
FROM THE EDITOR

The five research C's

It is naïve to think that successful research, like any lifelong academic pursuit, can be reduced to a pithy, simplistic formula. Yet, after years of attempting to get it right and with still much to learn, it strikes me that successful research is comprised of certain indispensable elements. Based on considerable personal experience and reflection, I humbly offer the “Five Research C's”; their intent is to provide a framework for novice and expert investigators alike, to contemplate some of the basic constituents of empirical research.

Curiosity: Without curiosity, there is no research; it's as simple as that. Questions are the essence of research, and it takes curiosity to generate those all-important questions. There is nothing more coveted by researchers than questions that intrigue, questions that generate intellectual excitement, questions that grab hold and simply will not let go. Questions such as these make looking for answers worthy of immense effort. The person whose curiosity elicits questions of this caliber brings the most precious of commodities to the research endeavor. The questions and methods used to answer them need not be elaborate. But questions, even straightforward, seemingly simple questions, can make for very fine research.

As a rather wonderful case in point, sometime in the early 1880s, one of the early “microbe hunters,” Robert Koch, noticed several different colored droplets scattered on the surface of a half, boiled potato that had been left on a table in his laboratory.¹ Could each of these droplets represent pure colonies of one species of germs? That observation, and the ability to couple it with an astute question, was a giant, revolutionary step forward in mankind's fight against microbial diseases. As with Koch, research

begins with questions whose answers are unknown. The capacity to pose good questions requires an awareness of what is, or might be, relevant, where information is limited and where the knowledge envelope might be pushed forward. Indeed, good clinicians are often well positioned to pose relevant and astute questions. Whatever the source, research begins with curiosity.

Creativity: Asking a good question is one thing, but determining how to arrive at a solid answer is quite another. This is where creativity is utterly indispensable. Feeling preoccupied with research—imaging how things work, how to obtain evidence that examines specific hypotheses, anticipating how to overcome obstacles (intellectual, methodological, systemic, and/or financial)—is not so much a hazard of the trade but, rather, a necessity. In spite of occasions that may feel onerous, it is the creative process that entices and invigorates researchers most. Although there will always be contingencies that threaten success, imagination usually sets the ceiling of research achievement.

One needs to be creative to devise experimental approaches that are ethical, feasible, rational, and nonmisleading. Sometimes, researchers are fortunate enough to be able to rely upon, or adapt, previously proven methods. In other instances, it is far less straightforward. Take, for instance, Thonius Philips van Leeuwenhoek, commonly known as the Father of Microbiology. Sometime in the mid-17th century, this Dutch scientist found himself curious about the nature of things that could not be seen by the human eye. First, however, he needed to perfect the workings of the microscope. With ingenuity, determination, and years of plain hard work, he was finally able to observe and describe—for the first time in recorded history—single-celled organisms, microscopic muscle fibers, bacteria, spermatozoa, and blood flow in capillaries.

Not every methodological challenge is quite as daunting as the one Leeuwenhoek faced, and not every challenge need be faced alone. Modern research and researchers often rely on collaboration. It is important, particularly for novice researchers, to understand that it is perfectly reasonable to look

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¹All the examples in this article are taken from Paul de Kruif's best-selling *Microbe Hunters* (Harcourt, Brace, 1926/1996). They are wonderful historic vignettes that readers will find illustrative and entertaining.

outside of themselves for expertise and the benefits of “collective creativity.” Putting together a team (based on trust, along with personal and intellectual compatibility) requires creativity, humility, and good judgment. But whether surrounded by others or isolated within their own thoughts, researchers will find creativity indispensable.

Cash-In: Conducting research requires the investment of resources, and the “C” for *cash-in* highlights this stage of the research trajectory. *Cash-in* refers to the outlay of intellectual energy, human resources, or money—and in most instances, all three—needed to proceed with launching a study or program of research. Good ideas and even solid, creative methods do not ensure success without some “sweat equity.” In this day and age, researchers spend much of their time writing applications, attempting to convince granting agencies that their particular study is worthy of funding. Although this may not always seem like the most efficient or, dare I say, pleasant way of distributing research funding, it does ensure that certain principles—such as peer review and a commitment to fairness and excellence—guide whose work is supported.

The need for research funds is by no means a new phenomenon in science. Take the case of Louis Pasteur. Shortly after developing his rabies vaccine, 19 Russian peasants from Smolensk were attacked by a rabid wolf. Upon their arrival in Paris, Pasteur himself provided them treatment, while their countrymen watched and waited. Of the 19, 3 died while the other 16 survived. Pasteur was hailed as a hero. As a show of gratitude, the Tsar of All Russias sent him the cross of Ste. Anne and a hundred thousand francs to start a laboratory, today known as the Institut Pasteur. (We now know that fewer than 1 in 100 people bitten by a rabid animal are likely to get infected, making it easy to speculate that several, if not all, of the deaths among the 19 were as a result of Pasteur’s vaccination; www.whale.to/v/ruesch.html).

