SCIENCE, SCIENTISTS, AND SOCIETY

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INTRODUCTION

I was stimulated to reflect on my 60 years of teaching, research, and public service in the fields of biological and agricultural science by Irving Rothchild's fascinating article, "Induction, Deduction, and the Scientific Method" [1]. If you have not read the discussion by Dr. Rothchild, please do. It is stimulating. He begins by discussing how induction and deduction provide complementary tools in research. I agree. We use these two processes in our analysis and synthesis of ideas as part of the scientific method.

Rothchild disagreed sharply on this point with Peter Medewar, who believed strongly that deduction has no place in science. Despite this controversial view, Medewar and his Nobel prize-winning colleague, Burnet (inadvertently referred to by Rothchild as MacFarlane), made extraordinary contributions to immunology. The Nobel addresses [2, 3] of both scientists are worth reading. One of the strengths of science is the diversity of approaches used by its thoughtful practitioners.

Rothchild provides a stimulating personal perspective on elements of the scientific method and the attributes of a scientist searching for the truth while dealing with public opinion and conflicts with authority. As I reflect on science, scientists, and society, some of my thoughts mirror, some contrast with, and some are additional to those expressed by Rothchild [1]. The reader may make his or her own comparisons. To each his or her own, as individuals adopt methods in science that mesh with their own principles and modes of operation. Presented here are my perspectives on science in general, with a focus on reproductive biology.

One area of special interest to me, but that is omitted in the discourse presented here, is the debate on evolution versus religion. Rothchild [1] refers to this debate, and many books on the subject are being published. Some are confusing because the author seems lost in details of facts versus beliefs. My opinion is that there should be no debate. Evolution is a fact, but encompasses huge gaps—as exist in every field of science.

As a checklist for training myself and for use in "rump sessions" with research staff, I organized notebooks into sections containing information from various sources and included mimeographed guidelines I had prepared for discussions with graduate students. Table 1 consists of a sample of topics from a notebook focused on mentoring. These topics were interspersed for discussion at appropriate times during our weekly schedule of scientific meetings.

TABLE 1. Educational aids discussed with research staff.

Titles of sections in my notebooks
1. How to manage your time and life.
2. Philosophy of research.
3. Getting the most out of scientific literature.
4. Components of the scientific method.
5. Statistics.
6. Essential characteristics of scientists.
a. Responsibility and accountability.
b. Ethics and integrity.
7. Language and scientific writing.
8. Publication of research.
9. Writing grant proposals.

SCIENCE AND THE SCIENTIFIC METHOD

Science, most would agree, is a systematic study—by observation and experimentation—of the natural world, with the objective of increasing our understanding of the particular area being studied. Science is a search for the truth. As such, it depends on freedom of inquiry and freedom of opinion. This search is never-ending: one may prove that something is wrong, but not that it is right. In experimental design and statistical analysis, one tests the null hypothesis, i.e., that *observed* differences are not *real* differences. One cannot prove the null hypothesis, but probability statements allow for the possibility that it may be disproved. If an experiment is repeated, especially by different groups, with similar rejections of the null hypothesis, we can be quite sure that there are real differences among the specific conditions tested. If no differences result repeatedly, this information helps the investigator focus on other subject areas.

From the foregoing it is clear that science involves both theory and action (or doing things). In the beginning, a theory may be little more than a guess. Then the real work begins. The researcher collects and collates all relevant facts and points of view available from published literature and from his or her own experience. This process helps to determine if the right question is being asked. Eventually, a point is reached where the particular problem to be studied is so clear that it can be narrowly defined, and the particular hypothesis to be studied can be stated succinctly. The hypothesis should suggest a possible experimental design with appropriate sampling, replication, controls, and endpoints. Equally rigorous interpretation of the results, limited to the conditions tested in the experiment, should follow. Finally, in keeping with the basic tenets of science—that is, freedom of inquiry and opinion—the reporting and discussion of the results should be forthright and consistent with the facts.

One must always remember that the conclusions will be only an approximation of the truth. Several years ago, I saw a Sidney Harris cartoon in which scientists were happily discussing a neat equation they had developed to explain their results. Simultaneously, they were depressed by the thought that what they believed was correctly expressed by the equation might be disproved within a few years. This cartoon contains a lesson for all of us. Yes, we should feel joy and comfort that our carefully conducted research probably has helped to push back the boundaries of ignorance. Even a bit of speculation is allowed. The theory may prove to be wrong, but it can stimulate further studies, which then result in the never-ending joy of learning and revising our concepts. Also, discoveries should be sprinkled with a bit of humility.

