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Title: THE USE OF HISTORY OF SCIENCE CASE STUDIES WITH
FIRST YEAR EDUCATION STUDENTS TO TEACH SKILLS
INVOLVED IN SCIENTIFIC THINKING

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The purpose of the study was to prepare and statistically evaluate a series of 11 history of science case studies designed to teach the following abilities involved in scientific thinking:

1. Recognizing problems, hypotheses, experimental conditions, and conclusions.
2. Understanding the relationship of evidence to hypotheses.
3. Understanding experimental conditions and the control of variables.
4. Making conclusions.
5. Interpreting data.

Population and Treatment Groups

The population consisted of the entire enrollment of first year education students in a general science course at the University of

Victoria. The experimental group included 156 students randomly selected from this population to read history of science case studies. The control group included 154 students randomly selected from the same population to read a science textbook.

Collection and Analysis of Data

The Burmester Test of Aspects of Scientific Thinking was administered under standardized conditions to both treatment groups. This test was designed to measure the same five abilities mentioned above as case study objectives. Mean test scores for the two treatment groups were compared by analysis of variance, using the sex of the student as a covariable. The Nature of Science Scale was also administered and mean test scores compared by the same statistical analysis.

Results

Mean test scores of the treatment group reading history of science case studies were significantly higher (0.05 level) than the control group on the total Test of Aspects of Scientific Thinking and on the sub-test on the ability to make conclusions. Mean test score differences between the experimental group and the control group were not significant for the other four abilities involved in scientific thinking, although all differences favored the experimental group. No

significant differences were found between treatment groups in attitudes toward science, as measured by the Nature of Science Scale, or in general science course grades. Differences between males and females were not statistically significant on any of the criterion tests.

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The Use of History of Science Case Studies With First Year
Education Students To Teach Skills Involved
In Scientific Thinking

by

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THE USE OF HISTORY OF SCIENCE CASE STUDIES WITH FIRST YEAR EDUCATION STUDENTS TO TEACH SKILLS INVOLVED IN SCIENTIFIC THINKING

I. INTRODUCTION

First year university science courses are traditionally descriptive and fact centered. The student is seldom given any insight into the type of inquiry undertaken by scientists between the formation of a problem and the statement of a conclusion, as in the approach developed by Dressel and Mayhew in Science Reasoning and Understanding (15).

Innovation, while difficult at any level, has been particularly slow at the university level for the following reasons:

- (a) Expanding enrollments and high pupil-teacher ratios.
- (b) Faculty commitments in research and administration
reduce time available for classroom preparation.
- (c) Little emphasis on methods of teaching in the
academic preparation of faculty.

Materials are needed to teach skills involved in scientific thinking to the non-specialist in science, which can be used practically within the time, space, and staff limitations imposed by many large universities.

If students are to understand the sort of thing a scientist does, it is not necessary to plunge into the depths of the most recent or abstruse scientific thought; indeed, some of the simplest and

historically earliest episodes of modern science, if studied in depth, are valuable in clarifying the nature of scientific inquiry. These episodes help to elicit an image of science as an ongoing, exciting enterprise in place of the all-finished, museum piece image traditionally found in science textbooks.

According to James B. Conant (13), science can best be understood by laymen through the close study of a few relatively simple case histories, which would develop the strategy and tactics of science. Conant did not believe that this type of study could be introduced earlier than the college level and favored the selection of case histories from the early days in the evolution of the modern discipline. His reasons were twofold:

1. Relatively little factual knowledge and mathematics are required.
2. In the early days one sees the necessary fumbblings of even intellectual giants when they are also pioneers; one comes to understand what science is by seeing how difficult it is in fact to carry out glib scientific precepts.

J. A. Easley (16) examined the differences between case histories and the inductive type of organization he believe necessary in teaching scientific method. The historical record provided the raw material from which inductive procedures were discovered initially. Inductive principles often do not stand out clearly in the full historical

picture. Ideas needed to be rearranged so as to reduce greatly the actual complexities of the historical development of a theory. Easley proposed an inductive organization which would separate lines of argument building up to a theory and emphasize principles of scientific method rather than the approach of the Harvard case histories, written under Conant's editorship, which emphasize narrative and the historical complexity of scientific investigations.

While studies of important scientific experiments and their relationship to society could provide a good deal of interest for students majoring in the social sciences or humanities, an investigation of the literature has not shown any use of historical case studies to teach specific process skills in science, although a great deal of interest in the case study approach has been expressed in the literature (see Chapter II). The logic of Easley's recommendation and the importance of developing a better understanding of scientific inquiry in university science courses warrant an investigation of the use of history of science case studies to teach scientific thinking.

Purpose of the Study

The main objective of this study is to prepare and evaluate history of science case studies which have been organized inductively and designed to teach skills involved in scientific thinking. Evaluation will involve a comparison of university students reading history

of science case studies with similar students reading a science textbook. These two groups of students will be compared in terms of their ability to think scientifically and their attitudes about the nature of science.

Specific purposes of this study are summarized as follows:

1. To prepare a series of history of science case studies to be used by first year education students in learning the following skills involved in scientific thinking, as defined by M. A. Burmester (9):
 - A. Ability to recognize problems, hypotheses, experimental conditions and conclusions.
 - B. Ability to understand the relationship of evidence to hypotheses or possible solutions to a problem.
 - C. Ability to understand experimental methods and the control of variables.
 - D. Ability to make conclusions.
 - E. Ability to interpret data.
2. To compare students reading history of science case studies with students reading a science textbook in regard to the following:
 - A. The above mentioned skills in scientific thinking, as measured by the Burmester Test of Aspects of Scientific Thinking.

- B. Attitudes toward science, as measured by the Nature of Science Scale.

Hypotheses

The following null-hypotheses were tested in this study:

1. Students who have read history of science case studies do not differ significantly from students who have read a science textbook in their ability to think scientifically.
2. Students who have read history of science case studies do not differ significantly from students who have read a science textbook in their ability to recognize problems, hypotheses, experimental conditions and conclusions.
3. Students who have read history of science case studies do not differ significantly from students who have read a science textbook in their ability to understand the relationship of evidence to hypotheses or possible solutions to a problem.
4. Students who have read history of science case studies do not differ significantly from students who have read a science textbook in their ability to understand experimental methods and the control of the variables.
5. Students who have read history of science case studies do not differ significantly from students who have read a science textbook in their ability to make conclusions.

6. Students who have read history of science case studies do not differ significantly from students who have read a science textbook in their ability to interpret data.

7. Students who have read history of science case studies do not differ significantly from students who have read a science textbook in their attitudes about the nature of science.

Definition of Terms

Ability to think scientifically: A composite of the five process skills stated in the purpose of the study. The skills involved in scientific thinking have been defined operationally by Burmester (9), and her taxonomy of behaviors attending these skills is presented in Chapter III.

Attitude: A readiness which inclines the individual toward certain types of behavior. This "readiness", according to Robert L. Ebel (17), describes the attitude which influences behavior. Ebel identified three main areas which are involved in a scientific attitude.

1. Readiness to be confident that human intelligence can understand the phenomena of nature, and through that understanding can become able to control the forces of life.
2. Readiness to seek true understanding of the phenomena of nature.
3. Readiness to seek correctness in work and thinking so that

truth may be discovered.

Control group: The group of students randomly selected to read textbook assignments from Buchsbaum's "Principles of Ecology".

Experimental group: The group of students randomly selected to read history of science case studies prepared by the investigator.

History of science case studies: In-depth studies of original scientific papers and experiments, stressing the nature of a specific scientific investigation rather than chronology and historical complexity as in case histories and other historical materials. The case studies referred to in the experimental part of this investigation are presented in Appendix I.

Science textbook: Buchsbaum's Principles of Ecology during the entire 12 week period of this study.

Significant difference: A difference between test scores significant at the 0.05 level of confidence. This criterion was used in the testing of all hypotheses.

Student: Any individual enrolled in Education 145 at the University of Victoria. The total enrollment in Education 145 comprised the student population in this study.

Assumptions

1. The evaluation instrument, A Test of Aspects of Scientific Thinking: Form A, is a reliable and valid measure of the process

skills involved in scientific thinking, as defined in this study.

2. The Nature of Science Scale is a reliable and valid instrument for measuring attitudes about the nature of science, as defined in this study.

3. The experimental group and the control group remained relatively uncontaminated in regard to materials read during this study.

4. The different reading materials used by the two treatment groups were comprehensible to most students involved in this study.

Evidence in support of the assumptions stated above is presented in Chapter III.

Limitations of the Study

1. The study was limited to the population of first year Education students enrolled in a course in General Science at the University of Victoria.

2. The study was limited to the 12 week period between the assignment of the case studies and the science textbook to the two treatment groups and the final examination.

3. The random assignment of students to experimental and control groups was essential in controlling extraneous variables, particularly those related to methods of teaching. This limited the amount of instruction that could be provided in conjunction with the

use of the case studies. In the opinion of the investigator, however, the elimination of bias in the study must be of primary consideration.

Preparation of the Case Studies

A series of history of science case studies have been compiled by the investigator over the last four years and have been written with "open-ended" questions in the text. These questions have been structured to develop the ability to think scientifically, and are specific to the objectives stated in the purpose of the study. Many of the questions do not have specific right or wrong answers, but rather are designed to stimulate interest and discussion. Often the student is placed in the position of an investigator doing original research.

The student population, which is discussed more completely in Chapter III, included many students who are poorly motivated in science and tend to be more interested in the arts and humanities. For this reason the case studies were prepared to include a variety of subjects of varying difficulty which might meet the needs and backgrounds of these students. It was intended that students begin with conceptually simple readings and work through a sequence which gradually increased in reading difficulty.

The first three case studies included highly popularized accounts of the work of Spallanzani, Pasteur and Koch (see Appendix 1-A, 1-B, 1-C). These case studies were included to show scientific

investigation as an exciting activity as well as to develop an understanding of the methods of inquiry utilized by early investigators in micro-biology. Even though accounts of experiments in these case studies are oversimplified, problems and controlled experiments to test hypotheses are clearly identified and described. Questions in the first three case studies ask students to identify a number of hypotheses and the observations that support them. In each of these case studies students are also asked to explain how variables were controlled in testing a hypothesis.

Case Study Four: Why are we Here? was prepared to describe some rather controversial speculations about the origin of man. These particular readings were included because they should be interesting and thought provoking to students with a social science or humanities background and to get students to think critically about the types of evidence needed to formulate conclusions in science. This case study, while written in a very exciting style, includes some rather "borderline" scientific statements. In the opinion of the investigator, it is extremely important for students to learn to evaluate critically the evidence presented to support a conclusion. Questions in this case study (see Appendix 1-D) direct students to give examples of conclusions, observations supporting conclusions and hypotheses. Several questions involve the evaluation of evidence; for example, the use of indirect evidence and the possible dangers

involved. Students are also asked to formulate and support their own conclusions.

Case Studies 5 - 11 (see Appendix 1-E - 1-K) were selected to show the historical development of the concepts of combustion and respiration as well as to develop the ability to think scientifically. This sequence begins with brief descriptions of early experiments which developed the concept of combustion. The application of this concept to respiration in living systems is traced through experiments of Lavoisier, Laplace and Liebig. The sequence ends with a case study describing several experiments which formed the basis for modern ideas on intermediate metabolism.

Case Studies 5 - 8 were prepared to emphasize the ability to understand the relationship of evidence to hypotheses, experimental methods and the control of variables (see Appendix 1-E - 1-H). For example, a description of a famous experiment by Lavoisier and Laplace, in the author's own words, is followed by these questions (see Appendix 1-H):

- The double lid and the outer chamber (c) were essential controls for this experiment. Explain why.
- Why do you think the investigators chose to compare burning coal with a live animal in the same type of apparatus?
- Why were such accurate measurements of melted ice necessary?

- Does this experiment provide evidence to support the hypothesis that animal respiration is a form of combustion? Explain.

Why is more evidence also needed to test this hypothesis?

- Suggest new problems or new hypotheses which might logically follow this experiment.

- Do the results of this experiment support or reject the phlogiston theory? Explain how.

Case Studies 9 and 11 (see Appendix 1-I and 1-K) were prepared to develop the ability to interpret numerical data, data tables, and graphs. These two case studies are conceptually the most difficult in the sequence and were not intended to be mastered by all students. More capable students had the opportunity, however, to develop important concepts inductively from actual research data.

An attempt has been made by the investigator to organize these case studies inductively as recommended by J. A. Easley (16). Historical complexity has been avoided and principles of scientific method have been separated and emphasized according to specific objectives.

Evaluation of the Case Studies

Internal consistency in the case studies was checked in a pilot study carried out during the 1968-69 school year. As a result of

student feedback in this pilot study various questions and readings were revised to better meet the objectives of the study (see Chapter III).

Process skills learned through the use of these case studies were evaluated by means of the Burmester Test of Aspects of Scientific Thinking. This test was designed to measure the same process skills involved in scientific thinking which were used in structuring the case studies. The Nature of Science Scale was also administered to investigate the possibility of attitude changes. Data relating to objectives, reliability, and validity of the test instruments are presented in more detail in Chapter III.

Organization of the Remainder of the Study

Opinions of scientists, educators and research studies related to the use of history of science materials are discussed in the review of literature. Chapter II also elaborates on the need and rationale for the study.

Chapter III includes the experimental design and the procedures followed in testing hypotheses. Information on the criterion tests is also presented.

The basic statistical design is presented in Chapter IV, and is followed by a presentation and interpretation of the data.

Chapter V includes a summary and discussion of results,

conclusions drawn from the study, recommendations and suggestions for further study.

II. REVIEW OF LITERATURE

Introduction

Related literature will be surveyed in terms of:

(a) The opinions of scientists and educators regarding the rationale and values to be developed through the use of history of science case studies.

(b) Research studies related to the use of history of science case studies and the development of attitudes and skills involved in scientific thinking.

Development of the Historical Case Study Approach And Its Use In Science Teaching

Educators have expressed a good deal of concern during the last three decades about the lack of humanistic values in science teaching. The need for history of science case studies has been frequently mentioned in the literature to better develop an understanding of the relationship between scientific developments and the social, cultural and intellectual development of mankind. The review of literature in this area also suggests that an emphasis on history of science case studies could provide better motivation for students not majoring in science than the traditional textbook approach.

Richard B. Conant (14) stated that a science course emphasizing

historical case studies should show:

(a) the difficulties which attend each new push forward in the advance of science,

(b) the importance of new techniques -- how they arise, are improved, and often revolutionize a field of inquiry,

(c) the interplay between experiment, observation, and the development of new concepts, and how one conceptual scheme is modified or displaced by another.

The test of a new idea or concept involves its success or failure in stimulating further experimentation or observation which is in turn fruitful. This dynamic quality of science can be demonstrated by the historical approach, and/or else learned by direct professional experience. Conant also made the following assumptions regarding the non-science oriented student and a first year college science course:

Our program of instruction is based on the following assumptions about the majority of the students who, it will be recalled, are freshmen and sophomores in Harvard College not planning to concentrate in one of the natural sciences:

1. They enter the course with only a slight interest in science, pure or applied, and will furthermore be somewhat hostile to all mathematical formulations;
2. In addition to having a favorable response to the emotional appeal of art and literature, they will be more interested in human problems than in those questions presented by either a study of nature or machines;
3. History as a human drama will have a definite appeal;

4. Latent scientific curiosity which is so important an element in the motivation of embryo scientists will be difficult to discover and still more difficult to bring into action;
5. On the completion of the course, the understanding of science will be a more integral part of their intellectual equipment if there has been a constant emphasis on the relation of the material presented to the intellectual and cultural history of the last four hundred years. (13, p. 3-4).

The most expeditious way to present a science course for the non-scientist according to F. S. Allen (1) would be to rely on a core of detailed case studies such as those Conant organized. The case studies should focus sharply on the paths which led to discovery or change, provide biographical data on the men involved, and estimate the particular contribution of this work to knowledge and society. Laboratory exercises should be organized to support the historical principle of the course as well as the investigative principle so germane to the meaning of science.

If discoveries in science are to have an honest effect on human thought and on culture, they have to be understandable; and according to J. R. Oppenheimer (31), this is likely to be true only in the early periods of a science, when it is talking about things which are not too remote from ordinary experience. . . He states:

All these themes - the origin of science, its pattern of growth, its branching reticular structure, its increasing alienation from the common understanding of man, its freedom, the character of its objectivity and its openness

are relevant to the relations of science and culture and should be emphasized more than they are today (31, p. 101).

H. M. Thomas (41) recommended the widening of science teaching in British universities so that it could deal with the humanistic aspect of natural knowledge through well planned sequences in the history of science.

The humanities and the sciences differ primarily in the form in which experience is explored; the need to explore remains the same. For this reason the society of scientists is more important than their discoveries and the behaviors involved in scientific inquiry need more emphasis than the knowledge resulting from discovery.

A clear and interesting account of the personal qualities and behaviors involved in scientific investigation may be found in Walter B. Cannon's book The Way of an Investigator (11). Cannon pointed out the influence of circumstances, hunches, and chance on scientific discovery in addition to the responsibility of the scientist to mankind in general.

A. McAuley (27) discussed the origin of the cell principle in terms of the insights it affords into the process of scientific discovery and the development of knowledge in terms of the intellectual and social context of the time. McAuley concludes that there is no better way for non-scientists to develop insights into the methods and impact of science than by careful analysis of the classical documents of

scientific literature.

According to Henry Winthrop (43) most liberal arts students emerge from four years of undergraduate instruction with little or no appreciation of the history of science and the many convergent streams of thought which have produced its present social and intellectual organization. A course which would impart an appreciation of the many ways in which science and social concerns tend to become interlocked in some fashion would be a unique curricular experiment and would tend to remove a sense of alienation over the relevancy of science to the everyday life of the citizen.

The use of history of science case studies has been suggested in the literature to provide a more realistic picture of the nature of scientific inquiry. According to this view highly personal accounts of work done by scientists should be presented to show problems and mistakes in scientific investigation as well as successes. Alienation between science and society could be diminished if scientists were more often pictured as human beings with human needs and aspirations.

The historical approach to science instruction is sound teaching according to A. J. Ihde (20) since it enables the student to see the knowledge of the subject revealed in a manner similar to which it unfolded before the eyes of the greatest investigators in the field. Chemistry, for example, did not start out with a structural atom as some of our present-day textbooks do. Concepts of elements,

compounds, atomic weights, valence, and electro-chemical behavior had to be developed first. Only when these matters were understood was there a place and need for the structural atom. Students should be able to master the subject in the manner that it was mastered by the best investigators in the field. The alternative would seem to be a sterile mental exercise without any real understanding.

According to Leonard K. Nash (30), the public's misunderstanding of, and occasionally positive antipathy towards science and scientists is a bitter reflection on the methods by which we have previously attempted to teach science. Nash noted the widespread misapprehension of the real history of the oxygen theory -- an exciting and revealing story. Before Lavoisier's work, an oxygen theory could not meet the test of consistency. Since air was still regarded as an element it was very difficult to explain, on an oxygen theory, why it is that a flame expires before all the air available to it is exhausted. Some of the factors which promoted the delay in the creation of the oxygen theory are related to influences that are still active in retarding modern scientific progress. Nash believed that in calling attention to the difficulties, delays, and failures of science, as well as to its triumphs, we present a truer, better rounded, and much more useful picture of it as it was in the beginning and as it is today.

