such threats. The course that emerging technologies—nanotechnology, biotechnology, robotics, and more—will take in coming years is uncertain. What is certain, however, is that the future of government and the future of technology are inseparably linked.

See also **Government and Science**

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GRASSROOTS SCIENCE.

Grassroots science is science done by people outside the mainstream of professional science. Grassroots science includes research by amateurs and lay people as well as some dissident work by professional scientists.

Science—both professional and grassroots—involves the creation and use of systematic knowledge, using standard procedures, within a community of practitioners, involving both theory and experiment. Scientific knowledge is public knowledge, within the practitioner group and often beyond, thereby excluding some proprietary knowledge generated within corporations and some secret knowledge generated within intelligence agencies.

Professional science, in addition to these general features, is built around practitioners who have extensive formal training and work full-time as scientists. Professional science also often involves use of expensive equipment. Editors, referees, and prestigious scientists defend the boundaries of professional science, imposing definitions of what is and what is not science. Orthodox science is not as open to new or outside ideas as many people think.

Grassroots science, in contrast, is done by amateurs or by professionals separately from their main paid work, and it usually involves much less expensive equipment. Some people become grassroots scientists because they love to learn about nature but have no opportunity or no desire to undertake a professional career in science. Others want to challenge orthodox theories. Yet others believe that professional science is biased toward corporate and government priorities and that grassroots science provides a way to truths that are otherwise ignored or obscured by vested interests.

The boundaries between grassroots and professional science are blurry and changeable, and so are the boundaries between science and nonscience.

Amateur Science

There is a thriving community of amateur astronomers, ranging from beginners who look at stars and planets with small telescopes to experienced observers who systematically seek to observe new objects in space. There seems to be a de facto division of labor, with professional astronomers mainly using massive instruments to look into deep space, such as faraway galaxies, and amateurs using smaller instruments to look at planets, moons, comets, variable stars, and other more accessible phenomena. Because there are so few professional astronomers and so many possible astronomical objects to observe, amateurs can make important contributions, especially now with the availability of cheap powerful computers, the Internet, and lower-cost high-tech telescopes and other instruments. Unlike most sciences, astronomy does not involve experimentation. Amateurs are also prominent in botany and zoology, other fields where observation, either directly or using low-cost instruments, retains a central importance.

The primary differences between amateur and professional astronomy are that the latter involves formal training, full-time paid work, and expensive equipment. The two groups largely agree on the goals and methods of science. The sophistication of new tools used by amateurs is making many professionals appreciate their contributions. Amateurs sometimes can support professional scientific endeavors by providing labor or resources, such as computer users who contribute spare computing power to the Search for Extraterrestrial Intelligence (SETI).

Ufology is the study of unidentified flying objects (UFOs). Mainstream scientists mostly reject the view that UFOs are manifestations of alien intelligence, and the whole field of ufology is often dismissed as pseudoscience. Although a few professionals are involved with ufology, the field is dominated by amateurs, with a thriving community of magazines, meetings, and communication networks. Ufology is thus a facet of grassroots science that is stigmatized by mainstream science. Mainstream scientists take various actions to ensure that their own work is kept separate from ufology, such as preventing UFO research from being published in mainstream journals. This process of distinguishing and separating mainstream science from what is labeled pseudoscience is called *boundary work.*

Independent inventors could be called grassroots technologists. James Lovelock, who made many important scientific contri-

butions and developed the Gaia hypothesis, was a home-based inventor. Independent inventors typically work alone; many of them make a living from other activities. Computer hackers—in the original sense of building or modifying computers and software—are another species of grassroots technologist.

Much of science conducted before World War II was small in scale. Through the 1800s, amateurs played a major role in science. So it might be said that until the twentieth century, most science was grassroots science in that it was less dependent on governments, large corporations, or universities.

