Chapter

1

INTRODUCTION

Background

Most transportation agencies have either a research organization or a research function. However, staff who perform or supervise research often have no formal training in research; a situation which has been aggravated in some agencies where people without prior research experience have been assigned to lead research programs or conduct research.

Not all research projects are successful, and such will always be the case. If success were certain, then the solution would be known when the work began, and, by definition, the project would not be research. Furthermore, not all individual projects need to be successful for a research organization to thrive, and generate benefits considerably in excess of the cost of the research program. Nevertheless, it is important that all projects have, at the outset, a reasonable expectation of success. At times, research projects have been initiated which had no possibility of solving the original problem. Some efforts, where vast amounts of data were collected over many years before the project was terminated, have been particularly wasteful. Unsuccessful projects can often be traced to a failure to formulate measurable objectives, or specific hypothesis to be tested, coupled with the design of unsuitable experiments, or the selection of an inappropriate research approach.

Recognising the deficiencies in current practice, TRB committee A5001, Conduct of Research, met in Vail, Colorado in July 1994, and held a workshop with the objective of identifying ways of conducting transportation research more effectively. The participants identified the need for a manual, comprising a single, comprehensive source of information for methods of research, project planning, and execution. It was envisaged that the manual would include state-of-the-art techniques for problem statement development; literature searching; development of the research work plan; execution of the experiment; data collection, management, quality control, analysis, and interpretation; reporting of results; and evaluation of the effectiveness of the research, as well as the requirements for the systematic, professional and ethical conduct of transportation research.

Purpose and Scope

The purpose of the manual is to improve the quality of transportation research. The manual presents the principles of scientific enquiry in the context of transportation problems. It has been written for transportation agency personnel, who perform or supervise research, though it will also be useful to people conducting transportation research in other work environments such as universities and consulting. The principal audience for the manual comprises agency personnel with a college or university education, but with no formal training in research.

The manual describes all phases of research activities from identification of research needs, through execution of the research, to evaluation and audit. The scope of the manual has been defined by the activities involved in the conduct of research, rather than the management of research, or technology transfer.

Most transportation agencies do not conduct nor fund basic research, and therefore the manual deals primarily with applied research. Emphasis has also been placed on applied research because this constitutes the dominant research activity of most transportation agencies. Traffic, safety, materials, bridges, pavements, and planning research examples are scattered throughout Volume II. The manual also identifies a "bookshelf" of significant references to be read in conjunction with the manual, and an outline of a training and development course intended to introduce the manual to its principal audience.

Basic Research, Applied Research, and Development

The essential difference between basic and applied research is in the application of the results. Basic research is undertaken to extend knowledge and gain understanding, without concern for its utility. Applied research is original work undertaken to acquire new knowledge with a specific practical application in view. It is undertaken to determine possible uses for the findings of basic research, or to determine new methods or ways of achieving some specific and pre-determined objective.

Further discussion of the attributes of basic and applied research first demands a definition of research itself. According to the Oxford Dictionary research is "careful study and investigation, especially in order to discover new facts or information." The inclusion of the word "careful" is significant because this implies that research is a methodical process and the existence of a scientific method. It is also important to distinguish between information beyond the knowledge of the individual, and information not known to society. When a student says "I have to do some research for my homework tonight so that I can give a presentation in class tomorrow", the word "research" is used correctly because the student must discover information outside his or her current knowledge. However, "research" in this manual is used to mean the extension of knowledge in the global context, as opposed to the education of the individual.

"Development" is usually taken to mean the process which follows research and involves identifying and designing applications of new knowledge. A distinction is sometimes drawn between development, which creates new applications based on new knowledge, and applied research that improves current practice or develops solutions to existing problems. However, applied research may include gaining a better understanding of a problem before a solution can be realized. The distinction is a moot point, and of little practical significance, because most organizations combine research and development activities as a single function.

Basic research involves making observations and developing new ideas that describe the physical, biological or social world more accurately or completely. It usually relies on funding from federal governments or philanthropic foundations. Most basic research is done in universities and government or public research institutes. Some commercial laboratories allocate a portion of the research budget to basic research. This is seen as providing enrichment for staff as well as a long-term investment in the future of the company. New ideas, highly motivated staff and access to modern facilities are keys to success in basic research. It is true that simple, elegant solutions that have eluded other investigators have emerged in unlikely places but, more often, the case is that an old problem is solved because new instrumentation or computing capacity becomes available. This means that the resources needed to support basic research have increased enormously in recent years.