The study of the history of science breaks down the myth that progress is only made by scientists who are coldly objective and who

are humble only before facts. Sentiment, bias, passion, and prejudice play a role in the history of science. Michael Polanyi (32) noted that what is to be regarded as scientific evidence and what is not to be so regarded, often tends to be a result of intellectual passions. The misuse of the mathematical theory of probability and the inaccurate description of skills and processes are often a product of sentiment or strong conviction.

Ernest Nagel (29) noted that the history of science records an impressive quota of abandoned theories, corrected assumptions, and mistakes. Consequently, he believed that no account of the scientific method is adequate which does not take notice of the ways inquiry can go astray, e. g., the premature delimitation of the set of variables upon which the occurrence of a phenomenon may depend and the pressure of social or political institutions or the desire of scientists to justify their specialized labors to a larger community of scholars.

The Use of History of Science Case Studies in Teaching Scientific Thinking

History of science case studies have been used in a variety of ways to illustrate skills involved in scientific processes. These approaches have usually involved seminar-type discussions, but in very few cases have history of science materials been used to develop specific behaviors involved in scientific thinking.

According to W. C. Van Deventer (42) the increased interest in and emphasis on the history of science has coincided with a growing realization of the ineffectiveness of much laboratory teaching and the impossibility of teaching all of this body of knowledge, even to a major student. Many teachers therefore, have been led to the conviction that the important factor, particularly in beginning courses, is to bring students to an understanding and an appreciation of the point of view of the scientist and the things he does in gaining new knowledge and fitting it into meaningful patterns.

Even though there is no single definable scientific method, there is a kind of common denominator which is also involved in problems of everyday living. This common procedure, according to Van Deventer involves data accumulation, tentative solutions, and a simple cycle of proof involving both inductive and deductive thinking.

According to Joseph Schwab (33) general statements of scientific method are of little value because no historically given statements suffice to interpret all inquiries of science. Thus, he argues that an instance of science requires methodological classification, i. e., a taxonomy of scientific methods. To be liberalizing in its effects, science teaching must demonstrate methods that are genuine and stimulate their practice as well as lead to knowledge of scientific subject matter. Schwab believed that the discussion of original scientific papers is the most appropriate means of achieving this purpose

at the college level.

Seminar-type discussions of original scientific papers were described by Schwab (34) at the University of Chicago. These discussions, as well as means to achieve knowledge, also represented "that kind of attack upon the problem at hand which would be found appropriate and proper, defensible as a part of the discipline of the field in question, by a master in that field" (34). Students in these discussions participated in some way or other in the processes of examining the data, selecting and rejecting alternative notions, trying and testing that which originally went into the production of the theory.

Dressel and Mayhew (15) have recommended the use of popular articles on scientific developments in general science courses for non-science majors to be used with specific questions related to the objectives of science in a liberal education as developed by the Natural Science Committee of the Cooperative Study of Evaluation in General Education in 1949. A guide was developed to construct questions designed to develop the following five abilities involved in scientific thinking:

1. Ability to recognize and state problems.
2. Ability to select, evaluate, and apply information in relation to problems.
3. Ability to recognize, state, and test hypotheses.
4. Ability to recognize and evaluate conclusions, assumptions,

and generalizations.

5. Ability to recognize and formulate attitudes and take action after critical consideration.

Melvin Berger (4) described one way in which the history of science might be used as the "detective story approach". The experiments and discoveries become clues, leading to a solution of a mystery. Experiments are described and students are asked, "What does this tell us?"

Berger states the following reasons for using historical materials in science:

The student is lead to a full awareness of process and scientific method. This can lead to clearer thinking and experimenting on the student's own projects ... it also makes it easier to grasp in greater and greater depth the new information he is given. And finally, it enables him to accept, and put into perspective, the new discoveries in science that are coming from today's laboratories. If he knows and understands the thinking and experimenting that led to the older information, it is an easy task for him to build on that foundation, and assimilate the new findings (4, p. 25).

Leon Lessinger (25) described a high school seminar in the history of science for outstanding science students. Students studied certain men and their scientific achievements. These studies were related to the period in history and the types of behaviors involved. Students were asked to defend their position in the seminar in relation to the basic question, "Is science an intellectual game the rewards of

which are objective truths, or is it a practical task which produces knowledge and projects of value?" The author reported that interest was high in these discussions and that the seminar fulfilled a basic gap in the curriculum.

Dorothy Stimson (38) described a course on the history of the scientific point of view which had been taught for 25 years in a liberal arts college for women. This was an attempt to show the importance of subject matter in the opinion and from the experience of the students themselves. Stimson stated that the historical approach reached many students who would otherwise be deterred by their own unfamiliarity with technical terminology and helped to relate science to knowledge as a whole. The development of science was traced through the civilizations of western Europe from primitive man to Pasteur. Detailed study of two important ideas involved classroom talks and discussions. Major documents were read to give students firsthand glimpses of the thread of science through the maze of historical material available. An informal questionnaire was given to students to determine the significance of this course. The most frequently checked items involved the development of interest in the history of ideas, the historical perspective and an increased appreciation of the scientific method. Stimson also claimed that students were able to apply the scientific method to a variety of endeavors as a result of this course.

Jeffrey Baker and Garland E. Allen (2) made use of historical case studies in a supplementary textbook, Hypothesis, Prediction, and Implication in Biology. This book is unique in that it uses case study material which is organized inductively as suggested by Easley. Separate lines of argument leading to a theory are separated and analyzed, and case studies are used to illustrate principles of scientific method, particularly hypothesis testing and interpretation of data.

Research Studies Evaluating the Use of History of Science Case Studies

A small number of experimental studies have been carried out at the high school level to determine the effectiveness of history of science case studies in teaching various aspects of scientific thinking. With the exception of the Klopfer and Cooley study (24), samples in these studies have been small and poorly controlled, and the investigator has not noted any comparable studies at the university level. There is some evidence, however, that skills involved in scientific thinking can be developed through the use of history of science case studies.

Klopfer and Cooley (24) have used history of science case studies with a large group of tenth grade students and have concluded that the method was definitely effective in increasing student

understanding of science and scientists. Highly significant gains on the Test on Understanding Science (TOUS) were achieved with little or no loss of achievement in the usual content of high school science courses. Klopfer and Cooley claimed that the so-called "intangible" objectives of science instruction can be measured and that with the expenditure of relatively little class time and through the use of instructional materials specifically designed for this purpose, significant student gains in these important understandings can be achieved.

The history of science case study "The Chemistry of Fixed Air" was used at the junior high school level in a study by Elba O. Carrier (12). Significant increases in scores on the Test on Understanding Science are reported as a result of the use of the case study. There is some question as to the validity of such a conclusion, however, since the experimental and control groups involved only two classes and were not taught by the same instructor, thus leaving variables associated with teaching methodology uncontrolled. Subjects were randomly assigned to classes, although the number of subjects, e. g. 20 students in the control group, may have been too low to completely eliminate bias.

A study by B. S. Thomas (40) involved the use of a history of science case study entitled "The Earth's Crust", with high school students in high ability and low ability groups. Significant gains in

student's understanding of science and scientists, as measured by the Test on Understanding Science (TOUS), were found only in the high I. Q. group. No definite conclusions were drawn from this study. Problems were mentioned regarding lack of time and guidance regarding the objectives of the work. It is likely that insufficient time was given to the control of variables associated with teacher methodology, possible bias in the selection of subjects and ability to read.

Research Studies Evaluating the Ability to Think Scientifically

A study by Louis Teichman (39) involved specific teaching techniques designed to teach ninth grade pupils to evaluate the conclusions made from experiments. A test battery was designed to measure students ability to make conclusions and was administered to 550 ninth grade students. Students in the experimental group who received specific instruction in the ability to draw conclusions made significantly higher mean scores on the test instrument than the control group.

Science variables associated with teacher effectiveness were not controlled in this study, only limited conclusions should be drawn. However, Teichman's study does present some evidence that student's ability to make conclusions can be improved by specific classroom instruction in a relatively short period of time.

In a study by Blair and Goodson (5), ninth grade pupils were tested on Form 1 of Noll's "What Do You Think?" test of scientific thinking. Students given special instruction in how to think scientifically made average gains of 7.3 points on this test compared to 4.8 points by students not given this instruction. Blair and Goodson concluded that general science does not, in and of itself, make a unique contribution to the development of scientific thinking and that a marked improvement in scientific thinking is obtained when special exercises are utilized which emphasize the evaluation of other person's thinking.

A study of high ability secondary school student's critical thinking ability and understanding of scientists and the scientific enterprise was reported by Paul M. Smith (36). Boys made significantly higher scores on both the Watson-Glaser Critical Thinking Appraisal (WGCTA) and the Test on Understanding Science (TOUS) even though all students tested had chosen a summer science training program. A significant finding in this study is that the older girls achieved at the lowest level of all the sub-groups.

A study by Mason (26) compared students taking a lecture and laboratory program designed to teach scientific thinking with students in a control group taught by the descriptive method of instruction. The program designed to teach scientific thinking emphasized the ability to:

1. Recognize cause and effect relationships.
2. Interpret data and draw conclusions therefrom.
3. Recognize and test hypotheses.
4. Recognize problems.
5. Critically evaluate experimental procedures.

Mason concluded that (1) the "telling" or descriptive method of teaching is more effective in teaching factual information and may be more economical in time and effort to present materials to be learned; (2) the ability to think scientifically can be taught more effectively when students are given direct training in the methods of science than when they do not receive such training. However, the techniques used in lecture for the direct teaching of the abilities associated with scientific thinking were apparently no more effective than the traditional lecture method. And (3) it is possible to construct effective materials for the direct teaching of scientific attitudes and methods, as students using a laboratory guide designed to teach scientific thinking did significantly better on a test designed to measure scientific thinking than students who did not use this guide. Mason also points out the need for further research with respect to the development of materials and procedures for the direct teaching of the skills inherent in scientific thinking.

There seems to be some evidence, therefore, that materials of instruction can be utilized to develop skills involved in scientific

thinking and within the framework of the one year university course. This objective would seem to be particularly important for students in Science Education, as in order to teach science one must certainly understand the nature of the scientific enterprise.

The Development of Scientific Attitudes

To facilitate the investigation of scientific attitudes, a distinction must be made between scientific attitude and various aspects of scientific method, which are related but are by no means identical.

Scientific attitude involves the use of knowledge as well as the techniques involved in obtaining it, and involves tendencies to pursue certain types of activity as well as tendencies to avoid others. Robert L. Ebel has set up the following criteria which are useful in identifying a scientific attitude:

1. Can the thing suggested be a mental set?
2. Can the thing suggested affect a variety of stimuli?
3. Can the thing suggested condition the mind to a certain type of response?
4. Can the thing suggested become stabilized?
5. Can the thing suggested foster scientific achievement, which includes:
 - A. Additions to the world's store of organized truth,
 - B. Addition to the individual's store of organized truth,
 - C. Use of organized truth as a basis for determining action? (17, p. 78).

An investigation of the literature has not shown any studies evaluating specific attitudes resulting from the use of history of science materials. Related studies indicate that little progress has been made toward the development of positive and realistic attitudes toward science. Evidence is conflicting and inconclusive regarding the possibility of changing scientific attitudes within the framework of the traditionally organized one year science course.

Traditional fact oriented science courses have been criticized by educators, scientists and science educators for not developing any real understanding of the nature of scientific inquiry. This viewpoint is supported by an attitude survey by Mead and Metraux (28), who conclude that high school students' understanding of how scientists work is grossly inadequate and in many cases is seriously distorted.

A study by Catharine Bergen (3) indicated that the student reader of a science textbook is not always a good judge concerning his understanding of the type of information needed to dispel his ignorance. This implies that the student is not generally a reliable judge of the science information he is likely to find useful. According to Bergen long range motivation is needed for the non-scientist to develop positive attitudes toward science study.

According to E. D. Heiss (19) students who engage in wide reading in general science develop scientific attitudes more so than those who study a single textbook. Episodes in the history of science

can help students to gain a better understanding of the attitudes, emotions, and safeguards in thinking which characterize confidence in scientific methods.

A study by T. R. Brown (7) showed that students taking a course in high school chemistry scored significantly higher (.05 level) than non-chemistry students in attitudes toward science. Scholastic aptitude was controlled in this study and the Reaction Inventory, Attitudes Toward Science and Scientific Careers was used as the evaluation instrument. This study may indicate that attitude changes can result from specific course work in science, or that these attitudes existed beforehand in the group of students who elected to take chemistry.

In a study of relationships between scientific attitude and the teaching of general science, J. W. Eberhard and George W. Hunter (18) concluded that the added emphasis given to the teaching of the scientific attitude and the use of a text that is organized for the purpose of imparting skill in this type of thinking does not modify scientific attitude scores. The test instrument used in this study was the Hoff Scientific Attitude Test. Eberhard and Hunter also expressed doubt that scientific attitude could be changed in a short period of time through classroom teaching procedures. Extraneous variables such as maturation and the effect of other classes were also mentioned as difficult to control in this type of study.

In a survey reported by Simmons (35), 54.1 percent of 107 colleges and universities did not include in their curriculum, in any form whatever, a course directly or indirectly connected with the teaching of the history of science. Of the schools offering history of science, slightly more than half included the course under the offerings of the Department of Philosophy, while the remainder list the course under the Department of History. In all but two cases the course was offered as an elective. Lack of an available textbook and suitably trained faculty members are listed as frequent reasons for not offering the course.

Summary

During the last 20 years many educators have expressed the opinion that science courses should place more stress on objectives which develop an understanding of scientific inquiry and the relationship between science and the social, cultural and intellectual development of mankind. Interest has been expressed in the use of historical case studies to achieve these objectives.

A survey of the literature, however, revealed relatively little classroom emphasis on the history of science in contrast to the interest shown by many educators. A small number of research studies indicate that some of the "intangible" process objectives of science teaching have been achieved through the use of history of

science case studies at the high school level. There have been no comparable studies at the college level even though most of the references to the use of historical case studies were made by educators concerned with college level teaching.

Most of the concern expressed in this survey has resulted in opinions and belief statements. These statements require documentation and define the need for research in this area.

III. THE STUDY

Student Population

The subjects in this study were students at the University of Victoria, who during the 1969-70 school year were enrolled in Education 145: General Science. Since this is a required course for all first year students in Elementary Education, the sample consisted of the entire population of first year Elementary Education majors at the University of Victoria. Since Education 145 is not open to students outside the Faculty of Education, all students involved in this study are preparing to become elementary school teachers. The homogeneity of this student population was further increased by the fact that a maximum of one elective was allowed in the first year of the program.

The great majority of students involved in this study were unmarried and between the ages of 18 and 21. Less than ten percent of these students were either married or over the age of 21. Of the 310 students who took part in this study, 278 were females and 32 were males. Approximately three-quarters of the students in this population came from homes on lower Vancouver Island and live at home. The remainder of these students who board at the University came from widely separated areas around the province of British Columbia.

The student population was relatively homogeneous in that the typical student was a female between the ages of 18 and 21, who lived in the Greater Victoria area and is majoring in Elementary Education.

From the experience of this investigator, the student profile described above conforms rather closely to the assumptions made by Conant regarding the non-science oriented college student (see Chapter II). Most students entering Education 145 seem to have only a slight interest in science, are somewhat hostile to mathematical formulations, and are more interested in art, literature, and human problems. In an unpublished survey conducted at the University of Victoria (44), students were asked to rank ten elementary school subjects in order of teaching preference. Science ranked 5.35 out of ten with one the first choice.

Procedures and Experimental Design

Education 145 is divided into two semesters, each of approximately 12 weeks duration consisting of three hours of lecture and a two hour lab per week. Four instructors were involved in teaching Education 145, which deals with subject matter concepts from the areas of Physics, Chemistry, and Biology. Students meet as a group with one instructor for lectures but meet with different instructors during laboratory periods. To eliminate any bias associated with

different instructional methods, therefore, all students were randomly assigned to either the experimental or the control group. A table of random numbers from Kendall (22) was used to assign one digit to each name on the class list. Students receiving even digits were designated as the experimental group. Students receiving odd digits were designated as the control group.

At the beginning of the second semester, students in the control group were given reading assignments in a textbook, Buchsbaum's Basic Ecology. At this time, students in the experimental group were given the first of several case studies (see Appendix 1).

The Randomized Post Test Only Control Group Design was used in this study because it was thought to be impossible to control all of the instructional variables present in 14 different laboratory sections. By randomly assigning reading materials, however, instructional variations and biases applied equally to the experimental treatment and the control treatment. Students, therefore, received different treatment only in the type of material they read and the discussions related to the reading.

Campbell and Stanley (10) note that the most adequate all-purpose assurance of lack of initial biases between groups is randomization. Within the limits of confidence stated by the tests of significance, randomization can suffice without the pre-test. Furthermore, in educational research, we must frequently

experiment with methods for the initial introduction of entirely new subject matter, for which pre-tests in the ordinary sense are impossible or would be inappropriate.

There is evidence of highly significant pre-test post-test gains in the use of the Burmester Test of Aspects of Scientific Thinking. Kaplan (21) reports a four year study in which the improvement in performance through the use of two forms of the Burmester test in every case was significant at the 0.01 level of confidence. It would seem, therefore, that the use of a pre-test in this situation would be inappropriate since the use of the pre-test itself would result in learning effects which would vary from individual to individual. The variables introduced by the use of a pre-test would be very difficult to control.

Campbell and Stanley (10) note further that the largest number of extraneous variables, which might be confounded with the effect of the experimental stimulus, are adequately controlled in the Post-Test Only Control Group Design: history, maturation, testing, instrumentation, regression, selection, mortality, and interaction of selection and testing. The Post-Test Only Control Group Design is compared with other experimental designs in the table on the following page from Campbell and Stanley (10, p. 178).

The mimeographed case studies were passed out weekly during the semester to students in the experimental group in the following

Table 1. Sources of Invalidity for Designs 1 through 6

	Sources of Invalidity											
	Internal								External			
	History	Maturation	Testing	Instrumentation	Regression	Selection	Mortality	Interaction of Selection and Maturation, etc.	Interaction of Testing and X	Interaction of Selection and X	Reactive Arrangements	Multiple-X Interference
Pre-Experimental Designs:												
1. One-Shot Case Study X O	-	-				-	-			-		
2. One-Group Pretest- Posttest Design O X O	-	-	-	-	?	+	+	-	-	-		?
3. Static-Group Comparison X O O	+	?	+	+	+	-	-	-		-		
True Experimental Designs:												
4. Pretest-Posttest Con- trol Group Design R O X O R O O	+	+	+	+	+	+	+	+	-	?		?
5. Solomon Four-Group Design R O X O R O O R X O R O	+	+	+	+	+	+	+	+	+	?		?
6. Posttest-Only Control Group Design R X O R O	+	+	+	+	+	+	+	+	+	?		?

Note: In the tables, a minus indicates a definite weakness, a plus indicates that the factor is controlled, a question mark indicates a possible source of concern, and a blank indicates that the factor is not relevant.