Amateur astronomy and independent invention can be highly sophisticated. These forms of grassroots science and technology are not easy or obvious for most people. Just as some members of amateur theater groups can be of professional caliber but not receive any payment, some grassroots science can be of professional standard but be undertaken out of pure interest.

Dissident Science

Dissent is central to science: the formulation of new ideas and the discovery of new evidence is the driving force behind scientific advance. At the same time, certain theories, methods, and ways of approaching the world—often called paradigms—are treated as sacrosanct within the professional scientific community. Those who persist in challenging paradigms may be treated not as legitimate scientists but as renegades or outcasts. Some of these dissidents could be said to be doing grassroots science because they operate outside the normal system of training, employment, and major equipment.

For example, there are many individuals who have developed challenges and alternatives to relativity, quantum mechanics, and the theory of evolution, three theories central to modern science. Some of these are amateurs who have jobs outside of science. Others are professional scientists who have degrees, publications, and honors but who undertake their dissident work as an adjunct to their mainstream careers. These dissident individuals, though they may espouse incompatible theories, are brought together through meetings, networks, and organizations such as the Natural Philosophy Alliance.

Linus Pauling is an example of a professional scientist who became a dissident: He won a Nobel Prize in chemistry but later developed unconventional ideas about vitamin C and cancer, in an area in which he had no formal training.

Dissident scientists usually agree with mainstream scientists about the aims of science—namely, the advancement of knowledge—and about the methods of science—namely, critical examination of theory and evidence—but disagree about what theories are correct.

Mainstream scientists sometimes ignore dissidents, sometimes attack them, and sometimes seek to incorporate their ideas into the mainstream. Cold fusion—nuclear fusion at room temperature—started out as a dramatic challenge to orthodoxy by established scientists. When initial results could not be widely reproduced, cold fusion research was attacked and then forgotten. In the aftermath of the original attention, many scientists continue to explore cold fusion, some with funding from corporations, but their findings are ignored by the mainstream. Cold fusion has elements of grassroots science, though professionals play a significant role in it.

Acupuncture is a method of healing long used in China as part of a non-Western understanding of the body. Traditional Chinese acupuncturists were often full-time healers, but the practice itself is inexpensive, so it can be said to be a form of grassroots medicine. Western medical authorities at first rejected acupuncture as unscientific but, following demonstrations of its effectiveness, eventually accepted or tolerated it as a practice under the canons of Western biomedicine, rejecting its associations with non-Western concepts of the body. Acupuncture thus is an example of grassroots science that has been incorporated into Western professional practice, in part severing its links with the grassroots. A similar process has occurred with some other parts of complementary medicine such as meditation.

Science and Social Movements

A social movement involves many people acting in concert to create a preferred image of society; familiar examples are the environmental, peace, and feminist movements. Social movements typically have a core of activists (professionals, volunteers, or both), a wider group of occasional participants, and a still wider group of passive supporters. Social movements can contain great internal diversity but agree about general goals. Social movements are natural homes to grassroots science, especially when a movement challenges an establishment that has the backing of professional science.

The Alternative Health Movement. The alternative health movement emphasizes prevention and, for dealing with disease, concentrates on nutrition and natural products and methods. The alternative health movement includes many trained professional practitioners but also encourages popular learning and self-help, whereas conventional medicine, in contrast, emphasizes cure through intervention by medical professionals.

Many individuals make observations about their own health and the health of family and friends, noting that a certain food, herb, or method of behavior has beneficial effects. When these observations are shared with others, some become widely adopted, becoming "folk medicine."

Some proponents of alternative health keep a close eye on conventional medical research findings, noting those that are relevant to nutritional healing and other movement interests. Participants in the movement sometimes recommend to mainstream researchers that they test particular substances or methods. Thus there can be a mutually supportive relationship between the movement and portions of mainstream medical research.

At the same time, some mainstream medical practitioners and researchers are hostile to alternative health. This is apparent in pronouncements that taking vitamin supplements is a waste of money or in police raids on alternative cancer therapists, the raids being encouraged by mainstream opponents.