A characteristic of applied research is that it is undertaken in pursuit of objectives, which are linked to the strategic objectives of those funding the research. In the private sector, applied research may extend from a relatively minor improvement in an existing product to the development of an entirely new product line. In either case the cost of the research would be weighed in terms of potential gains in profit and market position. In the case of transportation agencies, applied research projects may range all the way from high risk development of a new piece of equipment to more utilitarian goals of repeating experiments performed elsewhere to investigate the effect of local conditions or materials. In either case the project: should have been requested or approved by management, be considered a good investment, and be consistent with the agency's strategic plan.

The purpose of both Basic and Applied Research, as distinguished from Technology Transfer, is to "extend knowledge and gain understanding". The primary product of research is the distributed research report, which contains new knowledge and understanding. The products that might be used in the process are temporary and expendable. Even technology transfer outputs of a research project, such as prototypes, software, devices, specifications designs, processes, or practices, etc. are either expendable or often have only temporary and limited utility.

There is always the idea of, at least, eventually arriving at something useable. But, it should never present an opportunity for confusion between evaluating manufactured products or materials for the purpose of their acceptance and doing applied research.

While the reality is that the funding of basic research is neither within the mandate nor budget of most transportation agencies, there are risks in pursuing short-term solutions at the expense of a lack of basic understanding. Wilson (1) relates the story of the student who on three consecutive nights drank bourbon and soda, rye and soda, and scotch and soda. On each of the following days his head was sore. The solution being obvious, on the fourth night he eliminated the soda!

A more serious example involves the correlation between the reduced incidence of cancer in populations where the diet includes large quantities of fruits and vegetables. This led to the conclusion that beta-carotene, a common ingredient in fruits and vegetables, was effective in reducing the risk of cancer, and many westerners added beta-carotene to their diet. It has now been shown that while there is an inverse relationship between cancer and eating fruits and vegetables, taking beta-carotene does not reduce the risk of cancer. (A more recent theory is that monoterpenes, a family of substances found in more than 100 fruits and vegetables, may be the key to inducing the body to fight cancer by breaking down a growth factor that cancer cells require to divide).

Many applied research projects involve trying a new technique and observing the result. Other projects involve establishing a relationship between two or more properties. However, the existence of a statistically valid correlation is not the same as establishing cause and effect. Sometimes a basic understanding of the science involved is necessary before substantial progress can be made. For example, an understanding of the structural behavior of bridge decks has permitted a substantial reduction in the amount of reinforcement used in thin slab decks; an understanding of the chemistry of asphalt binders has led to advances in the design of bituminous concrete mixtures.

Transportation Research

Transportation is the act of moving people and goods. Transportation research involves studies pertinent to the understanding, design, and function of transportation systems including

- The planning, design, construction, operation, safety, and maintenance of transportation facilities and their components;
- The economics, financing and administration of transportation facilities and services; and
- The interaction of transportation systems with one another and with the physical, economic, and social environment.

Transportation is a major component of the lives of most people, and a cornerstone of modern society. Its breadth and pervasiveness only become apparent when it is expressed as a sum of its many components.

The simplest subject classification of transportation is by mode:

- highways
- rail
- air
- water, and
- other (e.g. pedestrian, bicycle, pipeline).

The activities listed above apply to each of the modes, such that the complexity of classifying transportation research activities readily becomes apparent. For instance, in 1996 the Transportation Research Board had approximately 175 technical committees (not including task forces, policy committees and coordinating committees) organized under five groups and 21 sections. A complete listing of all the committees is published annually in the TRB Directory, which generally tends to grow in size as the number of transportation specialties and sub-specialties mature with time.

An alternative classification system is that used by TRB to administer the National Cooperative Highway Research Program. It is reproduced to assist state transportation agencies in classifying research activities and monitoring projects included in the NCHRP.

1. Administration:
   - Economics
   - Law
   - Finance
2. Transportation Planning:
   - Forecasting
   - Impact Analysis (Social, Environmental, Economic, Energy)
3. Design:
   - General Design
   - Pavements
   - Bridges
   - Roadside Development
   - Vehicle Barrier Systems
4. Materials and Construction:
   - General Materials
   - Bituminous Materials
   - Concrete Materials
   - Specifications, Procedures and Practices
5. Soils and Geology:

- Testing and Instrumentation
- Properties
- Mechanics and Foundations

6. Maintenance:
   - Snow and Ice control
   - Equipment
   - Maintenance of Way and Structures

7. Traffic:
   - Operations and Control
   - Illumination and Visibility
   - Traffic Planning
   - Safety
8. Special Projects:
   - Topics not readily identified with other problem areas.