It is with extreme reluctance that these summary tables are presented because they are apt to be "too helpful," and to be depended upon in place of the more complex and qualified presentation in the text. No + or - indicator should be respected unless the reader comprehends why it is placed there. In particular, it is against the spirit of this presentation to create uncomprehended fears of, or confidence in, specific designs.

order:

1. Spallanzani and Spontaneous Generation
2. Important Experiments by Louis Pasteur in Micro-biology
3. Robert Koch: Microbes and Disease
4. Why Are We Here? A Study of Some Controversial
Scientific Speculations about the Origin of Man.
5. Experiments by John Mayow on the Substance Involved in
Both Burning and Respiration
6. The Phlogiston Theory
7. Joseph Black's Discovery of "Fixed-Air"
8. Combustion and Respiration: Experiments by Antoine
Lavoisier and Pierre LaPlace
9. Justus Liebig's Research on Biological Oxidations
10. Edward Buchner and the Discovery of Enzymes
11. The Search for Intermediate Compounds in Metabolism

A pilot study carried out during 1968-69 indicated that this sequence represented the approximate order of reading difficulty, from easiest to hardest. As a result of this pilot study, the Lavoisier case was rewritten and diagrams included. Two case studies, 9. Justus Liebig's Research on Biological Oxidations and 11. The Search for Intermediate Compounds in Metabolism, were assigned as optional reading since student feedback in the pilot study indicated that little more than 25% of the students sampled could profit from

these readings.

Case Study 4: Why Are We Here? was expanded greatly after the pilot study because of the large amount of interest indicated in student feedback.

Careful instructions were given to all students at the onset of the study that different reading assignments of approximately equal difficulty would be given in order to determine the type of reading materials best suited for students in a general science course. Students were assured that neither group would be at a disadvantage since alternate forms of the final examination would include questions specific to each reading assignment. It was emphasized, however, that a student would be penalized if he or she read the wrong reading assignment. These instructions were essential to avoid contamination of the two reading groups. Experience has shown that students generally read only examinable materials and the investigator did not detect any contamination of the two groups. A few students expressed some apprehension that the different reading assignments might represent ability groupings. It was carefully explained, therefore, that the readings were assigned in a completely random manner. Student feedback at the end of the course indicated that readings in both the experimental and control groups were considered to be interesting, pertinent, and of reasonable difficulty. No comments from students indicated any wish to change reading materials nor was any serious

dissatisfaction indicated in either group. Therefore, it is reasonable to assume that the experimental and control groups were relatively uncontaminated.

Special instructions were given to students in the experimental group regarding the use of the case studies. For example, it was suggested that students underline examples of hypotheses, data supporting hypotheses, controls, conclusions, etc., while reading, and cite these examples in answering questions. The main objectives to be achieved through the use of the case studies were carefully emphasized at the beginning of the term. Students were assured that they would be examined on their ability to think scientifically, rather than on the factual knowledge contained in the case studies. The objectives were discussed in behavioral terms. For example, it was indicated that students should be able to identify the control in a discussion of a scientific experiment and be able to indicate to what extent the experimental evidence justifies a conclusion.

Since many of the questions in the case studies were of the open ended variety students were given the opportunity to discuss their answers during three 50 minute review sessions held during the laboratory periods. In the opinion of the investigator these review sessions provided positive reinforcement and motivation which was desirable in pursuing the reading assignments for the semester. Students in the control group also met in review sessions to discuss

text book readings.

With the exception of the three review sessions the experimental and control groups carried out the same laboratory activities and received the same lectures. To ensure complete randomization and to eliminate variables associated with teaching method, no change of laboratory instructors was made in conjunction with the use of the case studies. Since students in the experimental group were randomly selected to read case studies, these students were just as likely to have one lab instructor as another. The same was true of the control group. For this reason it was not necessary to equate the two groups in terms of teaching method, possible variations in ability, or time actually spent in the classroom.

The size of the sample was large enough to ensure complete randomization in the selection of the experimental group (N=156) and control group (N=154).

The Test on Aspects of Scientific Thinking was administered during the final laboratory period of the term (April 7, 1970). Identical instructions were given to each section and exactly one hour was allowed for the test. Out of 310 students who took part in this study, 19 students did not write this examination. Of these 19 students, ten were in the control group and nine were in the experimental group. These absentee students were excluded from the study to ensure standardization in the comparison of test results. It is not likely that

this small mortality rate would cause significant differences between the treatment groups.

The Nature of Science Scale was administered during the final lecture examination on April 9, 1970. Five students in the control group and three in the experimental group did not write this examination and were excluded in the final analysis of data.

In the determination of final course grades for students in Education 145, laboratory reports and quizzes counted 50% and examinations on subject matter concepts presented in lectures counted for the remaining 50%. Scores on the two criterion tests mentioned above were not used in determining final course grades.

Evaluation Instruments

The main test instrument used in this study was the Test on Aspects of Scientific Thinking: Form A. This test was developed by Mary Alice Burmester at Michigan State College and is based on educational objectives which were formulated and defined in terms of the following behaviors attending the objectives (9, p. 260-263):

1. 00 Ability to recognize problems.
 1. 10 Ability to recognize a problem or a perplexity in the context of a paragraph or an article.
 1. 20 Ability to distinguish between a fact (observation) and a perplexity or problem.
 1. 30 Ability to recognize a problem even when it is stated in expository form rather than in interrogatory form.

1. 40 Ability to distinguish a problem from a possible solution to a problem (hypothesis) even when the hypothesis is presented in interrogatory form.
1. 50 Ability to avoid becoming diverted from the major problem into side issues.
2. 00 Ability to delimit a problem.
 2. 10 Ability to distinguish between major and minor problems.
 2. 20 Ability to isolate the single major problem or single major idea in a problem.
 2. 30 Ability to see the relationship of minor problems to the major problems.
 2. 40 Ability to distinguish between relevant and irrelevant problems.
 2. 50 Ability to analyze the problem into its essential parts.
 2. 60 Ability to concentrate on the main problem.
 2. 70 Ability to recognize the basic assumptions of a problem.
3. 00 Ability to recognize and accumulate facts related to the solution of a problem.
 3. 10 Ability to select the kind of information needed to solve the problem.
 3. 20 Ability to recognize valid evidence.
 3. 30 Ability to differentiate between reliable and unreliable sources of information.
 3. 40 Ability to select data pertinent to the solution of the problem.
 3. 50 Ability to recognize the difference between data pertinent to the solution of the problem and that which is unrelated.
4. 00 Ability to recognize an hypothesis.
 4. 10 Ability to distinguish an hypothesis from a problem.
 4. 20 Ability to differentiate between a statement that describes an observation and a statement which is an hypothesis about the fact.
 4. 30 Ability to distinguish between an hypothesis as a possible solution to a problem and a conclusion (probable solution to a problem).
 4. 40 Ability to recognize the tentativeness of an hypothesis.

- 5.00 Ability to plan experiments to test hypothesis.
 - 5.10 Ability to select the most reasonable hypothesis to test.
 - 5.20 Ability to differentiate between an uncontrolled observation and an experiment involving controls.
 - 5.30 Ability to recognize the fact that only one factor in an experiment should be variable.
 - 5.31 Ability to recognize what factors must be controlled.
 - 5.32 Ability to recognize the overall control.
 - 5.33 Ability to recognize the partial controls.
 - 5.34 Ability to recognize the variable factor.
 - 5.35 Ability to understand why the overall control was included in an experiment.
 - 5.36 Ability to recognize the factor being held constant in the overall control.
 - 5.37 Ability to recognize the factors being held constant in the partial controls.
 - 5.40 Ability to recognize experimental and technical problems inherent in the experiment.
 - 5.50 Ability to criticize faulty experiments when:
 - 5.51 The experimental design was such that it could not yield an answer to the problem.
 - 5.52 The experiment was not designed to test the specific hypothesis stated.
 - 5.53 The method of collecting the data was unreliable.
 - 5.54 The data were not accurate.
 - 5.55 The data were insufficient in number.
 - 5.56 Proper controls were not included.
 - 5.57 No controls were included.
- 6.00 Ability to carry out experiments.
 - 6.10 Ability to recognize existence of errors in measurement.
 - 6.20 Ability to recognize when the precision of measurement given is warranted by the nature of the problem.
 - 6.30 Ability to make accurate observations.
 - 6.31 Ability to observe differences in situations which are similar.
 - 6.32 Ability to observe similarities in situations which are different.
 - 6.40 Ability to organize facts into tables, graphs, etc., for easy interpretation.

- 7.00 Ability to interpret data.
 - 7.10 Ability to handle certain basic skills necessary to the interpretation of data.
 - 7.11 Ability to read tables and graphs.
 - 7.12 Ability to perform simple computations.
 - 7.20 Ability to evaluate relevancy of data.
 - 7.21 Ability to recognize hypothesis and conclusions contradicted by the data.
 - 7.22 Ability to recognize hypotheses and conclusions which are unrelated to the data.
 - 7.23 Ability to select the hypothesis from a group of hypotheses which most adequately explains the data.
 - 7.24 Ability to recognize facts which support an hypothesis or a conclusion.
 - 7.25 Ability to recognize facts which contradict an hypothesis or a conclusion.
 - 7.30 Ability to differentiate between facts and inferences.
 - 7.31 Ability to differentiate between an observation and a conclusion drawn from the observation.
 - 7.32 Ability to differentiate a conclusion from an hypothesis.
 - 7.33 Ability to distinguish an assumption upon which a conclusion depends and the conclusion itself.
 - 7.34 Ability to distinguish a fact from an assumption.
 - 7.40 Ability to recognize the limitations of data.
 - 7.41 Ability to differentiate between what is established by the data alone and what is implied by the data.
 - 7.42 Ability to recognize that a statement which goes beyond the data cannot be absolutely true.
 - 7.43 Ability to recognize that generalizations from results of an experiment can only be extended to new situations when there is considerable similarity between the situations.
 - 7.44 Ability to confine definite conclusions to the evidence at hand.
 - 7.50 Ability to consider as possibly true or probably true inferences based on the data.

- 7. 51 Ability to make inference on the basis of trends.
- 7. 52 Ability to extrapolate.
- 7. 53 Ability to interpolate.
- 7. 54 Ability not to be so overcautious that all statements which go beyond the data are rejected because of insufficient evidence.
- 7. 60 Ability to perceive relationships in data.
 - 7. 61 Ability to make comparisons.
 - 7. 62 Ability to see element in common to several items of data.
 - 7. 63 Ability to recognize prevailing tendencies and trends in data.
 - 7. 64 Ability to recognize that when two things vary together that there may be a relationship between them, but does not assign cause and effect judgments on the basis of this relationship.
 - 7. 65 Ability to formulate reasonable generalizations based upon the data.
- 7. 70 Ability to recognize the nature of evidence.
 - 7. 71 Ability to recognize the difference between direct and indirect evidence.
 - 7. 72 Ability to recognize a statement which is given as evidence as not being evidence when the statement contradicts the conclusion.
 - 7. 73 Ability to recognize a statement which is given as evidence as not being evidence when the statement is unrelated to the conclusion.
 - 7. 74 Ability to recognize evidence for an inference and to choose such evidence from a series of statements.
 - 7. 75 Ability to recognize the validity of the evidence used to support conclusions.
- 7. 80 Ability to recognize the assumptions involved in the formulation of hypotheses and conclusions.
 - 7. 81 Ability to recognize assumptions which go beyond the data but which are essential to the formulation of an hypothesis.
 - 7. 82 Ability to recognize assumptions which must be maintained in the drawing of a conclusion.
 - 7. 83 Ability to recognize assumptions which can be checked experimentally.
 - 7. 84 Ability to recognize invalid assumptions.

- 8.00 Ability to apply generalizations to new situations.
 - 8.10 Ability to refrain from applying generalizations to new situations does not closely parallel the experimental situation.
 - 8.20 Ability to be aware of the tentativeness of predictions about new situations even when there is a close parallel between the two situations.
 - 8.30 Ability to recognize the assumptions which must be made in applying a generalization to a new situation.

Situations were identified in which students could be expected to display these behaviors and test items were written to appraise them. A total of 637 tentative test items were written and given to five experts for keying, criticism, and suggestion. The items were revised on the basis of these judgements and assembled into sub-tests. Tryout tests were administered to first year students at Michigan State University. Item validity was determined by the method of Davis and Flannigan, and item difficulties were estimated by the method proposed by Davis. Ten - twenty of the best items were selected for each sub-test.

The final forms of the test were administered to first year university students at the beginning of the year and after one term of science. The reliability of Form A as determined with beginning students by the split-half method with the Spearman-Brown correction was 0.91 ± 0.01 . The Kuder-Richardson formula gave a reliability of 0.89 ± 0.01 . Reliability figures after one term of science were 0.90 ± 0.02 as determined by the split-half method corrected by the Spearman-

Brown formula and 0.89 ± 0.02 as calculated by the Kuder-Richardson formula (8).

The first technique used by Burmester for statistical validation of the test was a correlation with measures of intelligence, reading ability, and factual information. These results are summarized in Table 2 (8, p. 134):

Table 2. Correlation of tryout test scores and scores on Test 1 with psychological examination scores and reading scores.

Tests	Quantitative	Linguistic	Total	
			Psychological	Reading
Tryout	0.45	0.38	0.51	0.49
Test 1	0.48	0.43	0.51	0.43

These data in a sense are a negative form of validation since a high correlation with traits such as reading ability or intelligence would indicate that the test could not measure what it purported to measure. Test validity cannot be assumed merely because a substantial relationship does not exist with any of the above mentioned factors, however.

A second validation technique involved the comparison of scores made by students who had not yet taken a university level science course with those who had taken such a course. A comparison of differences between the mean test scores of these two groups was

highly significant and in favor of the group having completed a science course. Burmester made the tentative inference, therefore, that the test had some validity in that there was an increase in score related to instruction in the methods of science.

A third validation technique involved the comparison of test scores with the ratings of students by competent judges. Students were rated by their instructors using a rating scale involving:

- (1) the ability to devise and evaluate experiments
- (2) the ability to interpret data, including the ability to form hypotheses and draw conclusions.

Coefficients of correlation were calculated between total scores on the rating scale and (a) scores made on the test prior to taking science and (b) scores made on the same test after one term of science. These correlations were 0.77 ± 0.04 and 0.72 ± 0.04 respectively. (8). In the opinion of Burmester, these correlations provide evidence that the test had a considerable degree of validity providing the ratings of the judges were valid.

The second evaluation instrument used in this study, the Nature of Science Scale, was developed by Merritt E. Kimball (23) and was based on a model composed of eight assertions about important characteristics of science. The following model, according to Kimball, is consistent in its agreement with views expressed by Conant and Bronowski, and also is supported in each assertion by the writings

of other philosophers of science (23, p. 112):

- (1) The fundamental driving force in science is curiosity concerning the physical universe. It has no connection with outcomes, applications, or uses aside from the generation of new knowledge.
- (2) In the search for knowledge, science is process oriented; it is a dynamic, ongoing activity rather than a static accumulation of information.
- (3) In dealing with knowledge as it is developed and manipulated, science aims at ever-increasing comprehensiveness and simplification, emphasizing mathematical language as the most precise and simplest means of stating relationships.
- (4) There is no one "scientific method" as often described in school science text books. Rather, there are as many methods of science as there are practitioners.
- (5) The methods of science are characterized by a few attributes which are more in the realm of values than techniques. Among these traits of science are dependence upon sense experience, insistence on operational definitions, recognition of the arbitrariness of definitions and schemes of classification or organization, and the evaluation of scientific work in terms of reproducibility and of usefulness in furthering scientific inquiry.
- (6) A basic characteristic of science is a faith in the susceptibility of the physical universe to human ordering and understanding.
- (7) Science has a unique attribute of openness, both openness of mind, allowing for willingness to change opinion in the face of evidence, and openness of the realm of investigation, unlimited by such factors as religion, politics, or geography.
- (8) Tentativeness and uncertainty mark all of science. Nothing is ever completely proven in science, and recognition of this fact is a guiding consideration of the discipline.

This test instrument was developed from a pool of more than 200 short statements about the nature of science which were based on

the model stated above. These statements were analyzed by a panel made up of science teachers, science supervisors, science professors, and professors of science education. Items approved by the panel were used in a pilot study from which the final statements were chosen by the panel on the basis of discrimination and agreement with the model. The resulting test was administered to 97 subjects, about half of whom majored in science. The split-half reliability for this form, as corrected by the Spearman-Brown formula was 0.72. Two items were discarded as not showing sufficient discrimination. The remaining 29 statements were arranged in a Likert-type scale, which became the Nature of Science Scale.

Analysis of Data

Statistical treatment of the data involved a two-way analysis of variance to determine the significance of mean test score differences between the control group and the experimental group. Sex was used as a covariate since in other studies, e. g., Smith (36), males have achieved higher scores on tests involving science processes.

Campbell and Stanley (10) recommend the analysis of variance technique with the post-test only control group design and also the use of available antecedent variables as covariates for two main reasons:

1. to increase the power of the tests of significance

2. to explore the generalizability of the findings more thoroughly.

Data are therefore organized according to the following design for all tests of hypotheses in this study:

	<u>Control Group</u>	<u>Experimental Group</u>
Male	-----	-----
Female	-----	-----

Mean total scores and five mean sub-test scores on the Burmester Test of Aspects of Scientific Thinking were analyzed according to the design above to test hypotheses 1-6. Mean total scores on the Nature of Science Scale were analyzed similarly to test hypothesis 7. The same statistical design was used to compare subject matter grades achieved by the control group and the experimental group in Education 145.

The I. B. M. 360-44 computer at the University of Victoria was used for the analysis of variance computation involving the least squares solution for unequal cell totals.

IV. PRESENTATION AND INTERPRETATION OF DATA

Introduction

For each hypothesis to be tested mean test score data and related analysis of variance data have been tabulated. Null hypotheses will be rejected on the basis of a variation in treatment which is significant at the 0.05 level of confidence. Data will also be presented which are not involved in the testing of hypotheses. This will include an analysis of variations due to sex, the interaction between sex and treatment, and variations in subject matter achievement.

Hypothesis One

Means and standard deviations for total scores on the Test of Aspects of Scientific Thinking in the control group and experimental group are presented in Table 3. Mean test scores in every category favor the experimental group. Analysis of variance data that were obtained by comparing group means for significant differences are presented in Table 4. The F ratio of 5.20 is significant beyond the 0.05 level. The first null hypothesis is rejected on the basis of this difference between the experimental and the control treatment. The mean score of the experimental group on the Test of Aspects of Scientific Thinking is significantly higher than that of the control group.

It may be noted in Table 3 that the difference in mean test scores between the experimental group and the control group is greater among males than females. Analysis of variance data in Table 4 compares the mean test scores of males and females. The F ratio of 0.31 for this difference is not statistically significant. Similarly, the F ratio of 0.52 indicates that the interaction effect between sex and treatment is not statistically significant.

Table 3. Means and standard deviations for total scores on the Burmester Test of Aspects of Scientific Thinking.

