overcome your fear of math."Alas, the octogenarian authority on social insects takes the opposite tack. Turns out he actually believes not only that the fear is justified, but that most scientists don't need math. "I got by, and so can you" is his attitude. Sadly, it's clear from the article that the reason Wilson makes these errors is that, based on his own limited experience, he does not understand what mathematics is and how it is used in science.

If mathematics were fine art, then Wilson's view of it would be that it's all about painting a fence in your backyard. Why learn how to do it yourself when you can hire someone to do it for you? But fine art isn't a painted fence, it's the paintings of the great masters. And likewise, mathematics is not about "number-crunching", as Wilson's article suggests. It's about concepts and ideas that empower us to describe reality and figure out how the world really works. Galileo famously said, "The laws of Nature are written in the language of mathematics." Mathematics represents objective knowledge, which allows us to break free of dogmas and prejudices. It is through math that we learned Earth isn't flat and that it revolves around the sun, that our universe is curved, expanding, full of dark energy, and quite possibly has more than three spatial dimensions. But since we can't really imagine curved spaces of dimension greater than two, how can we even begin a conversation about the universe without using the language of math?

Charles Darwin rightfully spoke of math endowing us "with something like a new sense." History teaches that mathematical ideas that looked abstract and esoteric yesterday led to spectacular scientific advances of today. Scientific progress would be diminished if young scientists were to heed Wilson's advice.

It is interesting to note that Wilson's recent article in *Nature* and his book claiming to show support for socalled group selection

且很可能有三个以上的空间维度。但是，因为我们真的不能想象维数大于二的弯曲空间，不用数学语言我们还怎么能开始与宇宙对话？

查尔斯•达尔文理所当然地谈到数学赋予我们以“一个新意义上的东西”。历史告诉我们，昨日还显得抽象和深奥的数学思想，今日就导致科学壮丽的突飞猛进。如果年轻的科学家听取威尔逊的建议，科学进步就会被削弱。

有趣的是注意到威尔逊最近的一篇刊登在《自然》上的文章和他声称有证据支持的所谓群选择的一本书遭到了理查德•道金斯(Richard Dawkins)和其他许多人尖锐的批评。一些批评者指出，错误的来源之一在于威尔逊的数学。因为我不是进化理论的专家，所以我不能提供我的意见，但从威尔逊的论断“伟大的科学家不需要数学”来看，我觉得这场争论有趣。

有一件事应该是清楚的：虽然我们感知的物理世界总有可能被扭曲，我们对数学真理的感知却不可能是这样的。它们是客观的、持久的、必要的真理。一个数学公式对任何人，在任何地方，都意味着同样的事情——无论什么性别、宗教，或肤色；对任何人，从现在开始的一千年，它的意思总是不变。这就是为什么数学在科学和技术上发挥着越来越重要的作用。

数学的关键功能之一是信息的排序。随着 3-D 印刷等新技术的到来，我们曾经习以为常的现实正在经历一个激进的变革：一切都将从现实的物理层迁移到信息层和数据。我们很快就能很容易地通过使用 3-D 打印机将信息变成所需的物质，就像我们现在将一个 PDF 文件转换成一本书，或将一个 MP3 文件转换成一段音乐。在这个勇敢的新世界，数学将是王者：它将被用来组织和整理信息并促进信息转换成物质。

在某些领域，仍有可能“数学不好”（但是我相信任何人都可以数学好，如果它能被正确的方式解释）却能成为一个好科学家，但这大概不会太长久。但是，这是一个缺陷，没什么可骄傲的。诚然，某些科学领域目前使用的数学比其它领域少，但是这些领域的工作者后来更从学习数学中受益。

威尔逊的文章如果仅仅限制在他个人的经验范围内，那没问题。对于现代生物学的学生，这是一个过时的职业生涯道路。然后我们就可以讨论真正的问题，这就是如何改善我们的数学教育并消除如他所说的对数学的恐惧。相反，通过制造恐惧，威尔逊给下一代特别是未来的科学家做出一个远离数学的错误建议。这不只是使人误入歧途，导致不良后果，更在于像他这样的领头科学家嘴里说出来，这简直是一种耻辱。不要接受这个建议——它是一个自我破灭的策略。

——爱德华•弗兰克尔，加州大学伯克利分校

have been sharply criticized, by Richard Dawkins and many others. Some of the critics pointed out that one source of error was in Wilson's math. Since I'm not an expert in evolutionary theory, I can't offer an opinion, but I find this controversy interesting given Wilson's thesis that "great scientists don't need math."

One thing should be clear: While our perception of the physical world can always be distorted, our perception of the mathematical truths can't be. They are objective, persistent, necessary truths. A mathematical formula means the same thing to anyone anywhere——no matter what gender, religion, or skin color; it will mean the same thing to anyone a thousand years from now. And that's why mathematics is going to play an increasingly important role in science and technology.

One of the key functions of mathematics is the ordering of information. With the advent of the 3-D printing and other new technology, the reality we are used to is undergoing a radical transformation: Everything will migrate from the layer of physical reality to the layer of information and data. We will soon be able to convert information into matter on demand by using 3-D printers just as easily as we now convert a PDF file into a book or an MP3 file into a piece of music. In this brave new world, math will be king: It will be used to organize and order information and facilitate the conversion of information into matter.

It might still be possible to be "bad in math" (though I believe that anyone can be good at math if it is explained in the right way) and be a good scientist——in some areas and probably not for too long. But this is a handicap and nothing to be proud of. Granted, some areas of science currently use less math than others. But then practitioners in those fields stand to benefit even more from learning mathematics.

It would be fine if Wilson restricted the article to his personal experience, a career path that is obsolete for a modern student of biology. We could then discuss the real question, which is how to improve our math education and to eradicate the fear of mathematics that he is talking about. Instead, trading on that fear, Wilson gives a misinformed advice to the next generation, and in particular to future scientists, to eschew mathematics. This is not just misguided and counterproductive; coming from a leading scientist like him, it is a disgrace. Don't follow this advice—it's a self-extinguishing strategy.

—Edward Frenkel
University of California at Berkeley