A more comprehensive classification system has been developed for the Transit Cooperative Research Program. A copy is included in the TRB Directory.

Professional and Ethical Research Practices

Scientific research is built on a foundation of trust. Scientists, engineers and other professional researchers trust that the results reported by others are valid. They also trust that research reports and papers are honest attempts by the authors to describe the results of their work accurately and without bias. Trust in the research community, and in society at large, will endure only if individual researchers devote themselves to exemplifying and transmitting the values associated with ethical scientific conduct.

In the past, young scientists learned the ethics of research largely through informal means. This often occurred in the university or laboratory environment by working with senior researchers and observing how they dealt with ethical questions. While that tradition is still important, science has become so complex that a more formal introduction to research ethics and responsibilities is needed. This is especially true in transportation agencies, where many staff has not had the benefit of formal university training in research, and the senior scientist, with the experience and availability to act as a mentor to junior staff, is rare.

Much of the content of this section has been taken from the publication "On Being a Scientist" (2), published by the National Academy Press. The information has been condensed and adapted to the context of a transportation agency. The original document is recommended to the reader interested in the broader issues of the role of science in society, and for hypothetical scenarios involving research ethics, which can be used for group discussion.

Techniques and the Treatment of Experimental Data

One goal of investigations is to facilitate the independent verification of the observations and conclusions. Many experimental techniques such as statistical tests of significance, double-blind trials, or the proper sequence and phrasing of questions in surveys, have been designed to minimize the influence of individual bias in research. By adhering to proven techniques, researchers produce results that others can reproduce more easily, which in turn promotes acceptance of the results.

In some cases, the methods used in scientific investigations are not well defined. In many cases experimental techniques are pushed to the limit. A common example is where interrogating waveforms are used to investigate a phenomenon and the reflected signal is difficult to separate from the electronic noise. Picking out reliable data from a mass of confusing and sometimes contradictory observations can be extremely difficult. In such circumstances, the researchers have to be extremely clear to themselves, and in reports to others, about the methods being used to gather and analyze data. Other researchers will need to judge not only the validity of the data, but also the accuracy of the methods used to derive those data. If someone is not forthcoming about the procedures used to derive a new result, the validation of the result by others will be hampered.

For example, many scientists reacted negatively to the initial reports of cold fusion in the late 1980's because the results were implausible and the experiments were not described sufficiently to permit independent verification. When the experimental techniques became widely known, and were replicated, belief in cold fusion faded quickly.

Commercial pressures may also dissuade full disclosure. There have been many papers in the transportation sector describing, for example, a new deicer or a corrosion-inhibiting admixture where the test procedures have been described but the product has not. This prevents validation by others and is a misuse of the publication process for marketing purposes. As a minimum, the paper should provide a generic description of the product and a scientific explanation for the observed performance. This may require that patents be filed before disclosure is made.

Data similar to that shown in Figure 1 are not uncommon, and the researcher is faced with how to deal with the two anomalous data points. Should the data be included in statistical analyses, mentioned only in the text, or dropped entirely? Other courses of action such as repeating the two measurements, or the entire experiment, also need to be considered. There is no general answer, because each case must be treated on its own merits, and should include an examination of the reasons why the researcher would consider removing outliers. All datum points should be considered valid until proven otherwise. There may be a simple explanation, such as an equipment malfunction, and there are statistical techniques described in Volume II, which can be used to indicate the probability of individual measurements being part of a larger population. Analyses with and without the outliers would be valid from the ethical standpoint, provided that, in the latter case, there was an explanation for their removal. However, data should not be dropped because it does not fit neatly with a curve, or with preconceived expectations of a relationship. In many cases, it is in seeking an explanation of anomalous data that significant advances in understanding relationships or experimental techniques are made.