Category	Control Group			Experimental Group		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Male	16	28.500	10.418	15	32.133	7.772
Female	128	30.195	6.601	132	31.886	7.020
Total	144			147		

Table 4. Analysis of variance data for the comparison of means in Table 3.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	Level of Significance
Treatments	261.9651	1	261.9651	5.20	0.023351
Sex	15.65259	1	15.65259	0.31	0.577747
Interaction between sex & treatment	26.09741	1	26.09741	0.52	0.472359
Error	14463.19	287	50.39438		

Hypothesis Two

Means and standard deviations for sub-test 1, The Ability to Recognize Problems, Experimental Conditions, Hypotheses and Conclusions, are presented in Table 5. Mean test scores in each category favored the experimental group, although the difference was much greater among males than females. Analysis of variance data for the comparison of these means are presented in Table 6. The F ratio of 2.50 is not significant at the 0.05 level. The second null hypothesis is therefore not rejected on the basis of a difference between experimental and control treatment. The mean difference in favor of the experimental group in the ability to recognize problems, hypotheses, experimental conditions and conclusions is not statistically significant. The magnitude of the difference, however, does indicate a trend in the data. This sub-test involves a variety of recognitions which may involve a more superficial level of understanding than the skills tested in the four other sub-tests. If more common knowledge is involved in the skills tested in this sub-test treatment differences would tend to be diminished.

Analysis of variance data in Table 6 indicate that the difference between mean test scores of males and females on sub-test 1 is not statistically significant. The F ratio of 6.91 in Table 6 indicates an interaction between sex and treatment which is significant at the

0.01 level. The mean score difference on sub-test 1 between males in the experimental group and males in the control group is significantly greater than the mean score difference between females in the experimental and control groups. The greater male variability in this skill indicates sex differences, but not necessarily male superiority.

Table 5. Means and standard deviations for scores on Sub-Test 1:
The Ability to Recognize Problems, Hypotheses,
Experimental Conditions and Conclusions.

Category	Control Group			Experimental Group		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Male	16	5.688	.2.024	15	8.333	1.952
Female	128	7.367	2.632	132	7.561	2.365
Total	144			147		

Table 6. Analysis of variance data for the comparison means in Table 5.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	Level of Significance
Treatments	15.02306	1	15.02306	2.50	0.115221
Sex	6.566025	1	6.566025	1.09	0.297107
Interaction between sex & treatment	41.60585	1	41.60585	6.91	0.009024
Error	1727.031	287	6017530		

Hypothesis Three

Means and standard deviations for sub-test 2, The Ability to Understand the Relationship of Evidence to Hypotheses, are presented in Table 7. Mean scores in every category favor the experimental group. Analysis of variance data that were obtained by comparing group means on sub-test 2 for significant differences are presented in Table 8. The F ratio of 0.10 is not significant. The third null hypothesis is not rejected on the basis of a difference between experimental and control treatment. The mean score of the experimental group in the sub-test on ability to understand the relationship of evidence to hypotheses or possible solutions to a problem was not significantly higher than the mean score of the control

group on the same sub-test. Sub-test 2 involves complex skills and reasoning ability which perhaps cannot be developed in the brief period of time spent on these case studies.

Analysis of variance data in Table 8 also show that variations in mean scores on sub-test 2 due to sex and interaction between sex and treatment are not statistically significant.

Table 7. Means and standard deviations for scores on Sub-Test 2: The Ability to Understand the Relationship of Evidence to Hypotheses or Possible Solutions to a Problem.

Category	Control Group			Experimental Group		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Male	16	7.250	2.569	15	7.467	3.044
Female	128	7.906	2.702	132	7.992	2.516
Total	144			147		

Table 8. Analysis of variance data for the comparison of means in Table 7.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	Level of Significance
Treatments	0.7259523	1	0.7259523	0.10	0.746172
Sex	9.725952	1	9.725952	1.41	0.236629
Interaction between sex & treatment	0.1177977	1	0.1177977	0.02	0.896253
Error	1984.605	287	6.915001		

Hypothesis Four

Means and standard deviations for sub-test 3, The Ability to Understand Experimental Methods and the Control of Variables, are presented in Table 9. Mean scores in each category favor the experimental group. In contrast to the other sub-tests, mean score differences due to experimental treatment were greater among females than males. Analysis of variance data for the comparison of mean scores on sub-test 3 are presented in Table 10. The F ratio of 2.70 is not significant at the 0.05 level. The fourth null hypothesis therefore is not rejected on the basis of a difference between experimental and control treatment. The mean difference in favor of the experimental group in the ability to understand experimental methods and the control of variables is not statistically significant. The magnitude of the difference, however, ($P=0.101150$) does approach significance and indicates a trend in the data. Apparently more time was needed for discussion and follow-up activities to fully develop this skill, although some progress is indicated by these results.

Analysis of variance data in Table 10 show that variations in mean scores on sub-test 3 due to sex and interaction between sex and treatment are not statistically significant.

Table 9. Means and standard deviations for scores on Sub-Test 3: The Ability to Understand Experimental Methods and the Control of Variables.

Category	Control Group			Experimental Group		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Male	16	8.250	4.107	15	8.333	3.109
Female	128	7.750	3.325	132	8.417	2.801
Total	144					

Table 10. Analysis of variance data for the comparison of means in Table 9.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	Level of Significance
Treatments	26.58353	1	26.58353	2.71	0.101150
Sex	1.294464	1	1.294464	0.13	0.716929
Interaction between sex & treatment	2.353973	1	2.353973	0.24	0.624928
Error	2820.422	287	9.827253		

Hypothesis Five

Means and standard deviations for sub-test 4, The Ability to Make Conclusions, are presented in Table 11. Mean scores in each category favored the experimental group. Analysis of variance data

for the comparison of mean scores on sub-test 4 are presented in Table 12. The F ratio of 5.39 is significant beyond the 0.05 level. The fifth null hypothesis is rejected on the basis of this difference between the experimental and the control treatment. The mean score of the experimental group in the ability to make conclusions is significantly higher than the mean score of the control group. The difference favoring the experimental group is more highly significant on sub-test 4 than on any of the other sub-tests. The effectiveness of the case studies in developing the ability to make conclusions may be related specifically to case study 4, since a good deal of student interest was expressed in this case study, which stressed the formation of conclusions.

Analysis of variance data in Table 12 show that variations in mean scores on sub-test 4 due to sex and interaction between sex and treatment are not statistically significant.

Table 11. Means and standard deviations for scores on Sub-Test 4:
The Ability to Make Conclusions.

Category	Control Group			Experimental Group		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Male	16	4.188	2.198	15	4.867	1.552
Female	128	4.359	1.813	132	4.864	2.022
Total	144			147		

Table 12. Analysis of variance data for the comparison of means in Table 11.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	Level of Significance
Treatments	19.88213	1	19.88213	5.39	0.020979
Sex	.2063446	1	.2063446	0.06	0.813256
Interaction between sex & treatment	.2116241	1	.2116241	0.06	0.810925
Error	1059.188	287	3.690548		

Hypothesis Six

Means and standard deviations for scores on sub-test 5, The Ability to Interpret Data, are presented in Table 13. Mean test scores in each category favored the experimental group. Analysis of variance data for the comparison of mean scores on sub-test 5 are presented in Table 14. The F ratio of 0.77 is not significant at the .05 level. The sixth null hypothesis is therefore not rejected on the basis of a difference between experimental and control treatment. The mean score of the experimental group in the ability to interpret data is not significantly higher than the mean score of the control group on the same sub-test.

Analysis of variance data in Table 14 also show that variations in mean scores on sub-test 5 due to sex and interaction between sex

and treatment are not statistically significant.

Table 13. Means and standard deviations for scores on Sub-Test 5:
Ability to Interpret Data.

Category	Control Group			Experimental Group		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Male	16	3.125	2.446	15	3.133	1.356
Female	128	2.813	2.187	132	3.053	2.039
Total	144			147		

Table 14. Analysis of variance data for the comparison of means
in Table 13.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	Level of Significance
Treatments	3.387280	1	3.387280	0.77	0.381905
Sex	1.102856	1	1.102856	0.25	0.617681
Interaction between sex & treatment	.3729744	1	.3729744	0.08	0.771578
Error	1267.612	287	4.416767		

Hypothesis Seven

Means and standard deviations for scores on the Nature of Science Scale in the control group and the experimental group are presented in Table 15. Mean scores among females slightly favored the control group. This is the only test score difference in the entire study favoring the control group. Analysis of variance data obtained by comparing group means for significant differences are presented in Table 16. Since the F ratio is not significant, the seventh null hypothesis is not rejected on the basis of a difference between experimental and control treatment. There was no significant difference between the mean score of the experimental group and the control group on the Nature of Science Scale.

Although males achieved higher mean scores in both the experimental and control groups, Table 16 shows an F ratio of 1.51 for this difference, which is not significant at the 0.05 level. The interaction between sex and treatment is also not significant on the Nature of Science Scale.

Table 15. Means and standard deviations for total scores on the Nature of Science Scale.

Category	Control Group			Experimental Group		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Male	15	14.333	3.244	13	14.385	3.305
Female	134	13.582	3.325	140	13.579	3.037
Total	149			153		

Table 16. Analysis of variance data for the comparison of means in Table 15.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	Level of Significance
Treatments	-33.58133	1	-33.58133	-0.00	1.000000
Sex	15.32086	1	15.32086	1.51	0.220716
Interaction between sex & treatment	-1.898313	1	-1.898313	0.00	0.965571
Error	3031.148	298			

Findings Not Related to Hypotheses

An item analysis for the 29 items on the Nature of Science Scale is presented in Table 17. A sharply divergent pattern is noted in comparing the responses of the experimental group and the control group on questions 17, 19, 28 and 29. Three of these statements will be mentioned here since they could indicate attitudes which were emphasized in the case studies.

In the experimental group 102 students disagreed with a statement that scientific investigations follow definite approved procedures, compared with 78 students in the control group. In the experimental group 74 students disagreed with the statement that an important characteristic of the scientific enterprise is its emphasis on the practical, compared with 55 students in the control group. In the experimental group 75 students agreed with the statement that scientific work requires a dedication which excludes many aspects of the lives of people in other fields of work, compared with 56 students in the control group.

Table 17. Nature of Science Scale - item analysis.

Question	<u>Control Group Answer</u>		<u>Experimental Group Answer</u>	
	Agree	Disagree	Agree	Disagree
1.	91	57	80	72
2.	63	83	55	98
3.	85	64	95	58
4.	91	57	87	66
5.	79	68	79	74
6.	40	109	52	101
7.	131	17	139	14
8.	111	38	104	49
9.	28	120	27	124
10.	20	129	20	133
11.	72	77	71	81
12.	64	85	58	95
13.	92	57	96	57
14.	46	103	55	98
15.	64	85	73	80
16.	87	62	87	66
17.	70	78	51	102
18.	39	110	37	115
19.	71	77	44	108
20.	80	69	80	72
21.	126	23	137	15
22.	52	97	63	89
23.	52	97	62	90
24.	116	32	107	44
25.	22	127	21	131
26.	45	103	41	111
27.	19	129	19	133
28.	56	92	75	77
29.	91	55	76	74

Comparison of Subject Matter Achievement

Mean grade point averages for the control group and the experimental group as determined from final course grades in Education 145 are presented in Table 18. Differences in each category favor the experimental group. Analysis of variance data comparing group means for significant differences are presented in Table 19. The F ratio of 0.14 is not significant and does not provide any evidence that grade point average differences between the experimental group and the control group are due to anything more than chance variations. This result indicates that the superiority of the experimental group in scientific thinking was not achieved at the expense of subject matter achievement, since grades in the experimental group were as high as those in the control group.

Analysis of variance data in Table 19 also show that variations in grade-point averages due to sex and interaction between sex and treatment are not statistically significant.

Table 18. Subject matter achievement in Education 145 as determined from final course grades.

Category	Control Group			Experimental Group		
	N	Mean Grade		N	Mean Grade	
		Point Average	Standard Deviation		Point Average	Standard Deviation
Male	16	3.875	2.125	15	4.267	2.963
Female	128	3.898	1.947	132	3.955	2.115
Total	144			147		

Table 19. Analysis of variance data for the comparison of mean grade point averages in Table 18.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	Level of Significance
Treatments	0.6116854	1	0.6116854	0.14	0.709017
Sex	0.5413729	1	0.5413729	0.12	0.725537
Interaction between sex & treatment	0.7789396	1	0.7789396	0.18	0.673688
Error	1258.094	287	4.383601		

V. SUMMARY, IMPLICATIONS, CONCLUSIONS, AND RECOMMENDATIONS

Summary of Results

The main results of the study are summarized on the basis of interpretations made from the statistical analysis of test data.

The following statements treat the hypotheses tested in this study:

1. Analysis of variance revealed that on the Test of Aspects of Scientific Thinking the mean score of the treatment group who read history of science case studies was significantly higher than the mean score of the treatment group who read a science textbook.
2. Analysis of variance revealed that on the sub-test on ability to make conclusions the mean score of the treatment group who read history of science case studies was significantly higher than the mean score of the treatment group who read a science book.
3. Analysis of variance did not reveal significant differences between the mean scores of the treatment group who read history of science case studies and the treatment group who read a science textbook on the sub-tests evaluating:

(a) the ability to recognize problems, hypotheses, experimental

- conditions and conclusions.
- (b) the ability to understand the relationship of evidence to hypotheses or possible solutions to a problem.
 - (c) the ability to understand experimental methods and the control of variables.
 - (d) the ability to interpret data.
4. Analysis of variance did not reveal a significant difference on the Nature of Science Scale between the mean score of the treatment group who read history of science case studies and the treatment group who read a science textbook.
- The following statements treat results of this study not specifically related to the testing of hypotheses:
- 5. Analysis of variance did not reveal a significant difference between the Education 145 grade point averages of the experimental group who read history of science case studies and the control group who read a science textbook.
 - 6. Significant differences between mean test scores of males and females were not revealed by analysis of variance data on the Test of Aspects of Scientific Thinking or on any of the five sub-tests, or on the Nature of Science Scale, although an interaction between sex and treatment was found on one sub-test (see 7).
 - 7. On the sub-test on the ability to recognize problems, hypotheses, experimental conditions and conclusions, analysis of variance

data revealed that the mean score difference between males reading case studies and males reading a science textbook was significantly greater than the mean score difference between females reading case studies and females reading a science textbook.

8. Analysis of variance did not reveal significant interactions between sex and treatment on any other sub-test or on the total score on the Test of Aspects of Scientific Thinking. Similarly, an interaction effect was not found between sex and treatment on the Nature of Science Scale.

Discussion and Implications of Results

Although mean scores on each of the five sub-tests on the Test of Aspects of Scientific Thinking favored the group reading history of science case studies, a wide range in levels of significance was found. This indicates that some skills involved in scientific thinking were better developed through the use of case studies, even though the number of questions and time spent on each skill were approximately equal.

The superiority of the case study group was most pronounced on the sub-test on the ability to make conclusions. This result provides evidence that students can learn to evaluate the validity of their own conclusions from reading accounts of the type of evidence which was

necessary to formulate conclusions in important scientific experiments. Questions in the case studies directed students to evaluate evidence for or against a particular conclusion and emphasized differences between direct and indirect evidence. The results of this study indicate that the case study approach may be most fruitful in developing the ability to make conclusions -- a crucial skill in the development of a scientifically literate citizen.

The superiority of the case study group on the sub-test on the ability to understand experimental methods and the control of variables fairly closely approached statistical significance ($P=0.101150$) and indicates an important trend in the data. The ability to understand experimental methods and the control of variables involves specific skills which were emphasized in several of the case studies, e. g., Spallanzani, Koch, Pasteur and Lavoisier. A good many questions asked students to identify the control in an experiment and indicate its significance in testing a particular hypothesis. It may be inferred from the results of this study that the case study approach would be best used initially to give students an insight into the techniques used in testing hypotheses and the necessity of controlling variables. Further research would be required to determine if additional activities could be used to develop greater mastery of the skills involved in hypothesis testing.

The superiority of the case study group on the sub-test on the

ability to recognize problems, hypotheses, experimental conditions and conclusions approached statistical significance ($P=0.115221$) and indicates a trend in the data which may be related to the results of sub-test 3 discussed above. The ability to recognize problems, hypotheses, experimental conditions and conclusions could involve more general knowledge than the abilities emphasized in the other sub-tests, and may be related to the more complex skills involved in the ability to understand experimental methods and the ability to make conclusions. This relationship could be inferred from the direction and magnitude of test score differences on sub-tests 1, 3, and 4.

The results of sub-tests 2 and 6 indicate that the skills involved in data interpretation and in understanding the relationship of evidence to hypotheses or possible solutions to a problem are not effectively developed through the use of the case studies in this investigation. The ability to understand the relationship of evidence to hypotheses or possible solutions to a problem involves evaluation and reasoning at a higher level of abstraction than the abilities emphasized in the other sub-tests. More time than was allowed in this study may be needed to develop this ability effectively. The ability to interpret data involves more quantitative skills than the abilities tested on the other four sub-tests. Further research is needed to determine the extent of student weaknesses in this area and types of activities which could better develop skills involved in data interpretation.

The grade point average of the experimental group did not differ significantly from the grade point average of the control group in Education 145. Grades from Education 145 only were used in this grade point average computation and were assumed to be a reliable indicator of subject matter achievement. This result indicates that in this study the ability to think scientifically was not developed at the expense of subject matter achievement. Since the textbook reading assignments were more directly related to material covered on examinations, however, two possible inferences could be made:

- (a) The textbook reading assignments were not effective in teaching subject matter concepts in Education 145.
- (b) The ability to think scientifically is transferable and has a positive relationship to subject matter achievement in Education 145.

There is insufficient evidence available in this study to validate either of these inferences.

Analysis of variance data on the Nature of Science Scale indicated that attitudes toward science in the group reading case studies were not significantly different from those of the group reading a science textbook. This result shows that it is likely to be difficult to develop scientific attitudes within the time available in a one term university course. This evidence supports the conclusion made by Eberhard and Hunter (18) that scientific attitudes take many years to

develop and are influenced by many courses and a variety of experiences. Significant changes in scientific attitudes, therefore are not likely to result from one isolated course. There is fragmentary evidence, which was not validated statistically, that students in this investigation reading case studies were less likely to look upon science as a necessarily practical enterprise involving definite approved procedures. More evidence could be gained from a further study in which more time was spent on history of science case studies and additional tests were used to measure attitudes toward science.

Conclusions

The history of science case studies prepared and used in this investigation are more effective than a science textbook in developing the ability to think scientifically, as defined and limited in this study. The evidence available in this study indicates that of the skills involved in scientific thinking, the ability to make conclusions, was best developed by this case study approach. The ability to understand experimental methods and the control of variables and the ability to recognize problems, hypotheses, experimental conditions and conclusions were developed to a lesser extent as a result of this approach. The ability to understand the relationship of evidence to hypotheses or possible solutions to a problem and the ability to interpret data were no more effectively developed through the use of the case studies than

through the use of a science textbook.

The general superiority of the group of students who read history of science case studies in the ability to think scientifically was not associated with poorer subject matter achievement and was not related to the sex of the student. The group of students who read history of science case studies did not show significantly different attitudes toward science than the group of students who read a science textbook.