SCIENTISTS

The principles of the scientific method do not change. However, science and scientists undergo evolution. I firmly believe that scientists are primarily made, not born—other than being born with a privileged brain. While none of us has control over the genes we are born with, each is responsible for controlling how these genes are used. Thus, the senior scientist has a major responsibility in mentoring young people to nurture them, helping each to develop maximally according to his or her capabilities. Graduate students and post-docs should not be hired as slave laborers; conversely, they should be expected to help in the team effort. As these students move on and develop their own careers, they will, in turn, transfer these principles to their students.

To promote this effort by the Society for the Study of Reproduction, I requested that funds contributed to the R.H. Foote Lectureship Fund be used to benefit young scientists. The fund supports the Trainee–Mentor Luncheon at each SSR Annual Meeting. It seems obvious that every senior scientist would place considerable emphasis on mentoring. However, the National Science Foundation recently found it necessary to notify their grantees that this was one of their responsibilities.

So what are desirable characteristics for scientists to foster? The late Dr. Noland VanDemark, former President of SSR, discussed multiple mental traits and attitudes that are helpful to cultivate in becoming an excellent scientist (Table 2) [4]. This table is not a mandate, but a checklist for self-improvement.

TABLE 2. Some generally desirable mental qualities, traits, and characteristics of the potential "whole person" scientist.

	Attitude		
Capability	General qualities	Toward self	Toward others
Intellectually sharp	Motivated	Self-accepting	Respectful
A rapid learner	Ambitious	Self-loving	Tolerant
Capable of good recall	Industrious	Self-respectful	Trusting
Able to concentrate	Dedicated	Self-developing	Communicative
Willing to think	Courageous	Self-disciplined	Team-spirited
Able to associate the unusual	Perseverant	Self-challenging	Cooperative
Perceptive	Truth-seeking	Self-confident	Competitive
Imaginative	Freedom-loving	Insightful	Responsible
Creative	Optimistic	Self-assertive	Flexible
Curious	Honest	Self-reliant	Sensitive
Intuitive	Aware	Self-sustaining	Considerate
Flexible	Prompt	Self-renewing	Caring
Critical	Willing to risk	Self-evaluative	Sharing
Judicious	Venturesome		Loving
	Humble		
	Fun-loving		
	Patient		

Integration of many traits in Table 2 is important. Knowledge is not simply an accumulation of facts, although correct memory of facts is important. Electronic retrieval has greatly facilitated access to an enormous array of facts. This has partly replaced the huge effort made by my generation in building personal libraries. The plus side of that laborious effort was that the handwork provided time for simultaneous headwork to do some ingenious thinking while storing that information. This need has not changed. Has it been partially lost if one succumbs to the power of our digital network? Every scientist should be careful to resist the temptation to spew out bits of data in this world of intense competition before there has been thought of how best to integrate these bits into the existing framework of knowledge. Piles of junk pollute, while streams of knowledge never run dry. So Table 2 is simply a checklist. Look it over. No one is perfect, but the largest room in the world is the room for improvement.

About the time that VanDemark's paper appeared, I was finishing my years of service on the Reproductive Biology Study Section of NIH. I was impressed during that time by how dedicated, perceptive, objective, and constructively critical the members of this panel were in attempting to provide an accurate merit appraisal in giving every grant applicant an opportunity to compete for the limited funds available. Of course, no panel is infallible. It was hard work.

After a very strenuous day of reviewing grants, the panelists relaxed at dinner to be ready for the next day. Part of relaxation is provided by humor, and such was the case then. After the last day of the last meeting of the last year of service for several of us, we again met for dinner. Before dinner I scribbled a poem that reflected the points we debated seriously at every review, but were incorporated into the poem in a humorous way. It follows as read at the final dinner.

Pros(E) and Poetry Reflections
by a Recent Member
of the Reproductive Biology Study Section
(June 5, 1979)

Prelude to Service

I wonder if I might be allowed a reflection
Of how one gets to Washington without an election.
'Tis that telephone call with words of affection
That lures one to serve on the study section.

Postlude on "The Warren Reports"

One soon learns to write a lengthy description
That will lead to some kind of doctor's prescription.
Next comes that all-comprehensive critique.
A summary of strengths and points that are weak.

Are the preliminary data "My-T-Fine"?
Have future plans jelled in a super design?
Is the fertility application well-conceived?
Are the specific aims likely to be achieved?
Are all possible pitfalls clearly perceived?

Are the investigators all uniquely trained?
Is the role of collaborators clearly explained?
What about facilities at the P.I.'s place?
A setup for humans, or the usual rat race?

And then we come to the budget "affair".
Do you slice a diamond knife or an office chair?
About one special item you guys should be wary.
Don't fool around and take out the secretary.

Finally, we assign the magical priority score.
With infinite wisdom(?) we've finished our chore.
So, my very best wishes to all you good sports
As you struggle next year with the "Warren Reports."