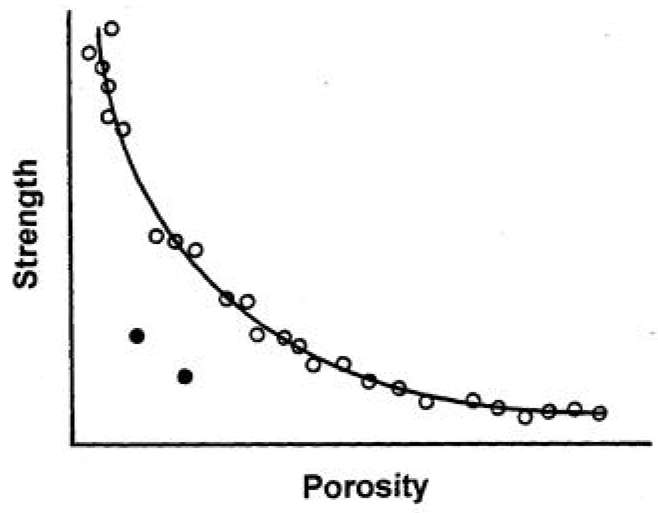

Figure 1: Relationship Between Strength and Porosity

Experimental techniques and equipment improve over time and conclusions drawn from data collected by the best available methods may ultimately prove to be incorrect. This does not mean that the researcher was ethically at fault but it does serve as a reminder of the importance of a healthy skepticism in science. Scientific knowledge and methods, whether old or new, must be scrutinized continually for possible errors. An openness to new ideas, together with an intellectual challenge of others' opinions, is essential to the advancement of science.

Values in Science

Scientific research is much more than performing experiments and reporting the results. Researchers must have the technical skills to make complex decisions about how to design an experiment, interpret data and formulate conclusions. They also have to have social skills to decide how best to work and communicate with others. Taken together, the ability to make judgements, and the character of the individual, have a major bearing on one's success as a researcher.

Much of the knowledge and skills needed to make good decisions in research are learned through formal education and personal interactions in the workplace. Yet many of the characteristics associated with successful research - curiosity, intuition, creativity, and judgement are hard to teach and largely defy rational analysis.

In a given area of research, several different explanations may account for the facts equally well. Over many years, criteria have been proposed for judging between competing hypotheses. For example, hypotheses should be internally consistent so that they do not generate contradictory conclusions. It is also desirable that the hypothesis be capable of extrapolation to a more general form so that it can be used to predict the outcome of other experiments. In disciplines where experimentation is difficult, such as driver behavior and safety, good hypotheses should be able to unify disparate observations, preferably in simple and elegant terms.

Although general criteria exist, the selection of the most favored hypothesis ultimately involves the judgement of the researcher, and consequently is influenced by the individual's values, including philosophical, thematic, religious, cultural, political, and economic beliefs. While it is easy to recognize that individual values have shaped scientific judgement in the past (for example Darwin's proposal of the theory of evolution or Einstein's rejection of quantum mechanics) it may be difficult to imagine that individual values can also influence conclusions in transportation research. However, one's personal bias can equally well influence the hypothesis one might draw from the benefits of public transit, or the relative merits of concrete and asphalt pavements.

The challenge for the individual researcher is to acknowledge and try to understand the effect one's values might have on one's work. A broad education can help, as can work in a team where many perspectives are represented. Above all, researchers must continually test their theories against observations and modify their hypotheses accordingly.

Conflicts of Interest

A conflict of interest occurs when an individual holds a private position that might influence, or appear to influence, professional judgement.

In academic research, conflicts of interest may occur if findings are biased by the commercial interest of the sponsor, or a researcher has a financial interest in a particular organization and works on a product for that organization, or a competing organization, which might affect stock prices. Other examples might be faculty using university facilities for personal consulting assignments, having scholarship students work on sponsored research, or withholding a postgraduate degree until a sponsored research project is completed or because the conclusions contradict earlier work by the professor. Or it might be more subtle, such as taking ideas from another scientist's manuscript or proposal that has been sent for review.

In the private sector, the researcher must be vigilant that judgement could be affected by a sense of loyalty to the company. This could take the form of exaggerating the effectiveness of the company's products, or withholding potentially damaging findings.

By comparison, there may appear to be fewer potential conflicts in the life of the researcher in a publicly funded transportation agency. Nevertheless there are many situations in which a conflict of interest could occur, as illustrated by the following examples:

- a researcher evaluates a product or process of a company in which he has a financial interest
- external relationships are not at arm's length (involving family or friends)
- a researcher does work privately for a company that also does business with his employer
- a researcher holds a part-time faculty position at an institution which has contracts with the agency

As public agencies look for new sources of funding, such as providing contract research and fee-for-service testing, the potential for conflicts of interest can be expected to increase.

Virtually all institutions that conduct research have policies for managing conflicts of interest. These policies are designed to protect the integrity of the scientific process, the institution and public confidence in the integrity of the research. Most policies rely of self-disclosure in which the onus is on the researcher to declare a potential conflict to management before work begins. In addition, the individual researcher must recognize that compromising one's personal and professional integrity can damage a career permanently.