Recommendations and Suggestions for Further Study

On the basis of the evidence presented in this study, the use of history of science case studies can be recommended as an effective method of teaching skills involved in scientific thinking, which is practical within the organization of a university science course with a large student enrollment. Further studies are needed to determine the feasibility of the case study approach in developing quantitative skills involved in data interpretation -- a weakness shown in the results of the present study.

Longer term studies are needed to better assess the development of scientific attitudes through the use of a wider variety of history of science materials over a longer period of time. Extraneous variables, particularly that of maturation, would be difficult to control in such a study, however. The sequence of history of science

materials could also be expanded to include more subject matter areas of science. Case studies in ecology could be most useful in unifying science concepts and in developing attitudes in an area of crucial concern.

A fruitful area for further study involves the identification of student behaviors related to the ability to think scientifically.

For example, Marvin D. Solomon (37) found that students identified as "non-rigid thinkers" were better able to utilize elements of the scientific method than students identified as "rigid thinkers". Solomon's criteria could be used to analyze the performance of students reading history of science materials. The results of such a study could be useful in identifying problems involved in developing scientific attitudes through the use of history of science case studies.

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APPENDICES

APPENDIX I: THE HISTORY OF SCIENCE CASE STUDIES

A. Case Study 1: Spallanzani and Spontaneous Generation

Lazzaro Spallanzani was a priest in the Catholic Church who helped support himself by saying masses.

Despising secretly all authority, he got himself snugly into the good graces of powerful authorities, so that he might work undisturbed. Ordained a priest, supposed to be a blind follower of the faith, he fell savagely to questioning everything, to taking nothing for granted -- excepting the existence of God, of some sort of supreme being. At least if he questioned this he kept it -- rogue that he was -- strictly to himself. Before he was 30 years old he had been made professor at the University of Reggio, talking before enthusiastic classes that listened to him with saucer-eyes. Here he started his first work on the little animals, those weird new little beings that Leeuwenhoek had discovered. He began his experiments on them as they were threatening to return to that misty unknown from which the Dutchman had dredged them up.

The little animals had got themselves involved in a strange question, in a furious fight, and had it not been for that, they might have remained curiosities for centuries, or even have been completely forgotten. This argument, over which dear friends grew to hate each other and about which professors tried to crack the skulls of priests, was briefly this: Can living things arise spontaneously, or does every living thing have to have parents? Did God create every plant and animal in the first six days, and then settle down to be managing director of the universe, or does He even now amuse Himself by allowing new animals to spring up in humorous ways?

In Spallanzani's time the popular side was the party that asserted that life could arise spontaneously. The great majority of sensible people believed that many animals did not have to have parents -- that they might be the unhappy illegitimate children of a disgusting variety of dirty messes. Here, for example, was a supposedly sure recipe for getting yourself a good swarm of bees. Take a young bullock, kill him with a knock on the head, bury him under the ground in a standing position with his horns sticking out. Leave him there for a month, then saw off his horns -- and out will fly your swarm of bees.

Even the scientists were on this side of the question. The English naturalist Ross announced learnedly that: "To question that beetles and wasps were generated in cow dung is to question reason, sense, and experience." Even such complicated animals as mice didn't have to have mothers or fathers -- if anybody doubted this, let him go to Egypt, and there he would find the fields literally swarming with mice, begot of the mud of the River Nile -- to the great calamity of the inhabitants!

Spallanzani heard all of these stories which so many important people were sure were facts, he read many more of them that were still more strange, he watched students get into brawls in excited attempts to prove that mice and bees didn't have to have fathers or mothers. He heard all these things -- and didn't believe them. He was prejudiced. Great advances in science so often start from prejudice, on ideas got not from science but straight out of a scientist's head, on notions that are only the opposite of the prevailing superstitious nonsense of the day. Spallanzani had violet notions about whether life could rise spontaneously; for him it was on the face of things absurd to think that animals -- even the wee beasts of Leeuwenhoek -- could arise in a haphazard way from any old thing or out of any dirty mess. There must be law and order to their birth, there must be a rhyme and reason! But how to prove it?

Then one night, in his solitude, he came across a little book, a simple and innocent little book, and this book told him of an entirely new way to tackle the question of how life arises. The fellow who wrote the book didn't argue with words -- he just made experiments -- and God! thought Spallanzani, how clear are the facts he demonstrates. He stopped being sleepy and forgot the dawn was coming, and read on. . . .

The book told him of the superstition about the generation of maggots and flies, it told of how even the most intelligent men believed that maggots and flies could arise out of putrid meat. Then -- and Spallanzani's eyes nearly popped out with wonder, with excitement, as he read of a little experiment that blew up this nonsense, once and for always.

"A great man, this fellow Redi, who wrote this book," thought Spallanzani, as he took off his coat and bent his thick neck toward the light of the candle. "See how easy he settles it! He takes two jars and puts some meat in each one. He leaves one jar open and then

puts a light veil over the other one. He watches -- and sees flies go down into the meat in the open pot -- and in a little while there are maggots there, and then new flies. He looks at the jar that has the veil over it -- and there are no maggots or flies in that one at all. How easy! It is just a matter of the veil keeping the mother flies from getting at the meat. . . . But how clever, because for a thousand years people have been getting out of breath arguing about the question -- and not one of them thought of doing this simple experiment that settles it in a moment. "

Next morning it was one jump from the inspiring book to tackling this same question, not with flies, but with the microscopic animals. For all the professors were saying just then that though maybe flies had to come from eggs, little sub-visible animals certainly could arise by themselves.

Spallanzani began fumblingly to learn how to grow wee beasts, and how to use a microscope. He cut his hand and broke large expensive flasks. He forgot to clean his lenses and sometimes saw his little animals dimly through his fogged glasses -- just as you can faintly make out minnows in the water riled up by your net. He raved at his blunders; but despite his impetuosity he was persistent -- he must prove that these yarns about the animalcules were yarns, nothing more. But wait! "If I set out to prove something I am no real scientist -- I have to learn to follow where the facts lead me -- I have to learn to whip my prejudices" And he kept on learning to study little animals, and to observe with a patient, if not an unprejudiced eye, and gradually he taught the vanity of his ideas to bow to the hard clearness of his facts.

At this time another priest, named Needham, a devout Catholic who liked to think he could do experiments, was becoming notorious in England and Ireland, claiming that little microscopic animals were generated marvelously in mutton gravy. Needham sent his experiments to the Royal Society, and the learned Fellows deigned to be impressed.

He told them how he had taken a quantity of mutton gravy hot from the fire, and put the gravy in a bottle, and plugged the bottle up tight with a cork, so that no little animals or their eggs could possibly get into the gravy from the air. Next he even went so far as to heat the bottle and its mutton gravy in hot ashes. "Surely", said the good Needham, "this will kill any little animals or their eggs that might remain in the flask. " He put this gravy flask away for a few days, then pulled the cork and -- marvel of marvels -- when he examined

the stuff inside with his lens, he found it swarming with animalcules.

"A momentous discovery, this," cried Needham to the Royal Society, "these little animals can only have come from the juice of the gravy. Here is a real experiment showing that life can come spontaneously from dead stuff!" He told them mutton gravy wasn't necessary -- a soup made from seeds or almonds would do the same trick.

The Royal Society and the whole educated world were excited by Needham's discovery. Here was no old wives' tale. Here was hard experimental fact; and the heads of the Society got together and thought about making Needham a Fellow of their remote aristocracy of learning. But away in Italy, Spallanzani was reading the news of Needham's startling creation of little animals from mutton gravy. While he read he knit his brows, and narrowed his dark eyes. At last he snorted: "Animalcules do not arise by themselves from mutton gravy, or almond seeds, or anything else! This fine experiment is a fraud -- maybe Needham doesn't know it is -- but I'm going to find it. . . ."

The devil of prejudice was talking again. Now Spallanzani began to sharpen his razors for his fellow priest -- the Italian was a nasty fellow who liked to slaughter ideas of any kind that were contrary to his -- he began to whet his knives, I say, for Needham. Then one night, alone in his laboratory, away from the brilliant clamor of his lectures and remote from the gay salons where ladies adored his knowledge, he felt sure he had found the loophole in Needham's experiment. He chewed his quill, he ran his hands through his shaggy hair. "Why have those little animals appeared in that hot gravy, and in those soups made from seeds?" Undoubtedly because Needham didn't heat the bottles long enough, and surely because he didn't plug them tight enough!

Here the searcher in him came forward. He didn't go to his desk to write Needham about it -- instead he went to his dusty glass-strewn laboratory, and grabbed some flasks and seeds, and dusted off his microscope. He started to test, even to defeat, if necessary, his own explanations. Needham didn't heat his soups long enough -- maybe there are little animals, or their eggs, which can stand a tremendous heat, who knows? So Spallanzani took some large glass flasks, round bellied with tapering necks. He scrubbed and washed and dried them till they stood in gleaming rows on his table. Then he put seeds of various kinds into some, and peas and almonds into others, and following that poured pure water into all of them. "Now I won't only heat these soups for a short time," he cried, "but I'll

boil them for an hour!" He got his fires ready -- then he grunted: "But how shall I close up my flasks? Corks might not be tight enough, they might let these infinitely wee things through." He pondered. "I've got it, I'll melt the necks of my bottles shut in a flame, I'll close them with glass -- nothing, no matter how small, can sneak through glass!"

So he took his shining flasks one by one, and rolled their necks gently in a hot flame till each one was fused completely shut. He dropped some of them when they got too hot -- he sizzled the skin of his fingers, he swore, and got new flasks to take the smashed ones' places. Then when his flasks were all sealed and ready, "Now for some real heat," he muttered, and for tedious hours he tended his bottles, as they bumped and danced in caldrons of boiling water. One set he boiled for a few minutes only. Another he kept in boiling water for a full hour.

At last, his eyes near stuck shut with tiredness, he lifted the flasks of stew steaming from their kettles, and put them carefully away -- to wait for nervous anxious days to see whether any little animals would grow in them. And he did another thing, a simple one which I almost forgot to tell you about, he made another duplicate set of stews in flasks plugged up with corks, not sealed, and after boiling these for an hour put them away beside the others.

Then he went off for days to do the thousand things that were not enough to use up his buzzing energy. He wrote letters to the famous naturalist Bonnet, in Switzerland, telling him his experiments; he played football; he went hunting and fishing. He lectured about science, and told his students not of dry technicalities only, but of a hundred things -- from the marvelous wee beasts that Leeuwenhoek had found in his mouth to the strange eunuchs and the veiled multitudinous wives of Turkish harems. At last he vanished and students and professors -- and ladies -- asked: "Where is the Abbe Spallanzani?"

He had gone back to his rows of flasks of seed soup.

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He went to the row of sealed flasks first, and one by one he cracked open their necks, and fished down with a slender hollow tube to get some of the soup inside them, in order to see whether any little animals at all had grown in these bottles that he had heated so long, and closed so perfectly against the microscopic creatures that might be floating in the dust of the outside air. He was not the lively

sparkling Spallanzani now. He was slow, he was calm. Like some automaton, some slightly animated wooden man, he put one drop of seed soup after another before his lens.

He first looked at drop after drop of the soup from the sealed flasks which had been boiled for an hour, and his long looking was rewarded by -- nothing. Eagerly he turned to the bottles that had been boiled for only a few minutes, and cracked their seals as before, and put drops of the soup inside them before his lens.

"What's this?" he cried. Here and there in the gray field of his lens he made out an animalcule playing and sporting about -- these weren't large microbes, like some he had seen -- but they were living little animals just the same.

"Why, they look like little fishes, tiny as ants," he muttered -- and then something dawned on him: "These flasks were sealed -- nothing could get into them from the outside, yet here are little beings that have stood a heat of boiling water for several minutes!"

He went with nervous hands to the long row of flasks he had only stoppered with corks -- as his enemy Needham had done -- and he pulled out the corks, one by one, and fished in the bottles once more with his tubes. He growled excitedly, he got up from his chair, he seized a battered notebook and feverishly wrote down obscure remarks in a kind of scrawled shorthand. But these words meant that every one of the flasks which had been only corked, not sealed, was alive with little animals! Even the corked flasks which had been boiled for an hour, "were like lakes in which swim fishes of all sizes, from whales to minnows."

"That means the little animals get into Needham's flasks from the air!" he shouted. "And besides I have discovered a great new fact: living things exist that can stand boiling water and still live -- you have to heat them to boiling almost an hour to kill them!"

It was a great day for Spallanzani, and though he did not know it, a great day for the world. Spallanzani had proved that Needham's theory of little animals arising spontaneously was wrong -- just as the old master Redi had proved the idea was wrong that flies can be bred in putrid meat. But he had done more than that, for he had rescued the baby science of microbe hunting from a fantastic myth, a Mother Goose yarn that would have made all scientists of other kinds hold their noses at the very mention of microbe hunting as a branch of knowledge.

Excited, Spallanzani called his brother Nicolo, and his sister, and told them his pretty experiment. And then, bright-eyed, he told his students that life only comes from life; every living thing has to have a parent -- even these wretched little animals! Seal your soup flasks in a flame, and nothing can get into them from outside. Heat them long enough, and everything, even those tough beasts that can stand boiling, will be killed. Do that, and you'll never find any living animals arising in any kind of soup -- you could keep it till doomsday. Then he threw his work at Needham's head in a brilliant sarcastic paper, and the world of science was thrown into an uproar. Could Needham really be wrong? asked thoughtful men, gathered in groups under the high lamps and candles of the scientific societies of London and Copenhagen, of Paris and Berlin.

The argument between Spallanzani and Needham didn't stay in the academies among the highbrows. It leaked out through heavy doors onto the streets and crept into stylish drawing rooms. The world would have liked to believe Needham, for the people of the 18th century were cynical and gay; everywhere men were laughing at religion and denying any supreme power in nature, and they delighted in the notion that life could arise haphazardly. But Spallanzani's experiments were so clear and so hard to answer, even with the cleverest of words. . . .

Meanwhile the good Needham had not been resting on his oars exactly; he was an expert at publicity, and to help his cause along he went to Paris and lectured about his mutton gravy, and in Paris he fell in with the famous Count Buffon. This count was rich; he was handsome; he loved to write about science; he believed he could make up hard facts in his head; he was rather too well dressed to do experiments. Besides he really knew some mathematics, and had translated Newton into French. When you consider that he could juggle most complicated figures, that he was a rich nobleman as well, you will agree that he certainly ought to know -- without experimenting -- whether little animals could come to life without fathers or mothers! So argued the godless wits of Paris.

Needham and Buffon got on famously. Buffon wore purple clothes and lace cuffs that he didn't like to muss up on dirty laboratory tables, with their dust and cluttered glassware and pools of soup spilled from accidentally broken flasks. So he did the thinking and writing, while Needham messed with the experiments. These two men then set about to invent a great theory of how life arises, a fine philosophy that every one could understand, that would suit devout Christians as well as witty atheists. The theory ignored Spallanzani's cold facts, but what

would you have? It came from the brain of the great Buffon, and that was enough to upset any fact, no matter how hard, no matter how exactly recorded.

"What is it that causes these little animals to arise in mutton gravy, even after it has been heated, my Lord?" you can hear Needham asking of the noble Count. Count Buffon's brain whirled in a magnificent storm of the imagination, then he answered: 'You have made a great, a momentous discovery, Father Needham. You have put your finger on the very source of life. In your mutton gravy you have uncovered the very force -- it must be a force, everything is force -- which creates life. "

"Let us then call it the Vegetative Force, my lord," replied Father Needham.

"An apt name," said Buffon, and he retired to his perfumed study and put on his best suit and wrote -- not from dry laboratory notes or the exact records of lenses or flasks but from his brain -- he wrote, I say, about the marvels of this Vegetative Force that could make little animals out of mutton gravy and heated seed soups. In a little while Vegetative Force was on everybody's tongue. It accounted for everything. The wits made it take the place of God, and the churchmen said it was God's most powerful weapon. It was popular like a street song or an off-color story -- or like present-day talk about relativity.

Worst of all, the Royal Society tumbled over itself to get ahead of the men in the street, and elected Needham a Fellow, and the Academy of Sciences of Paris made him an Associate. Meanwhile, in Italy, Spallanzani began to walk up and down his laboratory and sputter and rage. Here was a danger to science, here was ignoring of cold facts, without which science is nothing. Spallanzani was a priest of God, and God was perhaps reasonably sacred to him, he didn't argue with anyone about that -- but here was a pair of fellows who ignored his pretty experiments, his clear beautiful facts!

But what could Spallanzani do? Needham and Buffon had deluged the scientific world with words -- they had not answered his facts, they had not shown where Spallanzani's experiment of the sealed flasks was wrong. The Italian was a fighter, but he liked to fight with facts and experiments, and here he was laying about him in this fog of big words, and hitting nothing. Spallanzani stormed and laughed and was sarcastic and bitter about this marvelous hoax, this mysterious Vegetative Force. It was the Force, prattled Needham, that had

made Eve grow out of Adam's rib. It was the Force, once more, that gave rise to the remarkable worm-tree of China, which is a worm in winter, and then marvelous to say is turned by the Vegetative Force into a tree in summer! And much more of such preposterous stuff, until Spallanzani saw the whole science of living things in danger of being upset, by this alleged Vegetative Force with which, next thing people knew, Needham would be turning cows into men and fleas into elephants.

Then suddenly Spallanzani had his chance, for Needham made an objection to one of his experiments. "Your experiment does not hold water," he wrote to the Italian, "because you have heated your flasks for an hour, and that fierce heat weakens and so damages the Vegetative Force that it can no longer make little animals."

This was just what the energetic Spallanzani was waiting for, and he forgot religion and large classes of eager students and the pretty ladies that loved to be shown through his museum. He rolled up his wide sleeves and plunged into work, not at a writing desk but before his laboratory bench, not with a pen, but with his flasks and seeds and microscopes.

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"So Needham says heat damages the Force in the seeds, does he? Has he tried it? How can he see or feel or weigh or measure this Vegetative Force? He says it is in the seeds, well we'll heat the seeds and see!"

Spallanzani got out his flasks once more and cleaned them. He brewed mixtures of different kinds of seeds, of peas and beans and vetches with pure water, until, his workroom almost ran over with flasks -- they perched on high shelves, they sat on tables and chairs, they cluttered the floor so it was hard to walk around.

"Now we'll boil a whole series of these flasks different lengths of time, and see which one generates the most little animals." he said, and then doused one set of his soups in boiling water for a few minutes, another for a half hour, and still another for two hours. Instead of sealing them in the flame he plugged them all up with corks-- Needham said that was enough -- and then he put them carefully away to see what would happen. He waited. He went off fishing and forgot to pull up his rod when a fish bit, he collected minerals for his museum, and forgot to take them home with him. He plotted for higher pay, he said masses, and studied the copulation of frogs and

toads -- and then disappeared once more to his dim workroom with its regiments of bottles and weird machines. He waited.

If Needham were right, the flasks boiled for minutes should be alive with little animals, but the ones boiled for an hour or two hours should be deserted. He pulled out the corks one by one, and looked at the drops of soup through his lens and at last laughed with delight -- the bottles that had been boiled for two hours actually had more little animals sporting about in them than the one he had heated for a few minutes.

"Vegetative Force, what nonsense! So long as you only plug up your flasks with corks the little animals will get in from the air. You can heat your soups till you're black in the face -- the microbes will get in just the same and grow, after the broth has cooled."