Many proponents of alternative health say that mainstream medical science is distorted by corporate, government, and professional pressures. In this context, grassroots medical science presents itself as being truer to the ethos of science as a search for truth unsullied by vested interests.

The Feminist Movement in Medicine. The feminist movement has also developed a grassroots challenge to orthodox medicine, which the movement sees as patriarchal, both dominated by men and oriented to male concerns. Reproduction has been a key area of contention, with mainstream (or "malestream") medicine alleged to have medicalized reproduction through contraceptives and Caesarean sections, ignoring the practical knowledge that women have of the operation of their own bodies.

With the second wave of the feminist movement beginning in the 1960s, women's personal knowledge was collected and circulated by feminist collectives, most famously the Boston Women's Health Book Collective. Movement activists thus served to codify the knowledge of individual women, also drawing on mainstream research, some of it by researchers sympathetic to the movement.

One practice promoted by the women's health movement has been breastfeeding, which went into decline in many industrialized countries through pressure by medical authorities for rigid weight gain targets linked to a bottle-fed norm. Breastfeeding advocates have developed great understanding of what is needed to make breastfeeding successful (for example, how to deal with cracked nipples) and promoted this alternative model to both new mothers and medical professionals. Grassroots science in this instance involves development of knowledge about breastfeeding in a community of practitioners who are in an ongoing challenge to mainstream practice.

AIDS Activism. From the time AIDS first became recognized as a disease in 1981, it was apparent that gay men were prime targets. By that time, the gay movement was

well organized in many western countries. Gay men's health activists learned as much as they could about AIDS, studying virology, immunology, epidemiology, and other specialized fields relevant to the disease. As well as drawing on conventional biomedical science, AIDS activists also knew a great amount about the behavior of gay men, knowledge they could use to recommend interventions against the spread of AIDS. AIDS activists thus combined their knowledge of sophisticated professional science with grassroots behavioral knowledge.

Some activists intervened in orthodox medical policy making, influencing the design of trials of potential AIDS drugs and pushing for speedier release of drugs, thus becoming de facto adjuncts of mainstream biomedicine—a case of grassroots science being partially incorporated in professional science. Other AIDS activists have taken a more alternative route, investigating substances such as dinitrochlorobenzene (DNCB)—of little interest to pharmaceutical companies because it is not patentable—and distributing them via so-called guerrilla clinics.

Community Epidemiology. In the 1970s in Japan, *minamata* disease was causing devastation in some communities. Teams of community volunteers, aided by sympathetic scientists, used simple techniques, including interviewing members of local communities, to track down the source of the disease, which was poisoning by mercury pollution from industry. They did this more effectively than well-funded teams of professional scientists using sophisticated methods for analyzing samples and running computer models.

Since then, there has been a considerable expansion of community research, especially in the United States, with much of the work being done in environmental and health areas, where mainstream research is often influenced by corporate and government agendas. In terms of doing good science, community research follows the model of conventional scientific research, but there are several differences. Community researchers are usually unpaid, often without formal research training. They pick topics relevant to local community concerns, often challenging corporate or government agendas. They largely communicate with their local communities and other community researchers, not necessarily seeking publication in conventional scientific journals.

In professional epidemiology—the study of the incidence and transmission of disease—researchers may dismiss anecdotal evidence as unworthy of attention (sometimes in a selective fashion that may or may not be related to its relevance to corporate sponsors). In popular epidemiology, in contrast, the same anecdotal evidence can provide the inspiration for a more detailed investigation.

The Appropriate Technology Movement. The appropriate technology movement pursues development and use of technology that is appropriate to people's needs, especially poor people in poor countries. It includes organic gardening, biogas generators, inexpensive water filtration techniques, passive solar design, and a host of other technologies and techniques that can be locally used and controlled. Many of the developers and promoters of such technology are grassroots technologists.