Publication and Openness

Science is not an individual experience, but shared knowledge based on a common understanding of some aspect of the physical, economic, or social world. The conventions of science, which include the way in which information is disseminated, play an important role in establishing the reliability of scientific knowledge.

In the late seventeenth century, when modern science began, scientists were reluctant to disclose their discoveries for fear that others may claim the ideas as their own. The Royal Society of London developed a solution that is the foundation of modern scientific journals. It guaranteed rapid publication following peer review of the manuscript. It also established the convention that, unless a discovery is protected by a patent, the first to publish a view or finding, not the first to discover it, tends to get the most credit for the discovery. Once results are published, other researchers can use them freely, though convention dictates that the source of the information be acknowledged.

Before publication, different considerations apply. If someone exploits another's unpublished material (in a manuscript or grant application for example) that person is essentially stealing intellectual property. In academic research, intellectual property rights usually belong to the individual unless a research contract specifies otherwise. In industry and government the commercial rights to scientific discoveries usually belong to the employer. No matter who owns the rights, research results are privileged until they are published or otherwise disseminated publicly.

Publication in a peer-reviewed journal remains the standard means of disseminating scientific results, but other methods of communication are changing how researchers disclose and receive information. Posters, lectures, conference presentations, preprints and proceedings are all being used more frequently to present results, especially preliminary results of work. Computer networks are also increasing the ease and speed of communications. These newer methods of communication encourage openness in the scientific community and can be considered an extension of the informal exchanges between researchers working in similar fields. However, these practices should not be considered a replacement for the formal publication process because they bypass the quality control mechanisms imposed by peer review and rigorous editing, and risk weakening a foundation that has served science well.

The risks can be illustrated by the example of the scientist who releases important and controversial results directly to the public before submitting them to the scrutiny of peers, as was the case with cold fusion noted previously. Where such news is released to the press, it should be done after peer review is complete, which is normally the time when the work is published in a scientific journal.

It should be noted that the academic community has always drawn a clear distinction between a paper published in a peer-reviewed journal, and a paper in a publication which is not reviewed, which is the case with magazine articles and some conference proceedings. Researchers working in other environments do not always recognize this distinction.

The academic community, and some research institutions, reward staff for the number of publications, (the "publish or perish" syndrome), which can have unfortunate consequences. If the goal becomes only the number of publications, researchers may be tempted to publish two short papers, instead of a single, more complete treatment of the subject, or they may publish similar results in two different places. However, a researcher's reputation is soon tarnished by substandard publications, and one or two inferior quality papers can result in all an author's work being viewed with skepticism. In an attempt to focus on quality, rather than quantity, some institutions and federal agencies have adopted policies that limit the number of papers that will be considered when an individual is evaluated for appointment, promotion, or funding. These pressures are significantly diminished in research groups in transportation agencies, where publications are not usually tied directly to promotions.

Sometimes researchers and the sponsors of the research have different interests in making the results public. For example, a researcher may desire the recognition for a discovery, while the industrial sponsor may want to withhold the results. In some cases this may be a temporary delay until patents are filed, but in other cases the sponsor may not wish to publish at all because it may be more advantageous not to disclose an invention than to file a patent. Research institutions and government agencies often have policies to reduce conflicts over intellectual property and publication rights. It is not uncommon to allow the researcher to publish the results of work after a certain period of time has elapsed even if the sponsor has withheld publication.

Patents enable an individual or institution to profit from a scientific discovery in return for making the results public. Researchers who may be doing patentable work have obligations to document the time and details of their experiments very carefully. For example, they may need to have their laboratory notebooks validated and dated by others. They may also have to disclose potentially valuable discoveries promptly to their institution and sponsor.

Allocation of Credit

When writing a scientific paper or research report, it is important to give credit to the work of others, not only because of the principle of fairness, but also because of the need to place the new work in context.

There are three places in which credit is acknowledged explicitly:

- in the list of authors
- in the list of references or citations
- in the acknowledgments.

Authorship practices are discussed in the next section.

Referring to the work of others, and citing the source of the information in a list of references, serves a number of purposes. Most importantly, it acknowledges the work of others, and makes it clear whether the information or views expressed in the paper are original to the author. It also directs the reader to additional sources of information. Further, it acknowledges conflicts with other results, or provides support for the view expressed, and places the paper in its scientific context by relating the work described to the current state of scientific knowledge.

Failure to cite the work of others reduces the value of a paper and can damage the author's professional reputation, particularly if there are reports of similar work in the literature. This inevitably gives rise to the question of why the research was undertaken if the author should have known the findings. Some scientists ignore the work of others while including numerous references to previous work of their own. This is poor professional practice because it fails to place the paper in its scientific context, and immodesty rarely enhances one's reputation.