Spallanzani was triumphant, but then he did the curious thing that only born scientists ever do -- he tried to beat his own idea, his darling theory -- by experiments he honestly and shrewdly planned to defeat himself. That is science! That is the strange self-forgetting spirit of a few rare men, those curious men to whom truth is more dear than their own cherished whims and wishes. Spallanzani walked up and down his narrow workroom, hands behind him, meditating -- "Wait, maybe after all Needham has guessed right, maybe there is some mysterious force in those seeds that strong heat might destroy."

Then he cleaned his flasks again, and took some seeds, but instead of merely boiling them in water, he put them in a coffee-roaster and baked them till they were soot-colored cinders. Next he poured distilled water over them, growling: "Now if there was a Vegetative Force in those seeds, I have surely roasted it to death."

Days later when he came back to his flasks, with their soups brewed from the burned seeds, he smiled a sarcastic smile -- a smile that meant squirming for Buffon and Needham -- for as one bottle after another yielded its drops of soup to his lens, every drop from every bottle was alive with wee animals that swam up and down in the liquid and went to and fro, living their funny limited little lives as gaily as any animals in the best soup made from unburned seeds. He had tried to defeat his own theory, and so trying had licked the pious Needham and the precious Buffon. They had said that heat would kill their Force so that no little animals could arise -- and here were seeds charred to carbon, furnishing excellent food for the small creatures -- this so-called Force was a myth! Spallanzani proclaimed this to all of Europe which now began to listen to him. (1)

1. What was Spallanzani's hypothesis and what events led to its formulation?
2. What was Needham's hypothesis? What was wrong with the methods he used to test this hypothesis?
3. Spallanzani in trying to disprove his own hypothesis actually disproved Needham's hypothesis. Explain how this was done.
4. Explain the controls that Spallanzani used in his experiments that disproved the idea of a vegetative force in seeds.
5. How was Spallanzani's work important to the development of modern ideas in Biology?

(1) DeKruif, Paul. Microbe Hunters. New York, Harcourt, Brace, 1940. p. 25-37.

B. Case Study 2: Important Experiments by Louis Pasteur
in Micro-Biology

One day Mr. Bigo, a distiller of alcohol from sugar beets, came to Pasteur's laboratory in distress. "We're having trouble with our fermentations, Professor," he complained; "We're losing thousands of francs every day. I wonder if you could come over to the factory and help us out?" said the good Bigo.

Bigo's son was a student in the science course and Pasteur hastened to oblige. He went to the distillery and sniffed at the vats that were sick, that wouldn't make alcohol; he fished up some samples of the grayish slimy mess and put them in bottles to take up to his laboratory -- and he didn't fail to take some of the beet pulp from the healthy foamy vats where good amounts of alcohol were being made. Pasteur had no idea he could help Bigo, he knew nothing of how sugar ferments into alcohol -- indeed, no chemist in the world knew anything about it. He got back to his laboratory, scratched his head, and decided to examine the stuff from the healthy vats first. He put some of this stuff -- a drop of it -- before his microscope, maybe with an aimless idea of looking for crystals, and he found this drop was full of tiny globules, much smaller than any crystals, and these little globes were yellowish in color, and their insides were full of a swarm of curious dancing specks.

"What can these things be," he muttered. Then suddenly he remembered --

"Of course, I should have known -- these are the yeasts you find in all stews that have sugar which is fermenting into alcohol!"

He looked again and saw the wee spheres alone; he saw some in bunches, others in chains, and then to his wonder he came on some with queer buds sprouting from their sides -- they looked like sprouts on infinitely tiny seeds.

"Cagniard de la Tour is right. These yeasts are alive. It must be the yeasts that change beet sugar into alcohol!" he cried. "But that doesn't help Mr. Bigo -- what on earth can be the matter with the stuff in the sick vats?" He grabbed for the bottle that held the stuff from the sick vat, he sniffed at it, he peered at it with a little magnifying glass, he tasted it, he dipped little strips of blue paper in it and watched them turn red. . . Then he put a drop from it before his microscope and looked. . .

"But there are no yeasts in this one; where are the yeasts? There is nothing here but a mass of confused stuff -- what is it, what does this mean?" He took the bottle up again and brooded over it with an eye that saw nothing -- till at last a different, a strange look of the juice forced its way up into his wool-gathering thoughts. "Here are little gray specks sticking to the walls of the bottle -- here are some more floating on the surface -- wait! No, there aren't any in the healthy stuff where there are yeasts and alcohol. What can that mean?" he pondered. Then he fished down into the bottle and got a speck, with some trouble, into a drop of pure water; he put it before his microscope. . . .

His moment had come.

No yeast globes here, no, but something different, something strange he had never seen before, great tangled dancing masses of tiny rod-like things, some of them alone, some drifting along like strings of boats, all of them shimmying with a weird incessant vibration. He hardly dared to guess at their size -- they were much smaller than the yeasts -- they were only one-twenty-five-thousandth of an inch long!

That night he tossed and didn't sleep and next morning his stumpy legs hurried him back to the beet factory. His glasses awry on his nearsighted eyes, he leaned over and dredged up other samples from other sick vats -- he forgot all about Bigo and thought nothing of helping Bigo; Bigo didn't exist; nothing in the world existed but his sniffing curious self and these dancing strange rods. In every one of the grayish specks he found millions of them. . . . Feverishly at night with Madame Pasteur waiting up for him and at last going to bed without him, he set up apparatus that made his laboratory look like an alchemist's den. He found that the rod-swarming juice from the sick vats always contained the acid of sour milk -- and no alcohol. Suddenly a thought flooded through his brain: "Those little rods in the juice of the sick vats are alive, and it is they that make the acid of sour milk -- the rods fight with yeasts perhaps, and get the upper hand. They are the ferment of the sour milk-acid, just as the yeasts must be the ferment of the alcohol!" He rushed up to tell the patient Madame Pasteur about it, the only half-understanding Madame Pasteur who knew nothing of fermentations, the Madame Pasteur who helped him so by believing always in his wild enthusiasms

It was only a guess but there was something inside him that whispered to him that it was surely true. There was nothing uncanny about the rightness of his guess; Pasteur made thousands of guesses

about the thousand strange events of nature that met his shortsighted peerings. Many of these guesses were wrong -- but when he did hit on a right one, how he did test it and prove it and sniff along after it and chase it and throw himself on it and bring it to earth! So it was now, when he was sure he had solved the ten-thousand-year-old mystery of fermentation.

His head buzzed with a hundred confused plans to see if he was really right, but he never neglected the businessmen and their troubles, or the authorities or the farmers or his students. He turned part of his laboratory into a manure-testing station, he hurried to Paris and tried to get himself elected to the Academy of Sciences -- and failed -- and he took his classes on educational trips to breweries in Valanciennes and foundries in Belgium. In the middle of this he felt sure, one day, that he had a way to prove that the little rods were alive, that in spite of their miserable littleness they did giant's work, the work no giant could do -- of changing sugar into lactic acid.

"I can't study these rods that I think are alive in this mixed-up mess of the juice of the beet pulp from the vats," Pasteur pondered. "I shall have to invent some kind of clear soup for them so that I can see what goes on -- I'll have to invent this special food for them and then see if they multiply, if they have young, if a thousand of the small dancing beings appear where there was only one at first." He tried putting some of the grayish specks from the sick vats into pure sugar water. They refused to grow in it. "The rods need a richer food," he meditated, and after many failures he devised a strange soup; he took some dried yeast and boiled it in pure water and strained it so that it was perfectly clear, he added an exact amount of sugar and a little carbonate of chalk to keep the soup from being acid. Then on the point of a fine needle he fished up one of the gray specks from some juice of a sick fermentation. Carefully he sowed this speck in his new clear soup -- and put the bottle in an incubating oven -- and waited, waited anxious and nervous; it is this business of experiments not coming off at once that is always the curse of microbe hunting.

He waited and signed some vouchers and lectured to students and came back to peer into his incubator at his precious bottle and advised farmers about their crops and fertilizers and bolted absent-minded meals and peered once more at his tubes -- and waited. He went to bed without knowing what was happening in his bottle -- it is hard to sleep when you do not know such things. . .

All the next day it was the same, but toward evening when his legs began to be heavy with failure once more, he muttered: "There

is no clear broth that will let me see these beastly rods growing -- but I'll just look once more. . . "

He held the bottle up to the solitary gaslight that painted grotesque giant shadows of the apparatus on the laboratory walls. "Sure enough, there's something changing here," he whispered; "there are rows of little bubbles coming up from some of the gray specks I sowed in the bottle yesterday -- there are many new gray specks -- all of them are sprouting bubbles!" Then he became deaf and dumb and blind to the world of men; he stayed entranced before his little incubator; hours floated by, hours that might have been seconds for him. He took up his bottle caressingly; he shook it gently before the light -- little spirals of gray murky cloud curled up from the bottom of the flask and from these spirals came big bubbles of gas. Now he would find out!

He put a drop from the bottle before his microscope. Eureka! The field of the lens swarmed and vibrated with shimmying millions of the tiny rods. "They multiply! They are alive!" he whispered to himself, then shouted: "Yes, I'll be up in a little while!" to Madame Pasteur, who had called down begging him to come up for dinner, to come for a little rest. For hours he did not come.

Time and again in the days that followed he did the same experiment, putting a tiny drop from a flask that swarmed with rods into a fresh clear flask of yeast soup that had none at all -- and every time the rods appeared in billions and each time they made new quantities of the acid of sour milk. Then Pasteur burst out -- he was not a patient man -- to tell the world. He told Mr. Bigo it was the little rods that made his fermentations sick: "Keep the little rods out of your vats and you'll always get alcohol, Mr. Bigo." He told his classes about his great discovery that such infinitely tiny beasts could make acid of sour milk from sugar -- a thing no mere man had ever done or could do. He wrote the news to his old professor, Dumas, and to all his friends and he read papers about it to the Lille Scientific Society and sent a learned treatise to the Academy of Sciences in Paris. It is not clear whether Mr. Bigo found it possible to keep the little rods out of his vats -- for they were like bad weeds that get into gardens. But to Pasteur that didn't matter so much. Here was the one important fact:

It is living things, sub-visible beings, that are the real cause of fermentations!

Innocently he told everyone that his discovery was remarkable --

he was too much of a child to be modest -- and from now on and for years these little ferments filled his sky; he ate and slept and dreamed and loved -- after his absent-minded fashion -- with his ferments by him. They were his life.

He worked alone for he had no assistant, not even a boy to wash his bottles for him; how then, you will ask, did he find time to cram his days with such a bewildering jumble of events? Partly because he was an energetic man, and partly it was thanks to Madame Pasteur, who in the words of Roux, "loved him even to the point of understanding his work." On those evenings when she wasn't waiting up lonely for him -- when she had finished putting to bed those children whose absent-minded father he was -- this brave lady sat primly on a straight-backed chair at a little table and wrote scientific papers at his dictation. Again, while he was below brooding over his tubes and bottles she would translate the cramped scrawls of his notebooks into a clear, beautiful handwriting. Pasteur was her life and since Pasteur thought only of work, her own life melted more and more into his work. . . . (1)

1. How did Pasteur make use of a controlled observation to formulate a hypothesis about the cause of fermentation?
2. What method did Pasteur use to test this hypothesis?
3. Pasteur's method of cultivating bacteria is still used today. Why has this type of research been so important to mankind?

Now Pasteur ran hard up against a question that was bound to pop up and look him in the face sooner or later. It was an old question. Adam had without doubt asked it of God, while he wondered where the ten thousand living beings of the garden of Eden came from. It was the question that had all thinkers by the ears for a hundred centuries, that had given Spallanzani so much exciting fun a hundred years before. It was the simple but absolutely insoluble question: Where do microbes come from?

"How is it," Pasteur's opponents asked him, "how is it that yeasts appear from nowhere every year of every century in every corner of the earth, to turn grape juice into wine? Where do the little animals come from, these little animals that turn milk sour in

every can and butter rancid in every jar, from Greenland to Timbuktu?"

Like Spallanzani, Pasteur could not believe that the microbes rose from the dead stuff of the milk or butter. Surely microbes have to have parents! He was, you see, a good Catholic. It is true that he lived among the brainy skeptics on the left bank of the Seine in Paris, where God is as popular as a Soviet would be in Wall Street, but the doubts of his colleagues didn't touch Pasteur. It was beginning to be the fashion of the doubters to believe in evolution: the majestic poem that tells of life, starting as a formless stuff stirring in a steamy ooze of a million years ago, unfolding through a stately procession of living beings until it gets to monkeys and at last -- triumphantly -- to men. There doesn't have to be a God to start that parade or to run it -- it just happened, said the new philosophers with an air of science.

But Pasteur answered: "My philosophy is of the heart and not of the mind, and I give myself up, for instance, to those feelings about eternity that come naturally at the bedside of a cherished child drawing its last breath. At those supreme moments there is something in the depths of our souls which tells us that the world may be more than a mere combination of events due to a machine-like equilibrium brought out of the chaos of the elements simply through the gradual action of the forces of matter." He was always a good Catholic.

Then Pasteur dropped philosophy and set to work. He believed that his yeasts and rods and little animals came from the air -- he imagined an air full of these invisible things. Other microbe hunters had shown there were germs in the air, but Pasteur made elaborate machines to prove it all over again. He poked gun cotton into little glass tubes, put a suction pump on one end of them and stuck the other end out of the window, sucked half the air of the garden through the cotton -- and then gravely tried to count the number of living beings in this cotton. He invented clumsy machines for getting these microbe-loaded bits of cotton into yeast soup, to see whether the microbes would grow. He did the good old experiment of Spallanzani over; he got himself a round bottle and put some yeast soup in it, and sealed off the neck of the bottle in the stuttering blast lamp flame, then boiled the soup for a few minutes -- and no microbes grew in the bottle.

"But you have heated the air in your flask when you boiled the yeast soup -- what yeast soup needs to generate little animals is natural air -- you can't put yeast soup together with natural unheated

air without its giving rise to yeasts or molds or torulas or vibrions or animalcules!" cried the believers in spontaneous generation, the evolutionists, the doubting botanists, cried all Godless men from their libraries and their armchairs. They shouted, but made no experiments.

Pasteur, in a muddle, tried to invent ways of getting unheated air into a boiled yeast soup -- and yet keep it from swarming with living sub-visible creatures. He fumbled at getting a way to do this; he muddled -- keeping all the time a brave face toward the princes and professors and publicists that were now beginning to swarm to watch his miracles. The authorities had promoted him from his rat-infested attic to a little building of four or five two-by-four rooms at the gate of the Normal School. It would not be considered good enough to house the guinea pigs of the great institutes of today, but it was here that Pasteur set out on his famous adventure to prove that there was nothing to the notion that microbes could arise without parents. It was an adventure that was part good experiment, part unseemly scuffle -- a scuffle that threatened at certain hilariously vulgar moments to be settled by a fist fight. He messed around, I say, and his apparatus kept getting more and more complicated, and his experiments kept getting easier to object to and less clear, he began to replace his customary easy experiments that convinced with sledgehammer force, by long drools of words. He was stuck.

Then one day old Professor Balard walked into his workroom. Balard had started life as a druggist; he had been an owlsh original druggist who had amazed the scientific world by making the discovery of the element bromine, not in a fine laboratory, but on the prescription counter in the back room of a drugstore. This had got him fame and his job of professor of chemistry in Paris. Balard was not ambitious; he had no yearning to make all the discoveries in the world -- discovering bromine was enough for one man's lifetime -- but Balard did like to nose around to watch what went on in other laboratories.

"You say you're stuck, you say you do not see how to get air and boiled yeast soup together without getting living creatures into the yeast soup, my friend?" you can hear the lazy Balard asking the then confused Pasteur. "Look here, you and I both believe there is no such thing as microbes rising in a yeast soup by themselves -- we both believe they fall in or creep in with the dust of the air, is it not so?"

"Yes," answered Pasteur, "but --"

"Wait a minute!" interrupted Balard. "Why don't you just try the trick of putting some yeast soup in a bottle, boiling it, then fixing the opening so the dust can't fall in. At the same time the air can get in all it wants to."

"But how?" asked Pasteur.

"Easy," replied the now forgotten Balard. "Take one of your round flasks, put the yeast soup into it, then soften the glass of the flask neck in your blast lamp -- and draw the neck out and downward into a thin little tube -- turn this little tube down the way a swan bends his neck when he's picking something out of the water. Then just leave the end of the tube open. It's like this. ." and Balard sketched a diagram.

Pasteur looked, then suddenly saw the magnificent ingeniousness of this little experiment. "Why, then microbes can't fall into the flask, because the dust they stick to can't very well fall upward -- marvelous! I see it now!"

"Exactly," smiled Balard. "Try it and find out if it works -- see you later," and he left to continue his genial round of the laboratories.

Pasteur had bottle washers and assistants now, and he ordered them to hurry and prepare the flasks. In a moment the laboratory was buzzing with the stuttering ear-shattering b-r-r-r-r-r of the enamellers' lamps; he fell to work savagely. He took flasks and put yeast soup into them and then melted their necks and drew them out and curved them downward -- into swans' necks and pigtailed and Chinamen's queues and a half-dozen fantastic shapes. Next he boiled the soup in them -- that drove out all the air -- but as the flasks cooled down new air came in -- unheated air, perfectly clean air.

The flasks ready, Pasteur crawled on his hands and knees, back and forth, with a comical dignity, on his hands and knees, carrying one flask at a time, through a low cubbyhole under the stairs to his incubating oven. Next morning he was first at the laboratory, and in a jiffy, battered notebook in his hand, if you had been there you would have seen his rear elevation disappearing underneath the stairway. Like a beagle to its rabbit, Pasteur was drawn to this oven with its swan-neck flasks. Family, love, breakfast, and the rest of a silly world no longer existed for him.

Had you still been there a half hour later, you would have seen

him come crawling out, his eyes shining through his fogged glasses. He had a right to be happy, for every one of the long, twisty-necked bottles in which the yeast soup had been boiled was perfectly clear -- there was not a living creature in them. The next day they remained the same and the next. There was no doubt now that Balard's scheme had worked. There was no doubt that spontaneous generation was nonsense. "What a fine experiment is this experiment of mine -- this proves that you can leave any kind of soup, after you 've boiled it, you can leave it open to the ordinary air, and nothing will grow in it -- so long as the air gets into it through a narrow twisty tube."

Balard came back and smiled as Pasteur poured the news of the experiment over him. "I thought it would work -- you see, when the air comes back in, as the flask cools, the dust and their germs start in through the narrow neck, but they get caught on the moist walls of the little tube."

"Yes, but how can we prove that?" puzzled Pasteur.

"Just take one of those flasks that has been in your oven all these days, a flask where no living things have appeared, and shake that flask so that the soup sloshes over and back and forth into the swan's neck part of it. Put it back in the oven, and next morning the soup will be cloudy with thick swarms of little beasts -- children of the ones that were caught in the neck."

Pasteur tried it, and it was so! A little later at a brilliant meeting where the brains and wit and art of Paris fought to get in, Pasteur told of his swan-neck flask experiment in rapturous words. "Never will the doctrine of Spontaneous Generation recover from the mortal blow that this simple experiment has dealt it," he shouted. If Balard was there you may be sure he applauded as enthusiastically as the rest. A rare soul was Balard.