Doing research calls for investment. Throughout the ordeal of treating the peasants of Smolensk, Pasteur reportedly could neither eat nor sleep. For most researchers, thoughts regarding study ideas and ways of supporting them—although occasionally disruptive to sleep—are among the first they encounter upon awakening and the last they contemplate before drifting off at night. Although dreams of a benevolent Tsar may be anachronistic, how to sustain one’s work is a preoccupation among researchers as old as science itself.

Collection: Having posed the question, devised the methods, and obtained the necessary resources, researchers then move into a *collection* phase: that is, a time of obtaining whatever information is needed

to arrive at some answers. This can be a long and arduous process and requires attention to detail, along with patience and commitment. Take the story of Elie Metchnikoff. Metchnikoff was born in southern Russia in 1845 and is best remembered for his early contributions to human immunity. He was, in fact, awarded the Nobel Prize in 1908 for his novel idea that phagocytes fight off disease by engulfing and destroying harmful bodies such as bacteria. He conducted endless experiments over the course of his career. His dedication, commitment, and willingness to take risks in collecting data knew few bounds. Using his laboratory workers as human guinea pigs, he would feed them various bacteria to prove their immunity—or not. He himself is said to have swallowed more cholera bacilli than any of them.

The readership of *P&SC* might want to take note that in his later life, Metchnikoff began to ruminate about aging and death. Turning his scientific energy toward both, he was the first to coin the terms *gerontology* and *thanatology*. Based on fewer facts than inclination, he decided that certain bacilli within the large intestine caused “auto-intoxication,” which he believed could lead to hardening of the arteries and aging. To prove his point, for nearly 20 years, he drank sour milk, which he believed contained Bulgarian bacillus capable of “chasing” wild poisonous bacilli out of the intestine. He continued to test his various juices and excretions until his death at the age of 71.

Collection, that is, the gathering of research data, takes time, attention to detail, and essentially defines the “long haul” of the research process. Although it is rarely glamorous and very few days arrive at earth-shattering epiphanies, it is the care and integrity that mark this *collection* phase, which determines the solidity of whatever outcome the research might yield.

Cash-Out: As the name implies, *cash-out* is the culmination of the Five Research C’s framework. To be explicit, *cash-out* consists of determining what the research has shown and making those results known. Research describes a process of knowledge generation, and without *cash-out*, for all intents and purposes, there is no new knowledge. The early microbe hunters knew this, and they took the task of *cash-out* seriously. Over the course of nearly 50 years, Anton Van Leeuwenhoek wrote over 500 letters to the Royal Society, reporting until within days of death his studies and observations of various living and nonliving things; “whenever I found out anything remarkable, I have thought it my duty to put down my discovery on paper, so that all ingenious people might be informed thereof.” (Leeuwenhoek Letter of June 12, 1716). Robert Koch, the meticulous and stolid German doctor who discovered anthrax

bacilli, tuberculous bacilli, and cholera vibrio, presented his initial findings to scientists at the University of Breslau and, later, to the famous Professor Virchow and the Physiological Society at the University of Berlin; his findings rocked the scientific world and paved the way for the future of bacteriology. Louis Pasteur raised the notion of *cash-out* to an art form. Never one to shy away from attention, each of his discoveries was followed by a wish “to tell the world . . . the searcher in him changed into a showman, an exhibitor of stupendous surprises, a missionary in the cause of microbes. The world must know and the people of the world must gasp at this astounding news” (p. 69).

Cashing-out is as critical to research as performance is to music. If profound effort, practice, and creativity amount to little more than silence, the exercise is rather meaningless. Knowledge is meant to be shared, and data that sit idle in a drawer serve no one. Researchers have an obligation to themselves, their colleagues, their funders, and those they study to determine what they have learned and they must have the courage to follow where their data lead them. They have a similar obligation to make their findings known within a forum—most typically, a peer-reviewed publication—that safeguards integrity and excellence.

A final benefit of *cash-out* is that it perpetuates the research process. Determining what has been learned provides an important opportunity to ask

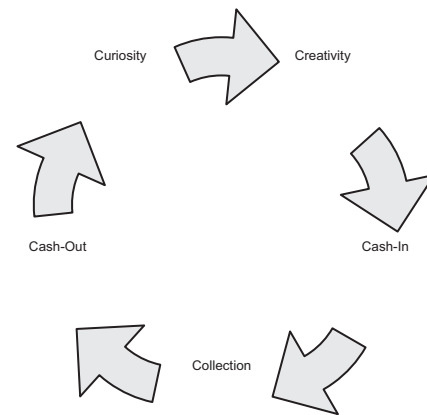


Fig. 1. The Five Research C's.

more questions. At the end of a study, researchers are almost always in a strategically better place—in view of what they now know—to reflect on where they need to go next. And so, with *curiosity* once again aroused, the Five Research C's will have come full circle (Figure 1). Once having entered this intriguing, exhilarating, and perpetual cycle of questions and discovery, researchers are rarely, if ever, inclined to take their leave.

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