Although not necessarily a desirable feature, citations have become part of the reward system of science. The value of a scientific paper is often measured by the number of times it is cited by others. While this may indicate the importance of a study within a narrow field of research, it does not measure the relevance of the research or the value of the contribution in the broader context of advancing scientific knowledge. In some circles, especially academic research, the number of citations may be used to rank the esteem of an individual or institution, such that there are implications for salaries and research grants. This raises the stakes beyond professional reputations built on peer recognition, to a reward system based on a crude measurement technique that is open to abuse.

Authorship Practices

The allocation of credit is an important issue in the listing of the authors' names on a scientific paper or report. As science has become more complex, and opportunities for collaboration have increased, there has been a trend for the average number of authors of articles to increase. This has also increased the possibility of differences and acrimony between authors.

Conventions differ between disciplines, but in many fields, including transportation, the earlier a name appears in a list of authors, the greater the implied contribution. The first-named author is known as the senior author (the age of the author is irrelevant). The order of the authors can be a source of conflict between team members, who may not agree on the relative value of the contributions. Frank and open communications of the division of credit, as early in the research process as possible, can prevent difficulties later.

The allocation of credit can be particularly sensitive when it involves researchers at different stages in their careers, for example graduate students, post-docs, junior faculty and senior professors. In such situations, differences in roles and status compound the difficulties of according credit. In some institutions, supervisors' names rarely appear on papers, and there are others where the name of the professor or head of department appears on almost every paper. Understandably, this may cause feelings of resentment among those who actually performed the research or wrote the paper. This situation is not confined to academia. It can happen in the public sector where a senior staff member insists on including his name on all papers or reports published by his staff. It can also occur in the private sector, especially in small companies, where the president's name might be added as a marketing technique to secure future contracts. In some cases, reports may be published bearing only the name of the company and not the individual authors.

Several considerations must be weighed in determining the proper division of credit between contributors. While a range of practices is acceptable, there are two criteria, both of which should be satisfied to be included as an author:

- there must be an intellectual contribution
- the contribution must be direct and substantial.

The first criterion distinguishes between the contribution of ideas and labor. Sometimes students or junior staff have a false impression of their contribution to a study because they have performed all the experiments and crunched all the numbers, without appreciating that someone else had identified the need for the research, assembled the resources, prepared the work plan, identified the method of analysis and drawn the conclusions. Unless there is an intellectual contribution to the experiment or to the writing of the report, the provision of labor would normally deserve no more than an acknowledgment. Conversely, where junior staff has made creative contribution to the research, the contribution deserves to be recognized. The same criterion applies in multi-disciplinary studies, where other professionals may have supplied services to the project. While routine analysis and testing do not constitute a basis for coauthorship, when the contributions are original and essential to the project, coauthorship is appropriate.

Occasionally a name is included in a list of authors even though that person had little or nothing to do with the content of a paper. Such "honorary authors" are often included to curry favor, as, for example, by including the head of department, or the contracting officer for a research contract. There have even been cases where a name has been included as an author without the person's consent. "Honorary" or ex-officio authorship demeans the publication process, which is intended to reward contributions through the proper attribution of credit. Where a senior staffer or contracting officer has, through discussion, influenced the direction or application of a research study, then authorship may be entirely appropriate if the "direct and substantial" criterion is satisfied.

Another practice sometimes employed is to include as an author, the name of an eminent colleague who may have only a peripheral association with a study, in the belief that the colleague's reputation will improve the chances of the paper being accepted for publication. This situation is a little different from the "honorary author" situation in that the colleague is risking his reputation because authorship establishes accountability as well as credit. The colleague would be expected to review the study and paper in detail because, if there are errors, mistakes or deceit, the colleague is equally responsible. In undertaking the review, the colleague may contribute to the paper, but listing as an author should be based on whether his contributions are intellectual, direct and substantial.

Some scientific journals have dealt with the question of accountability by requiring that all named authors sign a submission that accompanies the final version of a manuscript to ensure that no author is named without consent, and all authors agree with its contents. Unless a footnote or the text of a paper explicitly assigns responsibility for different parts of a paper to different authors, all the authors must share responsibility for all the contents of a paper or report.