Then Pasteur invented an experiment that was -- so far as one can tell from a careful search through the records -- really his own. It was a grand experiment, a semi-public experiment, an experiment that meant rushing across France in trains, it was a test in which he had to slither around on glaciers. Once more his laboratory became a shambles of cluttered flasks and hurrying assistants and tinkling glassware and sputtering, bubbling pots of yeast soup. Pasteur and his enthusiastic slaves -- they were more like fanatic monks than slaves -- were getting ready hundreds of round-bellied bottles. They filled each one of them part full of yeast soup and then, during many hours that shot by like moments -- such was their excitement -- they

doused each bottle for a few minutes in boiling water. And while the soup was boiling they drew the flask necks out in a spitting blue flame until they were sealed shut. Each one of this regiment of bottles held boiled yeast soup -- and a vacuum.

Armed with these dozens of flasks, and fussing about them, Pasteur started on his travels. He went down first into the dank cellars of the Observatory of Paris, that famous observatory where worked the great Leverrier, who had done the proud feat of prophesying the existence of the planet Neptune. "Here the air is so still, so calm," said Pasteur to his boys, "that there will be hardly any dust in it, and almost no microbes." Then, holding the flasks far away from their bodies, using forceps that had been heated red hot in a flame, they cracked the necks of ten of the flasks in succession; as the neck came off each one, there was a hissing "s-s-s-s" of air rushing in. At once they sealed the bottles shut again in the flickering flame of an alcohol lamp. They did the same stunt in the yard of the observatory with another ten bottles, then hurried back to the little laboratory to crawl under the stairs to put the bottles in the incubating oven.

A few days later Pasteur might have been seen squatting before his oven, handling his rows of flasks lovingly; laughing his triumph with one of those extremely rare laughs of his -- he only laughed when he found out he was right. He put down tiny scrawls in his notebook, and then crawled out of his cubby-hole to tell his assistants: "Nine out of ten of the bottles we opened in the cellar of the observatory are perfectly clear -- not a single germ got into them. All the bottles we opened in the yard are cloudy -- swarming with living creatures. It's the air that sucks them into the yeast soup -- it's the dust of the air they come in with!"

He gathered up the rest of the bottles and hurried to the train -- it was the time of the summer vacation when other professors were resting -- and he went to his old home in the Jura mountains and climbed the hill of Poupet and opened twenty bottles there. He went to Switzerland and perilously let the air hiss into twenty flasks on the slopes of Mont Blanc; and found, as he had hoped, that the higher he went, the fewer were the flasks of yeast soup that became cloudy with swarms of microbes. "That is as it ought to be," he cried, "the higher and clearer the air, the less dust -- and the fewer the microbes that always stick to particles of the dust." He came back proudly to Paris and told the academy -- with proofs that would astonish everybody! -- that it was now sure that air alone could never cause living things to rise in yeast soup. "Here are germs, right beside them

there are none, a little further on there are different ones . . . and here where the air is perfectly calm there are none at all," he cried. Then once more he set a new stage for possible magnificent exploits: "I would have liked to have gone up in a balloon to open my bottles still higher up!" But he didn't go up in that balloon, for his hearers were already sufficiently astonished. Already they considered him to be more than a man of science; he became for them a composer of epic searchings, a Ulysses of microbe hunters -- the first adventurer of that heroic age to which you will soon come in this story.

Many times Pasteur won his arguments by brilliant experiments that simply floored everyone, but sometimes his victories were due to the weakness or silliness of his opponents, and again they were the result of luck. Before a society of chemists Pasteur had insulted the scientific ability of naturalists; he was astonished, he shouted, that naturalists didn't stretch out a hand to the real way of doing science -- that is, to experiments. "I am of the persuasion that that would put a new sap into their science," he said. You can imagine how the naturalists liked that kind of talk, particularly Mr. Pauchet, director of the Museum of Rouen, did not like it and he was enthusiastically joined in not liking it by Professor Joly and Mr. Musset, famous naturalists of the College of Toulouse. Nothing could convince these enemies of Pasteur that microscopic beasts did not come to life without parents. They were sure there was such a thing as life arising spontaneously; they decided to beat Pasteur on his own ground at his own game.

Like Pasteur they filled up some flasks, but unlike him they used a soup of hay instead of yeast, they made a vacuum in their bottles and hastened to high Maladetta in the Pyrenees, and they kept climbing until they had got up many feet higher than Pasteur had been on Mont Blanc. Here, beaten upon by nasty breezes that howled out of the caverns of the glaciers and sneaked through the thick linings of their coats, they opened their flask -- Mr. Joly almost slid off the edge of the ledge and was only saved from a scientific martyr's death when a guide grabbed him by the coat tail! Out of breath and chilled through and through they staggered back to a little tavern and put their flasks in an improvised incubating oven -- and in a few days, to their joy, they found every one of their bottles swarming with little creatures. Pasteur was wrong!

Now the fight was on. Pasteur became publicly sarcastic about the experiments of Pouchet, Joly and Musset; he made criticisms that today we know are quibbles. Pouchet came back with the remark that Pasteur "had presented his own flasks as an ultimatum to science

to astonish everybody. " Pasteur was furious, denounced Pouchet as a liar and bawled for a public apology. It seemed, alas, as if the truth were going to be decided by the spilling of blood, instead of by calm experiment. Then Pouchet and Joly and Musset challenged Pasteur to a public experiment before the Academy of Sciences, and they said if one single flask would fail to grow microbes after it had been opened for an instant, they would admit they were wrong. The fatal day for the tests dawned at last -- what an interesting day it would have been -- but at the last moment Pasteur's enemies backed down. Pasteur did his experiments before the Commission -- he did them confidently with ironical remarks -- and a little while later the Commission announced: "The facts observed by Mr Pasteur and contested by Messrs. Pouchet, Joly, and Musset, are of the most perfect exactitude. "

Luckily for Pasteur, but alas for truth, both sides happened to be right. Pouchet and his friends had used hay instead of yeast soup, and a great Englishman, Tyndall, found out years later that hay holds wee stubborn seeds of microbes that will stand boiling for hours! It was really Tyndall that finally settled this great quarrel; it was Tyndall that proved Pasteur was right. (2)

4. Does Pasteur fit your conception of what scientists should be like? Why or why not?
5. In what way was Pasteur's hypothesis on the origin of microbes based on an emotional reaction?
6. What tests were made to support this hypothesis?
7. Why were so many tests necessary under so many different circumstances?
8. How were results compared to controls?

References:

1. DeKruif, Paul. Microbe Hunters. New York, Harcourt, Brace, 1940. p. 60-65.
2. Ibid. p. 73-81.

C. Case Study 3: Robert Koch - Microbes and Disease

Koch was spending his evenings fussing with his new microscope, he was beginning to find out just the right amount of light to shoot up into its lens with the reflecting mirror, he was learning just how needful it was to have his thin glass slides shining clean -- those bits of glass on which he liked to put drops of blood from the carcasses of sheep and cows, that had died of anthrax

Anthrax was a strange disease which was worrying farmers all over Europe, that here and there ruined some prosperous owner of a thousand sheep, that in another place sneaked in and killed the cow -- the one support -- of a poor widow. There was no rhyme or reason to the way this plague conducted its maraudings; one day a fat lamb in a flock might be frisking about, that evening this same lamb refused to eat, his head drooped a little -- and the next morning the farmer would find him cold and stiff, his blood turned ghastly black. Then the same thing would happen to another lamb, and a sheep, four sheep, six sheep -- there was no stopping it. And then the farmer himself, and a shepherd, and a wool-sorter, and a dealer in hides might break out in horrible boils -- or gasp out their last breaths in a swift pneumonia.

Koch had started using his microscope with the more or less thorough aimlessness of old Leeuwenhoek; he examined everything under the sun, until he ran onto this blood of sheep and cattle dead of anthrax. Then he began to concentrate, to forget about making a call when he found a dead sheep in a field -- he haunted butcher shops to find out about the farms where anthrax was killing the flocks. Koch hadn't the leisure of Leeuwenhoek; he had to snatch moments for his peerings between prescribing for some child that bawled with a belly-ache and the pulling out of a villager's aching tooth. In these interrupted hours he put drops of the blackened blood of a cow dead of anthrax between two thin pieces of glass, very clean shining bits of glass. He looked down the tube of his microscope and among the wee, round, drifting greenish globules of this blood he saw strange things that looked like little sticks. Sometimes these sticks were short, there might be only a few of them, floating, quivering a little, among the blood globules. But here were others, hooked together without joints -- many of them ingeniously glued together till they appeared to him like long threads a thousand times thinner than the finest silk.

"What are these things . . . are they microbes . . . are they alive? They do not move . . . maybe the sick blood of these poor

beasts just changes into these threads and rods," Koch pondered. Other men of science, Davaine and Rayer in France, had seen these same things in the blood of dead sheep; and they had announced that these rods were bacilli, living germs, that they were undoubtedly the real cause of anthrax -- but they hadn't proved it, and except for Pasteur, no one in Europe believed them. But Koch was not particularly interested in what anybody else thought about the threads and rods in the blood of dead sheep and cattle -- the doubts and the laughter of doctors failed to disturb him, and the enthusiasms of Pasteur did not for one moment make him jump at conclusions. Luckily nobody anxious to develop young microbe hunters had ever heard of Koch, he was a lone wolf searcher -- he was his own man, alone with the mysterious tangled threads in the blood of the dead beasts.

"I do not see a way yet of finding out whether these little sticks and threads are alive," he meditated, "but there are other things to learn about them . . ." Then, curiously, he stopped studying diseased creatures and began fussing around with perfectly healthy ones. He went down to the slaughter houses and visited the string butchers and hobnobbed with the meat merchants of Wollstein, and got bits of blood from tens, dozens, fifties of healthy beasts that had been slaughtered for meat. He stole a little more time from his tooth-pullings and professional layings-on-of-hands. More and more Mrs. Koch worried at his not tending to his practice. He bent over his microscope, hours on end, watching the drops of healthy blood.

"These threads and rods are never found in the blood of any healthy animal," Koch pondered. "This is all very well, but it doesn't tell me whether they are bacilli, whether they are alive . . . it doesn't show me that they grow, breed, multiply . . ."

But how to find this out? Consumptives -- whom, alas, he could not help -- babies choking with diphtheria, old ladies who imagined they were sick, all his cares of a good physician began to be shoved away into one corner of his head. How-to-prove-these-wee-sticks-are-alive? This question made him forget to sign his name to prescriptions, it made him a morose husband, it made him call the carpenter in to put up a partition in his doctor's office. And behind this wall Koch stayed more and more hours, with his microscope and drops of black blood of sheep mysteriously dead -- and with a growing number of cages full of scampering white mice.

"I haven't the money to buy sheep and cows for my experiments," you can hear him muttering, while some impatient invalid shuffled her feet in the waiting room. "Besides, cows would be a little inconvenient

to have around my office -- but maybe I can give anthrax to these mice . . . maybe in them I can prove that the sticks really grow . . ."

So this foiled globe-trotter started on his strange explorations. To me Koch is a still more weird and uncanny microbe hunter than Leeuwenhoek, certainly he was just as much of a self-made scientist. Koch was poor, he had his nose on the grindstone of a medical practice, all the science he knew was what a common medical course had taught him -- and from this, God knows, he had learned nothing whatever about the art of doing experiments; he had no apparatus but Emmy's birthday present, that beloved microscope -- everything else he had to invent and fashion out of bits of wood and strings and sealing wax. Worst of all, when he came into the living room from his mice and microscope to tell Frau Koch about the new strange things he had discovered, this good lady wrinkled up her nose and told him:

"But, Robert, you smell so!"

Then he hit upon a sure way to give mice the fatal disease of anthrax. He hadn't a convenient syringe with which to shoot the poisonous blood into them, but after sundry cursings and the ruin of a number of perfectly good mice, he took slivers of wood, cleaned them carefully, heated them in an oven to kill any chance ordinary microbes that might be sticking to them. These slivers he dipped into drops of blood from sheep dead of anthrax, blood filled with the mysterious motionless threads and rods, and then -- heaven knows how he managed to hold his wiggling mouse -- he made a little cut with a clean knife at the root of the tail of the mouse, and into this cut he delicately slid the blood-soaked splinter. He dropped this mouse into a separate cage and washed his hands and went off in a kind of conscientious wool-gathering way to see what was wrong with a sick baby . . . "Will that beast, that mouse die of anthrax? . . . Your child will be able to go back to school next week, Frau Schmidt. . . I hope I didn't get any of that anthrax blood into that cut on my finger. . . ." Such was Koch's life.

And next morning Koch came into his homemade laboratory -- to find the mouse on its back, stiff, its formerly sleek fur standing on end and its whiteness of yesterday turned into a leaden blue, its legs sticking up in the air. He heated his knives, fastened the poor dead creature onto a board, dissected it, opened it down to its liver and lights, peered into every corner of its carcass. "Yes, this looks like the inside of an anthrax sheep . . . see the spleen, how big, how black it is . . . it almost fills the creature's body . . ." Swiftly he cut with a clean heated knife into this swollen spleen and put a drop

of the blackish ooze from it before his lens. . .

At last he muttered, "They're here, these sticks and threads . . . they are swarming in the body of this mouse, exactly as they were in the drop of dead sheep's blood that I dipped the little sliver in yesterday." Delighted, Koch knew that he had caused in the mouse, so cheap to buy, so easy to handle, the sickness of sheep and cows and men. Then for a month his life became a monotony of one dead mouse after another, as, day after day, he took a drop of the blood or the spleen of one dead beast, put it carefully on a clean splinter, and slid this sliver into a cut at the root of the tail of a new healthy mouse. Each time, next morning, Koch came into his laboratory to find the new animal had died, of anthrax, and each time in the blood of the dead beast his lens showed him myriads of those sticks and tangled threads -- those motionless, twenty-five-thousandth-of-an-inch-thick filaments that he could never discover in the blood of any healthy animal.

"These threads must be alive," Koch pondered, "the sliver that I put into the mouse has a drop of blood on it and that drop holds only a few hundred of those sticks -- and these have grown into billions in the short 24 hours in which the beast became sick and died . . . But, confound it, I must see these rods grow -- and I can't look inside a live mouse!"

How-shall-I-find-a-way-to-see-the-rods-grow-out-into-threads? This question pounded at him while he counted pulses and looked at his patients' tongues. In the evenings he hurried through supper and growled good night to Mrs. Koch and shut himself up in his little room that smelled of mice and disinfectant, and tried to find ways to grow his threads outside a mouse's body. At this time Koch knew little or nothing about the yeast soups and flasks of Pasteur, and the experiments he fussed with had the crude originality of the first cave man trying to make fire.

"I will try to make these threads multiply in something that is as near as possible like the stuff an animal's body is made of -- it must be just like living stuff," Koch muttered, and he put a wee pin-point piece of spleen from a dead mouse -- spleen that was packed with the tangled threads, into a little drop of the watery liquid from the eye of an ox. "That ought to be good food for them," he grumbled. "But maybe, too, the threads have got to have the temperature of a mouse's body to grow," he said, and he built with his own hands a clumsy incubator, heated by an oil lamp. In this uncertain machine he deposited the two flat pieces of glass between which he had put the

drop of liquid from the ox eye. Then, in the middle of the night, after he had gone to bed, but not to sleep, he got up to turn the wick of his smoky incubator lamp down a little, and instead of going back to rest, again and again he slid the thin strips of glass with their imprisoned infinitely little sticks before his microscope. Sometimes he thought he could see them growing -- but he could not be sure, because other microbes, swimming and cavorting ones, had an abominable way of getting in between these strips of glass, overgrowing, choking out the slender dangerous rods of anthrax.

"I must grow my rods pure, absolutely pure, without any other microbes around," he muttered. And he kept flounderingly trying ways to do this, and his perplexity pushed up huge wrinkles over the bridge of his nose, and built crow's feet round his eyes . . .

Then one day a perfectly easy, a foolishly simple way to watch his rods grow flashed into Koch's head. "I'll put them in a hanging-drop, where no other bugs can get in among them," he muttered. On a flat, clear piece of glass, very thin, which he had heated thoroughly to destroy all chance microbes, Koch placed a drop of the watery fluid of an eye from a just-butchered healthy ox; into this drop he delicately inserted the wee-est fragment of spleen, fresh out of a mouse that had a moment before it died miserably of anthrax. Over the drop he put a thick oblong piece of glass with a concave well scooped out of it so that the drop would not be touched. Around this well he had smeared some vaseline to make the thin glass stick to the thick one. Then, dexterously, he turned this simple apparatus upside down, and presto! -- here was his hanging-drop, his ox-eye fluid with its rod-swarming spleen, imprisoned in the well -- away from all other microbes.

Koch did not know it, perhaps, but this -- apart from that day when Leeuwenhoek first saw little animals in rain water -- was a most important moment in microbe hunting, and in the fight of mankind against death.

"Nothing can get into that drop -- only the rods are there -- now we'll see if they will grow," whispered Koch as he slid his hanging-drop under the lens of his microscope; in a kind of stolid excitement he pulled up his chair and sat down to watch what would happen. In the gray circle of the field of his lens he could see only a few shreddy lumps of mouse spleen -- they looked microscopically enormous -- and here and there a very tiny rod floated among these shreds. He looked -- 50 minutes out of each hour for 2 hours he looked, and nothing happened. But then a weird business began among

the shreds of disease spleen, an unearthly moving picture, a drama that made shivers shoot up and down his back.

The little drifting rods had begun to grow! Here were two where one had been before. There was one slowly stretching itself out into a tangled endless thread, pushing its snaky way across the whole diameter of the field of the lens -- in a couple of hours the dead small chunks of spleen were completely hidden by the myriads of rods, the masses of thread that were like a hopelessly tangled ball of colorless yarn, living yarn -- silent murderous yarn.

"Now I know that these rods are alive," breathed Koch. "Now I see the way they grow into millions in my poor little mice -- in the sheep, in the cows even. One of these rods, these bacilli -- he is a billion times smaller than an ox -- just one of them maybe gets into an ox, and he doesn't bear any grudge against the ox, he doesn't hate him, but he grows, this bacillus, into millions, everywhere through the big animal, swarming in his lungs and brain, choking his blood vessels -- it is terrible."

Time, his office and its dull duties, his waiting and complaining patients -- all of these things became nonsense, seemed of no account, were unreal to Koch, whose head was now full of nothing but dreadful pictures of the tangled skeins of the anthrax threads. Then each day of a nervous experiment that lasted eight days Koch repeated his miracle of making a million bacilli grow where only a few were before. He planted a wee bit of his rod-swarming hanging-drop into a fresh, pure drop of the watery fluid of an ox eye and in every one of these new drops the few rods grew into myriads.

"I have grown these bacilli for eight generations away from any animal, I have grown them pure, apart from any other microbe -- there is no part of the dead mouse's spleen, no diseased tissue left in this eighth hanging-drop -- only the children of the bacilli that killed the mouse are in it. . . Will these bacilli still grow in a mouse, or in a sheep, if I inject them -- are these threads really the cause of anthrax?"