Two things I should clarify relative to content of this poem. One is that Dr. James Warren chaired our Study Section, and he was continuing for another year. The second is that we were conscientious (perhaps overly ambitious) in reducing possibly inflated budgets with the hope that more grants could be funded. Frequently we thought that a position for a secretary, although needed, probably was filled already at the institution, and the money likely would be used to hire another technician. A few applicants informed us by telephone, using a voice that needed no telephone, that we were wrong. So the poem refers to "take out" what in our discussions was "cut out the position for a secretary." More could be said about writing grants, but any grant applicant should be aware that all the components in this poem are part of the critical process of grant review. Those applicants whose grants ranked the highest were the recipients of taxpayers' dollars.

One component of an excellent grant application (not included in the poem) that enhances the likelihood of approval for funding, is the track record of the principal investigator. Generating a consistent stream of excellent papers from research previously supported generates enthusiasm among reviewers that the current proposal also will produce useful information that will be shared.

Writing research papers is valuable beyond adding to an investigator's C.V. It sharpens one's ability to think and write clearly, precisely and concisely, while including all the essential points. Constructive criticism by reviewers provides another opportunity for self improvement. Oral presentations also improve the scientist's ability to communicate ideas and facts to peers and to the public. An experienced speaker conveys his or her message by combining clear articulation, enthusiasm, positive facial expressions, and general body language. Presentations should be objective and not laced with anecdotes. I do remember chuckling at a directory sign at an andrology meeting that read "Posters on the testis and related subjects are in the ballroom."

Looking at Table 2 one more time, we note that the listed traits include several desirable personal characteristics as well as those important to pursue science at a high technical level. For example, a true mentor will be sensitive to the needs of others, recognizing both individual and group effort as one key to success. When an experiment appears to have failed do not blame others. Be positive. Examine why the experiment failed. No experiment is a failure if one learns something. While writing this paper I saw an article in Science [5] titled "Lessons from a Failed Drug Trial." How much more useful was this article than if it simply had been an account of "A Failed Drug Trial." Yes, benefiting from failures and serendipity [6] has led to new discoveries.

An example of the importance of sharing the credit is given in Dr. D.G. Ingle's presidential address at the 1960 meeting of the Endocrine Society [7]. This cleverly written fable describes how the "great Professor Suopmop" reported at a scientific meeting a discovery made independently by one of his postdoctoral fellows, Percy Diorets. Although Percy was mentioned, the professor gained the glory. Eventually, Percy rose through the ranks at another institution, and the situation was reversed. A discovery by a brilliant young postdoctoral fellow in Professor Diorets' laboratory was reported by and credited to Professor Diorets, while the assistant "was very hurt by the lack of recognition." The story is fictitious, but the parallels to occurrences in the scientific community are real. Some laboratory directors place their name first on almost all publications originating from their laboratory. I do not believe this is ethical nor is it the way to help build whole scientists.

Ethics and Integrity

Ethics and integrity are not specifically listed in Table 2. Several components of these traits, "honest" and "responsible," are included. To these traits I would add accountability (Table 1) and moral judgment. The world is full of smart people, but some have questionable ethics and integrity. I believe that it is most important for a scientist to have unquestionable ethics and integrity, and infuse these traits by example into his or her research group and students. Ethics and science should be combined and bound as hydrogen and oxygen are bound closely to form the very useful molecule, H_2O. Separately hydrogen and oxygen function very differently. Ethical values are not absolute. What is right for the group versus best for the individual may be difficult to determine, but we should consider both aspects.

One should have ethical concerns for animals used in research as well as for people. Much of our biological information stems from research on experimental animals. An example of ethical concerns relative to cloning studies, gleaned from many sources, was summarized by Foote [8] as follows:

"The major ethical concerns are 1) that the objectives of these biotechnologies be used to produce superior or especially useful animals, 2) that each animal produced will not itself be at risk, 3) that if some animals produced are at risk, they will be properly cared for, 4) that the impact of these rapid changes on social and economic well-being of the human population will be addressed and 5) that the genetic base (gene pool) of any species of animal being selectively propagated be preserved to provide future opportunities for maintaining species and producing individuals most compatible with changing environments."

Clearly the humane treatment of animals is of ethical and moral concern; who can predict accurately what the impact on society might be in the future? However, it should be considered.

The use of money by researchers also has an ethical and moral component. Is the money requested for an experiment used for that experiment, or an improved modification? A careful and extensive review of the literature and use of variances from previous experiments to plan optimal numbers of replicates for the most efficient experiment are ethical components of the scientific method.

Requesting money for real needs and spending it for allotted purposes also depends upon integrity and moral values. After all, someone else's money is being spent, and scientists have an obligation to use it wisely. The final payoff is accurate publication of the results. The greatest ethical-moral obligations of a scientist involve interactions with society. Reflections on this complex subject follow.