Acknowledgments

An 'Acknowledgments' section is usually included in a paper or report to provide a mechanism for the proper allocation of credit. The acknowledgments allow for the recognition of contributions to the study, which do not meet the criteria for listing as an author, as might be the case for discussions with a colleague, or assistance from students or technicians in collecting or analyzing data. Some authors thank family members for their support though this is not usually appropriate in a scientific article. It is appropriate to thank individuals who have contributed items otherwise not available, such as unpublished documents, computer programs or photographs. This is also the place to thank sponsors, contracting officers who have provided input, but not sufficient to warrant inclusion as an author, and colleagues who have reviewed the work and made helpful suggestions.

Error, Negligence, and Misconduct in Scientific Research

In a sense all scientific results are provisional, and therefore susceptible to error, because scientists can never prove that an investigation is completely accurate. Errors may also arise from human fallibility, and even a responsible scientist can make an honest mistake. When such errors are discovered, they should be acknowledged, preferably in the same journal as the mistaken information is published. Prompt and open admission of mistakes in this manner usually brings respect rather than condemnation by colleagues.

Mistakes made through negligent work are not so readily forgiven. Haste, carelessness, incompetence, or any factor that results in work not meeting standards demanded in science is not likely to be forgiven, and the reputation of the scientist will be damaged. Introducing preventable errors into science can do great damage because, though science is built on the idea of peer validation and acceptance, it may be several years before an investigation is repeated and the error discovered.

Beyond honest mistakes, and errors caused by negligence, is a third category of errors: those that involve deception. Deception may take one of three forms:

- fabrication - making up data or results
- falsification - changing or misrepresenting data or results
- plagiarism - using ideas, data or words of another person without giving appropriate credit.

These acts of scientific misconduct undermine the values on which science is based and transgressions often result in serious consequences. In addition to ostracism and placing one's scientific career at risk, violators may also face criminal or civil court proceedings.

There has been an unfortunate tendency for scientists to believe that their discipline is self-correcting and a corresponding reluctance to accept that cases of fraud do occur. It has been said (3) that, while cases of fraud in science are sometimes revealed by the checks in the system - peer review, referees and replication of experiments - these checks do not prevent the fraud. There is a danger in focusing on the ideology of the process, and more attention needs to be paid to the motives and needs of scientists. Modern scientists are pursuing their career and, to be successful, must secure grants, build up a staff, and be recognized through discoveries, publications, and presentations. There must be constant vigilance on the part of colleagues for those who may have manipulated the system for personal gain.

Instances of deception can have a devastating effect, not only on the individuals involved, but also on institutions. There are considerable pressures on an institution to contain incidences of fraud so as to preserve its reputation. When this is no longer possible, the institution often responds by blaming transgressions on one individual (the "bad apple" strategy). Broad and Wade (3) quote cases of fraud in medical research at Cornell University, the Harvard Medical School, and the Sloan-Kettering Institute. The facts were similar in all the examples. A young researcher who was enjoying spectacular success was found to be faking experiments. The eminent director of the laboratory was unwilling to accept the evidence presented to him. Only when irregularities became apparent to outside researchers was the offender discharged.

The damage to the institution, financially and to its reputation, is determined by both the nature of the incident and the manner in which it is handled. Experience has shown that the most successful responses are those that separate clearly a preliminary investigation to gather information from a subsequent adjudication during which the accused is afforded due process.

Eminence should not preclude scrutiny. There is evidence that Claudius Ptolemy heralded "the greatest astronomer in antiquity" did not make his own observations, but copied the work of an earlier astronomer, Hipparchus of Rhodes. It is thought that Galileo, often credited as the founder of the modern scientific method because of his insistence on experiments, did not actually perform some of the experiments that he reported. Gregor Mandel, who founded the science of genetics, published papers presenting statistical results that are, in the eyes of modern geneticists, too good to be true. Some argue that he reported only his best results, while others believe he may have erred in favor of his expected results when collecting his data. An examination of the note books of Robert Millikan, an American physicist, who won the Nobel Prize in 1923, for being the first to measure the electric charge of an electron, has also shown he reported only his best data, despite his assurances to the contrary (3).

In addition to deception, other ethical transgressions directly associated with research can cause serious harm to individuals and institutions. Examples include cover-ups of scientific misconduct, reprisals against whistleblowers, malicious allegations of misconduct, and violations of due process in handling complaints in science. Other categories of behavior, including sexual harassment, misuse of funds, gross personal negligence, tampering, and violations of regulations, are not necessarily associated with scientific conduct, and should be subject to applicable legal and social penalties.

