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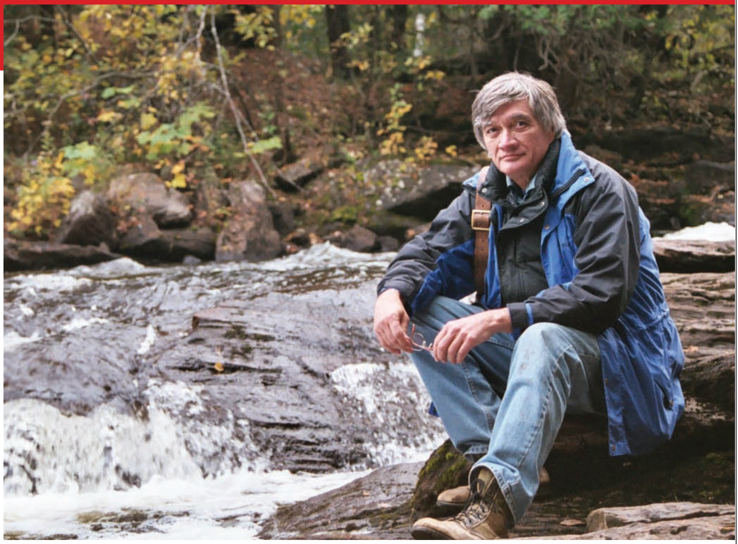

This past winter, I was invited by one of our undergraduates to participate in a student government symposium on scientific integrity. I joined colleagues from natural science departments on a panel to discuss scientific integrity and take questions from students. To my surprise, most of the discussion was about lab reports. The students do the laboratory exercises as a team but write separate reports. They are graded as individuals. The concern was about how to evaluate the work of an individual in the collective effort. The physics department had the ultimate weapon, a computer algorithm that compares all laboratory reports, past and present, sniffing out any evidence of plagiarism. Still, some students, several percent, take their chance, copy old reports, and test the power of the algorithm. When the evening ended, I thought that we had become part of the problem. Rather than focusing on how lab reports are graded, we had missed the perfect opportunity to discuss the role of teamwork and collaboration in modern science.

Collaborations consisting of large, multidisciplinary teams of scientists and engineers have become a hallmark of modern science. Complex scientific problems, such as the causes and impacts of climate change, require teams that can bring a wide variety of skills, experience, and perspectives to bear on these grand issues. Increasingly, funding agencies stimulate these collaborations with investments in centers and institutes rather than in individual principal investigators. The Intergovernmental Panel on Climate Change called on over 1200 lead and contributing authors over six years to create their three-volume 4^{th} assessment report. The IPCC is, perhaps, an unusual example, but the trend towards increased collaboration is science-wide and most evident in "big" science. A single paper describing the ATLAS detector for the Large Hadron Collider at CERN weighed in at 3522 authors (13 pages were required to list all of the authors). Other joint efforts, such as the sequencing of genomes, require hundreds of authors: 468 for the mouse (*Nature*, 2002, 420: 520-560) and 338 for rice (*Science*, 2002, 296: 79-92). Large-scale medical trials, galactic-scale surveys, and planetary exploration typically require from 50 to 900 authors. Based on ISI statistics (see *ScienceWatch*, 2004, July/August), there was a steep increase in the early 1990s in the number of papers in the physical sciences with fifty to one hundred authors. In 1990, the mean number of authors was 2.6, and in 2003, it was 3.6. During that same period the number of single-author papers declined from 38% to 25%. *Nature* reports that during the first nine months of 2008, there were only six single-author papers among some 700 reports (*Nature*, 455: 720-723). On a smaller scale are papers with fewer than 50 authors, and for these papers one might imagine that all of the authors have at least met. In the geosciences, the number of authors is usually at this scale: 52 for deep-sea ocean drilling (*Science*, 2006, 312: 1016-1020) and 33 for water on Mars (*Science*, 2007, 317: 1706-1709), to give just two examples.

What is one to make of the growing number of authors on each paper? How many authors does it take to write a paper? What "credit" should each receive from the collective effort? On the positive side of the ledger, which greatly outweighs the negative, this trend represents the best effort of scientists grappling with increasingly complex problems that require the collective skills of many. With the proliferation of advanced analytical techniques and increasingly sophisticated computational methods, it is the exceptional scientist who has all of the equipment or intellectual skills required to address even relatively "small" scientific questions. There are, however, negatives, such as the ill-named concept of "honorary" authorship (there is no honor in honorary authorship) and the difficulty of determining responsibility for error, as well as success. This leaves institutions struggling with the apportionment of "credit" as they conduct their annual reviews—the same problem that professors had in grading laboratory reports. Universities quantify and confuse, using algorithms that count citations, and they apportion credit based on the number of authors (fewer is better) and position in the sequence of authors (first, second, and last seem to be preferred; see *Science*, 2008, 322: 371). I have even listened to a vice-president for research encourage junior faculty to enter into collaborative, high-risk, multidisciplinary research, with the serious assurance that their individual contributions can be extracted from the whole at the time of the tenure decision.

> How many authors does it take to write a paper?

This dissection of teamwork into individual contributions is the antithesis of a good team-building philosophy. In parallel with the growth in team science, we need new rules and measures of success. Here sports provide guidance. Red Auerbach, with his victory cigar, led the Boston Celtics to nine NBA championships as a coach and seven more as general manager and team president. He changed modern basketball by emphasizing team play over the accomplishments of the individual. At a moment when the great center Bill Russell was struggling on court, Auerbach promised him that at the end of the year, during contract negotiations, Auerbach would not count the number of goals scored by Russell, but rather the number of games won by the Celtics. The rest is history. Bill Russell became one of the game's greatest defensive players (21,620 rebounds) but also scored 14,522 career points. Russell finished his career with 11 NBA championships. Wilt Chamberlain, Russell's long-time rival, scored 31,419 points (4^{th} all-time record), but had only two NBA championships. Teamwork prevailed over individual talent. Universities and professional societies with their individual awards and medals are not well suited for recognizing good team science. Individual scientists are rarely credited for their team's success, only their individual contributions. Academic mentors caution against too much collaboration prior to the tenure decision. From a scientist's earliest days as a student writing a laboratory report until tenure, the system discourages collaboration.

There must be a better way. Rather than insisting on separate laboratory reports, the evening's discussion of scientific integrity might have been an opportunity to discuss the obligations and benefits of being a team member (see "Group Theory," *Nature*, 2008, 455: 720-723). The students could have grappled with the common problem of the "weak" team member, and they could have argued over the sequence of authors on the lab report. Such discussion would inform our own perspectives of what it means to be a coauthor. Some journals, like *Nature*, require a clear statement of the contribution of each author as part of the publication process. This is a first step, but a step still focused on the individual contribution—not the impact or importance of the team.

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