SCIENTISTS AND SOCIETY

Ethics and Moral Values

When I started my career, there was little mention of ethics and moral values in the scientific literature. These were topics for discussion in the philosophy department. Strange, isn't it, that many of us have a Doctor of Philosophy degree (Ph.D.), yet how many of us took courses in a philosophy department? Fortunately, I was interested in exposure to scientific advances peripheral to reproductive biology and in thought-provoking articles on science and society that appeared in Science, American Scientist, New York Academy of Sciences Magazine, and the Phi Kappa Phi Journal. I became a life member in each society publishing these journals. Examples of copies of papers in my notebook relating to Table 2 include Pigman and Carmichael [9], Monson [10], Glass [11], and especially Callahan [12] in Lappé and Morrison [13], as I was exposed regularly to these journal articles.

The past 60 years has seen startling technological advances in agriculture, medicine, engineering, etc. The creative ability to improve our lives also has provided the capability of undermining our environment and destroying life. Thus we must continuously ask the question "Just because we can do it, should we?" This is a major question facing scientists, industrialists, government leaders, and society in general. In 1990, the American Association for the Advancement of Science prepared a questionnaire with 57 items listed, and asked its members to choose the most urgent ones to consider. The top choice was the discussion and development of a set of ethical principles. Since that time, articles on science and ethics have appeared frequently [14, 15].

Society depends increasingly on scientists for advice. Once we have thoughtfully considered the science and ethics in our field, we need to speak out. Jackson [14] states that "We must address the ethics of the application of science in key areas and how it ties into people's core beliefs is a two-way street that needs to be traveled more frequently." Most of us were not trained to deal with the public, but with time most of us gain some experience in that arena. We must mentor our students to get involved where their expertise is needed. The next generation deserves this.

TEACHING

Most researchers in academia have formal responsibilities for teaching undergraduate and/or graduate students. Helping others to learn (teaching) is a very honorable profession. Teaching provides the joyously rewarding experience of stimulating young minds to be critical thinkers as they yearn to learn. Nothing is more important in keeping a brain active than the desire to know.

There have been hundreds of papers and books on good teachers and good teaching. Only one example will be listed here. It was one of several that caught my eye when I assumed a major responsibility for teaching. The concepts expressed by Payne [16] I found to be consistent with my own experience over several decades.

Characteristics listed in Table 2 generally apply to teachers who are good at that art. A skilled researcher will be knowledgeable, critical of the material and ideas with which to challenge students, and experienced in communication. A great advantage of a teacher who also is a researcher is the obvious excitement that should carry over from research to teaching in one's general area of expertise. Enthusiasm is a major force in stimulating students to want to learn. However, a precautionary bit of advice from an old teacher to a new one: it is important to recognize the diversity of interests of your students and, in beginning courses, to recognize the need to provide balance in treating various components without overburdening students with advanced concepts that relate to the mysteries of one's own research. These more complex concepts can be shared with advanced undergraduates who elect to work on research projects in your laboratory as well as with your graduate and postdoctoral students.

Sprinkling in a bit of appropriate humor also is relaxing and facilitates learning. This approach was relatively easy to accomplish in a large undergraduate course in comparative domestic animal reproduction, called "Barnyard Sex" by the students. To relax students on an examination, I included an introductory, ungraded question in the true-false section. Two examples are "The uterine horn is an ancient musical instrument," and "The song the 'Lost Chord' was written as a protest of castration."

When I was hired to teach as well as do research, I received a very useful bit of advice: "You learn to teach as you teach to learn." Fortunately, that precept had been part of my graduate experience. My senior mentors, like most senior mentors today, were teaching as well as advising graduate students in research. Teaching in multiple, small undergraduate laboratories, and then finally giving selected lectures to the whole class as a senior graduate student was invaluable experience. Students and staff are generous with valuable feedback, of course, which provides the prospective teacher with an appreciation of individual student needs, and helps cultivate the patience and compassion needed to assist those who have various difficulties in getting off the starting block. Combining this humanistic approach with enthusiastic articulation of integrated facts and concepts enhances the teacher's effectiveness in motivating students to learn. Such students can learn by their own efforts when helped by a bit of guidance.

When I became a tenured professor I was instrumental in establishing specific courses for selected students to gain experience in undergraduate teaching and research. This was a new venture 50 years ago, and it became an integral part of our teaching and research program. This approach provided a new dimension of learning for me as well as new ideas that filtered out to an unstructured network of students through the undergraduate students in these programs. I hope every faculty mentor has a program with similar dimensions to provide for close, symbiotic interactions among all, as we journey together on the highway of learning.

It has been of enormous pleasure to watch young students grow and go on to fantastic careers in many fields. These fields are not limited to research, teaching, or clinical practice related to reproductive biology or production agriculture. I believe that these experiences in making decisions have helped each one—wherever he or she landed—to make wiser choices, thereby helping each individually as well as society as a whole.

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