Individual Response to Violations of Ethical Standards

One of the most difficult situations that a researcher can encounter is to see or suspect that a colleague has violated the ethical standards of the research community. It is easy to find excuses to do nothing, but someone who has witnessed misconduct has an unmistakable obligation to act. At the most immediate level one's own research may be compromised, but it can affect the reputation of the institution, and even the integrity of science.

Someone who is confronting a problem involving research ethics usually has more options than are immediately apparent. In most cases the best thing to do is to discuss the situation with a trusted friend or advisor. In most institutions, senior professionals or administrators can be valuable sources of advice in deciding whether to go forward with a complaint.

An important consideration is deciding when to put a complaint in writing. Once in writing, institutions are obligated to deal with a complaint in a more formal manner than if it is made verbally. If mishandled, an allegation can gravely damage the person charged, the one who makes the charge, the institutions involved, and science in general.

The National Science Foundation and Public Health Service require all research institutions that receive public funds to have procedures in place to deal with allegations of unethical practice. These procedures take into account fairness for the accused, protection for the accuser, coordination with funding agencies, and requirements for confidentiality and disclosure. In addition, many universities and other research institutions have designated an ombudsman, ethics officer, or other official who is available to discuss situations involving research ethics.

Government agencies enforce laws and regulations that deal with misconduct in science. At the National Science Foundation in Arlington, Virginia, complaints can be directed to the Office of the Inspector General. Within universities, research grant officials can provide guidance on whether federal rules may be involved in filing a complaint. In transportation agencies, many employees are professional engineers, in which case complaints can be directed to the state licensing body. Many institutions have prepared written materials that offer guidance in situations involving professional ethics. Volume II of Responsible Science: Ensuring the Integrity of the Research Process (National Academy Press, Washington D.C., 1993) reprints a number of these documents.

The researcher's responsibilities extend beyond those to the immediate employer to a commitment to ethical research, to the research community and to society. By its very nature, ethical conduct involves living by a moral code that is neither complete nor constant. Ethical questions are open-ended and have many answers, though some are better and some worse than others. Many ethical issues are still being discussed and the researcher has an obligation to move the debate forward. This requires talent, energy, an inquiring mind to challenge assumptions, and a resolute character that cannot be compromised. Senior staff has a special responsibility to uphold the highest standards of conduct, serve as role models for younger staff, and demonstrate leadership by responding to alleged violations of ethical norms.

Effective Research

In simple terms, it may seem that we could define effective research as research in which the objectives were satisfied. However, the criteria are actually much more complex. The objectives could have been satisfied even though the hypothesis was not posed correctly, or the problem might have been solved more quickly or cheaply, or a more elegant solution might have been possible. Effectiveness has little to do with completing a project on time and within budget. Effectiveness must be measured in terms of the application of the findings relative to the cost of the research. As with most cost-benefit analyses, the costs are known but the benefits are often less tangible. Sometimes benefits can be calculated quite reliably when the research has resulted in a more economical process, but more frequently, benefits must be estimated in terms of improved durability or safety. It must also not be forgotten that a negative result can be just as valuable as a positive result though, in this case, benefits must be calculated in terms of discontinuing an unsatisfactory process, or not using an unsuitable product or process. As noted at the beginning of this chapter, not all research projects will be successful, and effectiveness should be measured in terms of the research program, not individual projects.

While there is risk involved in all research, there are also ways of reducing the risk and increasing the effectiveness of research through management techniques and rigorous application of the scientific method. The management of research includes staffing, funding, program development, administration, reporting and implementation activities. Guidance on these issues is contained in Synthesis 113 "Administration of Research, Development, and Implementation Activities in Highway Agencies" (4) and in Synthesis 231 "Managing Contract Research Programs" (5).

To be effective, research needs a stable environment and a consistent direction free from the disruption of "urgent" problems that disappear before the work is completed. The content of the research program is also a key ingredient to success. Like the diversified portfolio of investments, the program should include a mix of pragmatic needs and long-term interests; including high-risk, high-pay-off projects, and low risk projects that will result in incremental improvements. In the same way that successful investors cut losses by selling nonperforming stocks, effective research programs have a mechanism for the timely termination of unsuccessful projects.

This manual describes the processes involved in the conduct of research. Where these processes overlap with management issues, as, for example, in project selection, measuring progress and implementing results, the subjects have been included at appropriate places in the manual. Following the procedures described in the manual will provide structure and rigor to the research process, which should eliminate poor science. However, research is a human endeavor and truly effective research results from the complex interaction of resources, application of the scientific method, and intangibles that include creativity, intuition, effort, and the ability to recognize the significance of observations.