The Free Software Movement. Free software (which may or may not be distributed free of charge) is open source (the code is openly available for inspection) and is licensed so that it cannot be turned into proprietary software. In constructing and improving free software, suggestions are taken from anyone who is interested, with a core group making decisions about implementing changes. The most famous free software is the operating system Linux, but there are many other programs.

The free software movement is a type of gift economy, in which participants do not seek financial gain but instead the respect of peers and the satisfaction of contributing to a worthwhile product. Some contributors are computer professionals who help with free software separately from their jobs; others are committed students or amateurs. The movement has begun to expand to other domains; for example, there has been an open-source

cola with the ingredients listed on each can, and the recipe posted on the Internet.

The free software movement has several similarities to grassroots science. Both harness tremendous voluntary efforts by participants through the satisfaction of contributing to a collective enterprise, and both contribute to alternative knowledge or products that challenge professional systems.

The Scientific Establishment as a Social Movement. Professional science is itself a social movement. There are proselytizers and lobbyists for professional science, necessary to win support for massive expenditures to train and pay scientists and support their research. In the early days of modern science, struggling in the face of hostility from churches and an indifferent public, its social movement characteristics were more obvious. Today, professional science is a social institution, but it still must maintain its struggle for resources and credibility.

Indigenous Knowledge

In order to survive, people in nonindustrial societies must learn a great deal about nature, for example about weather and the seasons, edible and medicinal plants, the behavior of animals, and human physical and mental capacities. This sort of indigenous knowledge has characteristics of grassroots science: it is systematic knowledge, publicly available in a community of practitioners, and involves theory and practice. Professional scientists have often ignored indigenous knowledge or dismissed it as unscientific because practitioners do not follow the scientific method and because the knowledge itself, for example interpreting disease as caused by spirits that need to pacified through rituals, is wrong.

On closer inspection, it is not so easy to dismiss indigenous knowledge as unscientific. First, scientific knowledge is open to revision: Just because knowledge is wrong, according to the judgment of today's scientists, does not mean that it is unscientific. Second, what is called "the scientific method" is, on closer inspection, more variable and situation-specific than commonly imagined. Some anthropologists say that the scientific method does not readily distinguish indigenous belief systems from modern science.

In indigenous societies, there are no paid knowledge-makers with access to major resources. If indigenous knowledge is a form of science, it is definitely grassroots science.

There is a similar type of knowledge found in everyday life in industrial and postindustrial societies, which can be called everyday knowledge. Within groups active on certain topics, there is a lot of folk knowledge that is developed, shared, modified, and used for practical activities. Examples include farmers' knowledge of local weather, carpenters' knowledge of materials and construction techniques, bodybuilders' knowledge about drugs, nutrition, and training techniques, and musicians' knowledge about instruments and ways of playing. There are a great many groups in which insider knowledge is cultivated. Some of this knowledge is articulated in handbooks and formal training; sometimes professional scientists take an interest and undertake observations and experiments that recast some of this everyday knowledge in terms of the frameworks of scientific disciplines. But much everyday knowledge remains embedded in the communities that cultivate it. In this sense, very many people are part of grassroots scientific communities.

The Future of Grassroots Science

The label "science" is normally restricted to scientific knowledge that is produced by credentialed professionals using sophisticated, expensive equipment, with other forms of knowledge being relegated to the status of being "unscientific." The idea of grassroots science is a challenge to this conventional image of science.

Grassroots science, in its clearest forms, is similar to professional science in creating systematic public knowledge through standard methods in a community of practitioners. The key difference is that grassroots science is far less dependent on formal training, professional employment, and expensive equipment.

The trend in the past century has been towards professional science, with the professionals usually ignoring, rejecting, or incorporating grassroots knowledge. Yet there remains interest and capacity, especially among amateurs and social movements, for embedding knowledge making into everyday lives. The future of grassroots science lies in the future of this resistance to the professionalization of every realm of activity.

See also Indigenous Knowledge

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