Carefully Koch smeared a wee bit of his hanging-drop that swarmed with the microbes of the eighth generation -- this drop was murky, even to his naked eye, with countless bacilli -- he smeared a part of this drop on to a little splinter of wood. Then, with that guardian angel who cares for daring stumbling imprudent searchers of nature standing by him, Koch deftly slid this splinter under the skin of a healthy mouse.

The next day Koch was bending nearsightedly over the body of this little creature pinned on his dissecting board; giddy with hope, he was carefully flaming his knives . . . Not three minutes later Koch is seated before his microscope, a bit of the dead creature's spleen between two thin bits of glass. "I've proved it," he whispers, "here are the threads, the rods -- those little bacilli from my hanging drop were just as murderous as the ones right out of the spleen of a dead sheep."

So it was that Koch found in this last mouse exactly the same kind of microbe that he had spied long before -- having no idea it was alive -- in the blood of the first dead cow he had peered at when his hands were fumbling and his microscope was new. It was precisely the same kind of bacillus that he had nursed so carefully, through long successions of mice, through I do not know how many hanging-drops.

First of all searchers, of all men that ever lived, ahead of the prophet Pasteur who blazed the trail for him, Koch had really made sure that one certain kind of microbe causes one definite kind of disease, that miserably small bacilli may be the assassins of formidable animals. He had angled for these impossibly tiny fish, and spied on them without knowing anything at all of their habits, their lurking places, of how hardy they might be or how vicious, of how easy it might be for them to leap upon him from the perfect ambush their invisibility gave them. (1)

1. Do you think Koch's personality and way of life could have had anything to do with his scientific discoveries? If so, how?
2. Upon what observations did Koch base his inference that micro-organisms cause disease?
3. How was this inference or hypothesis tested?

"One germ, one kind of germ only, causes one definite kind of disease -- every disease has its own specific microbe, I know that," said Koch -- without knowing it. "I've got to find a sure easy method of growing one species of germ away from all other contaminating ones that are always threatening to sneak in!"

But how to cage one kind of microbe? All manner of weird machines were being invented to try to keep different sorts of germs apart. Several microbe hunters devised apparatus so complicated that when they had finished building it they probably had already forgotten what they set out to invent it for. To keep stray germs of the air from falling into their bottles some heroic searchers did their inoculations in an actual rain of poisonous germicides!

v

One day, Koch -- who frankly admitted it was by accident -- looked at the flat surface of half of a boiled potato left on a table in his laboratory. "What's this, I wonder?" he muttered, as he stared at a curious collection of little colored droplets scattered on the surface of the potato. "Here's a gray-colored drop, here's a red one, there's a yellow, a violet one -- these little specks must be made up of germs from the air. I'll have a look at them."

He stuck his shortsighted eyes down close to the potato so that his scraggly little beard almost dragged in it; he got ready his thin plates of glass and polished off the lenses of his microscope.

With a slender wire of platinum he fished delicately into one of the gray droplets and put a bit of its slimy stuff in a little pure water between two bits of glass, under his microscope. Here he saw a swarm of bacilli, swimming gently about, and every one of these microbes looked exactly like his thousands of brothers in this drop. Then Koch peered at the bugs from a yellow droplet in the potato and at those of a red one and a violet one. The germs from one were round, from another they had the appearance of swimming sticks, from a third microbes looked like living corkscrews -- but all the microbes in one given drop were like their brothers, invariably!

Then in a flash Koch saw the beautiful experiment nature had done for him. "Every one of these droplets is a pure culture of one definite kind of microbe -- a pure colony of one species of germs. . . How simple! When germs fall from the air into the liquid soups we have been using -- the different kinds of them get all mixed up and swim among each other. . . But when different bugs fall from the air on the solid surface of this potato -- each one has to stay where it falls. . . it sticks there. . . then it grows there, multiplies into millions of its own kind. . . absolutely pure!"

Koch called Loeffler and Gaffky, his two military doctor assistants, and soberly he showed them the change in the whole mixed-up

business of microbe hunting that his chance glance at an abandoned potato had brought. It was revolutionary! The three of them set to work with an amazing -- loyal Frechmen might call it stupid -- German thoroughness to see if Koch was right. There they sat before the three windows of their room, Koch before his microscope on a high stool in the middle, Loeffler and Gaffky on stools on his left hand and his right -- a kind of grimly toiling trinity. They tried to defeat their hopes, but quickly they discovered that Koch's prophecy was an even more true one than he had dreamed. They made mixtures of two or three kinds of germs, mixtures that could never have been untangled by growing in flasks of soup; they streaked these confused species of microbes on the cut flat surfaces of boiled potatoes. And where each separate tiny microbe landed, there it stuck, and grew into a colony of millions of its own kind -- and nothing but its own kind.

Now Koch, who, by this simple experience of the old potato, had changed microbe hunting from a guessing game into something that came near the sureness of a science -- Koch, I say, got ready to track down the tiny messengers that bring a dozen murderous diseases to mankind. Up till this time Koch had had little criticism or opposition from other men of science, mainly because he almost never opened his mouth until he was sure of his results. He told of his discoveries with a disarming modesty and his work was so unanswerably complete -- he had a way of seeing the objections that critics might make and replying to them in advance -- that it was hard to find protestors.

Full of confidence, Koch went to Professor Rudolph Virchow, by far the most eminent German researcher in disease, an incredible savant, who knew more than there was to be known about a greater number of subjects than any 16 scientists together could possibly know. Virchow was, in brief, the ultimate Pooh-Bah of German medical science. He had spoken the very last word on clots in blood, vessels and had invented the impressive words heteropopia, agenesia, and ochranosis, and many others that I have been trying for years to understand the meaning of. He had -- with tremendous mistakenness -- maintained that consumption and scrofula were two different diseases; but with his microscope he had made genuinely good, even superb descriptions of the way sick tissues look and he had turned his lens into every noisome nook and cranny of 26,000 dead bodies. Virchow had printed -- I do not exaggerate -- thousands of scientific papers, on every subject imaginable, from the shapes of little German school-boys' heads and noses to the remarkably small size of the blood vessels in the bodies of sickly green-faced girls.

Properly awed --as any one would be -- Koch tiptoed respectfully into his presence.

"I have discovered a way to grow microbes pure, unmixed with other germs, Herr Professor," the bashful Koch told Virchow, with deference.

"And how, I beg you tell me, can you do that? It looks to me to be impossible. "

"By growing them on solid food -- I can get beautiful isolated colonies of one kind of microbe on the surface of a boiled potato -- and now I have invented a better way than that. . . I mix gelatin with beef broth. . . and the gelatin sets and makes a solid surface, and --"

But Virchow was not impressed. He made a sardonic remark that it was so hard to keep different races of germs from getting mixed up that Koch would have to have a separate laboratory for each species of microbe. . . In short, Virchow was very sniffish and cold to Koch, for he had come to that time of life when aging men believe that everything is known and there is nothing more to be found out. Koch went away a bit depressed, but not one jot was he discouraged. Instead of arguing and writing papers and making speeches against Virchow, he launched himself into the most exciting and superb of all his microbe huntings -- he set out to spy upon and discover the most vicious of microbes, that mysterious marauder which each year killed one man, woman, and child out of every seven that died, in Europe, in America. Koch rolled up his sleeves and wiped his gold-rimmed glasses and set out to hunt down the microbe of tuberculosis. (2)

4. How did the chance observation of a boiled potato lead to an important discovery? Discuss the role of chance observations in science.
5. Why are great discoveries such as Koch's often ridiculed by many intelligent people?
6. What is the importance of Koch's work to the development of microbiology as well as to human life?

References:

1. DeKruif, Paul. Microbe Hunters. New York, Harcourt, Brace, 1940. p. 102-110.
2. Ibid. p. 118-121.

D. Case Study 4: Why Are We Here?

A STUDY OF SOME CONTROVERSIAL SCIENTIFIC SPECULATIONS ABOUT THE ORIGIN OF MAN

What is the true nature of man and how did we come to be what we are?

Mankind has always been curious about this crucial question and it has been approached in many ways from the points of view of religion, philosophy, and science.

In spite of the recent explosion in the development of scientific knowledge, however, there is at best meagre and conflicting evidence regarding the biological nature of man himself.

If man is to have any hope of solving his complex personal, social, and economic problems it would seem that scientists must first seek the truth about the nature of man himself.

Natural Section: A Basic Theory or Model and its Use in Formulating Hypotheses

The theory of the origin of species by natural selection was first presented publicly in 1858. Papers were read by Charles Darwin and Alfred Russel Wallace at a meeting of the Linnaean Society both proposing natural selection as the means by which organisms evolve. Both men were naturalists and both had read and undoubtedly were influenced by the writings of Malthus. Malthus in his Essay on Population stressed the idea that food supply increases arithmetically while populations increase geometrically, i. e. food supply increases at a rate like 1, 2, 3, 4, 5, 6, 7, etc., while population increases at a much faster rate, e. g. 1, 2, 4, 8, 16, 32, 64, etc.

The following is Charles Darwin's own description of his theory and some of his predictions about possible changes in animal populations:

All nature is at war, one organism with another, or with external nature. Seeing the contented face of nature, this may at first well be doubted; but reflection will inevitably prove it to be true.

But for animals without artificial means, the amount of food for each species must, on an average, be constant, whereas the increase of all organisms tends to be geometrical, and in a vast majority of cases at an enormous ratio. Suppose in a certain spot there are eight pairs of birds, and that only four pairs of them annually (including double hatches) rear only four young, and that these go on rearing their young at the same rate, then at the end of seven years (a short life, excluding violent deaths, for any bird) there will be 2048 birds, instead of the original sixteen. As this increase is quite impossible, we must conclude either that birds do not rear nearly half their young, or that the average life of a bird is, from accident, not nearly seven years. Both checks probably concur.

Now, can it be doubted, from the struggle each individual has to obtain subsistence, that any minute variation in structure, habits, or instincts, adapting that individual better to the new conditions, would tell upon its vigour and health? In the struggle it would have a better chance of surviving; and those of its offspring which inherited the variation, be it ever so slight, would also have a better chance. Yearly more are bred than can survive; the smallest grain in the balance, in the long run, must tell on which death shall fall, and which shall survive. Let this work of selection on the one hand, and death on the other, go on for a thousand generations, who will pretend to affirm that it would produce no effect, when we remember what, in a few years, Blakewell effected in cattle, and Western in sheep, by this identical principal of selection.

To give an imaginary example from changes in progress on an island - let the organization of a canine animal which preyed chiefly on rabbits, but sometimes on hares, become slightly plastic; let these changes cause the number of rabbits very slowly to decrease, and the number of hares to increase; the effect of this would be that the fox or dog would be driven to try to catch more hares: his organization, however, being slightly plastic, those individuals with the lightest forms, longest limbs, and best eyesight, let the difference be ever so small, would be slightly favoured, and would tend to live longer, and to survive during that time of the year when food was scarcest; they would also rear more young, which would tend to inherit these slight peculiarities. The less fleet ones would be rigidly destroyed. I can see no more reason to doubt that these causes in a thousand generations would produce a marked effect, and adapt the form of the fox or dog to the catching of hares instead

of rabbits, than that greyhounds can be improved by selection and careful breeding.

Each new variety or species when formed, will generally take the place of, and thus exterminate its less well-fitted parent. This I believe to be the origin of the classification and affinities of organic beings at all times; for organic beings always seem to branch and sub-branch like the limbs of a tree from a common trunk, the flourishing and diverging twigs destroying the less vigorous - the dead and lost branches rudely representing extinct genera and families. (1)

1. How did Darwin's extensive background as a naturalist help him to test his hypotheses on natural selection?
2. A theory or concept such as natural selection has very wide applicability and may be used to formulate a great variety of hypotheses which explain how living things have changed. It may also be used to explain possible future changes. (Note Darwin's predictions about a fox population when food supply changes.) Using natural selection as a model, formulate two hypotheses of your own to explain how man has changed in the past or could change in the future. Use any human characteristic you wish and also indicate any way in which evidence could be gathered to test your hypotheses.

Robert Ardrey has conducted a personal investigation of the scientific evidence obtained during the last 30 years on the origins of man. He has presented this evidence in an exciting and provocative book - African Genesis:

A Hypothesis Regarding Territorial Behavior

The belated recognition by science of territorial behaviour serves in many ways to confirm the clear eyesight of poets and peasants. A century and a half before Eliot Howard, Oliver Goldsmith meditated that one rarely saw two male birds of a single species in a single hedge. And "one tiger to a hill" is a bold observation of equivalent discernment. But while peasant and poet may apprehend a truth, it is the obligation of science to define it, to prove it, to assimilate its substance into the body of scientific thought, and to make its conclusions both available and understandable to the society of which science is a part. It is an obligation which the sciences fulfill with the most conscientious discipline in any matter concerned with the

blowing up of man; yet in matters related to understanding the fellow, there has been a tendency to accept responsibility more lightly.

Only prime sources, such as we shall investigate in this chapter, will permit us to squeeze out for ourselves a definition, a comprehension, and an evaluation of one of science's most significant discoveries. But before we quite lose ourselves in the animal world, let us take a brief glance at the price we pay when science fails to digest its own fruit.

Sir Solly Zuckerman is one of the world's most distinguished scientists. When Zuckerman was a fairly young man he published a study of primate behaviour establishing sex as the basis of animal society. Few scientific books of the century have commanded such wide or lasting authority. But its conclusions were based largely on zoo observations.

The book was written in 1932 before the difference between animal behaviour in captivity and that in a state of nature had become apparent. The famous anatomist cannot be blamed for presuming that the sex-obsessed activities of London baboons reflected true primate behaviour, or for drawing the logical conclusions that the powerful magnet of sexual attraction must be the force that holds primate societies together. But over and over we shall encounter in this narrative the disastrous consequences of applying utter logic to a false premise. And Zuckerman's premise was false. The creature whom we watch in the zoo is one denied by the conditions of his captivity the normal flow of his instinctual energies. Neither the drives of hunger nor the fear of the predator stir the idleness of his hours. Neither the commands of normal society nor the demands of territorial defence pre-empt the energies with which nature has endowed him. If he seems a creature obsessed with sex, then it is simply because sex is the only instinct for which captivity permits him an outlet.

In 1934 Johns Hopkins University published the classic monograph by the American zoologist, C. R. Carpenter, The Behavior and Social Relations of Howling Monkeys. For eight months, over a period of two years, Dr. Carpenter had kept under systematic observation the activities of some 23 troops of howling monkeys on an island in Gatun Lake, in Panama. During the course of his study he created and perfected techniques for the observation of animal behaviour in a state of

nature which were to become standard in modern zoology. But he did far more than that. He discovered the role of territory in primate society.

Any reader of Dr. Carpenter's monograph must gain one impression overwhelming all others: that never again could science rest content with conclusions formed solely in zoos.

In 1940 Dr. Carpenter published another monograph, A Field Study in Siam of the Behavior and Social Relationships of the Gibbon, no copy of which exists today even in the immense libraries of the British Museum. In this rarely-read work, at this early date in the contemporary revolution, it was possible for the American zoologist to state on the basis of his own studies and those of others: "It would seem that possession and defence of territory which is found so widely among the vertebrates, including both the human and subhuman primates, may be a fundamental biologic need. Certain it is that this possession of territory motivates much primate behaviour. (2)

3. What erroneous hypothesis is stated above? How did it gain support? How was it finally disproven?
4. Why do you think that an idea, even when disproven, is still accepted by many capable scientists?
5. Can the "territory hypothesis" be accepted on the basis of what has been presented so far? Why or why not?

Ardrey next raises some questions about territory and looks at a wide variety of evidence:

How prevalent in animal life is the territorial instinct? What natural purposes does it serve? How is territory gained? Defended? Against whom? What is a territory, anyway?

Mrs. Margaret Morse Nice, writing in 1941 in The Midland Naturalist, gave a definition of territory which remains today as good as any. "The theory of territoriality in bird-life is briefly this: that pairs are spaced through the pugnacity of males towards each other of their own species; that song and display of plumage are a warning to other males as well as an invitation to the female; that males fight primarily over territory, and not over females; that the owner of a territory is nearly invincible on his own ground; and finally, that male

birds who fail to secure a territory form a reserve from which replacements come in the case of death of territorial owners. "

What holds for birds holds by and large for all those vertebrate species in which competition for territory is on an individual basis. In such species it is sometimes difficult to separate territorial from sexual rivalry. But when we come to social species in which a group defends a territory against other groups, then no sexual objective can play a part. The territorial compulsion stands cleanly on its own. Why, then, does it exist?

That the territorial drive confers benefits on breeding and safety of the young must be obvious. Paul Errington's studies of muskrat colonies in the American Middle West show that the number of breeding pairs tolerated by a given habitat tend to remain similar from year to year. Droughts, hard winters, plagues, or an access of foxes may cast notable shadows on the pleasures of muskrat life. But it is as if for any specific area there exists some threshold of security, and behind that threshold life goes on. The laws of territory make sure that muskrat families will divide up the area in no greater number than the threshold of security can sustain.

Good times may come to the muskrat community, and overpopulation threaten its future. The foxes may relax; but the demand for territory never. Surplus muskrats are driven out of the home range to find new ones for themselves in the unfamiliar countryside. Some succeed. But a variable number continue their footloose, hazardous wandering, and of them Errington paints a sad picture: "A harassed and battered lot, they congregate about the fringes of areas dominated by muskrats already in residence. Transients, they form a biological surplus largely doomed by one medium or another. "

Nature, by instilling in the individual a demand for exclusive living space, insures two consequences: First, that a minimum number of individuals in any population will be enabled to breed in relative security and pass on in fair certainty the conformation of their kind. And second, that the surplus will be cast to the wolves; to the owls, to the foxes, to the plagues and famines and lonely, unfamiliar places, there to make the most of perilous conditions or to die.

The territorial instinct may be fulfilled in many a way, depending upon the nature of the species. And a territory solely possessed may confer many a benefit on its proprietor: assurance of food supply whether for carnivore or vegetarian, spacing of individuals in a habitat; sorting of the fit from the misfit; attraction for mates; security against the predator. But while we may speak of benefits and purposes, the animal staking out a claim seizes simply for reasons of seizing. If man is so rarely conscious of the ultimate reasons for his actions, it seems highly improbable that the animal should be better informed. And he will fulfill his territorial instinct, as has been spectacularly demonstrated, whether or not benefit will accrue.

During the course of his studies of primate societies, Dr. C. R. Carpenter settled 350 rhesus monkeys from India on a small island off Puerto Rico. It was a famous experiment combining the behaviour of animals in a wild state with conditions of laboratory study and control. Many conclusions were derived from the experiment, and we shall refer to others in the course of this narrative. But the startling conclusion concerning territory will concern us now.

The monkeys had been gathered from random sources in India. They survived the misfortune of a bad sea voyage on which conditions prevailed that can only be described as animal anarchy. But arriving at Santiago Island they entered what any primate must regard as a monkey Utopia. There was ample space, 35 acres for a few hundred individuals. No leopards haunted their nocturnal hours, or pythons their day-time excursions. There was food in abundance distributed daily and evenly by the island caretakers. Yet within one year the whole monkey community divided itself into social groups, each holding and defending a permanent territory and living in permanent hostility with its neighbours.

When Eliot Howard confronted his critics in the early 1920's with the radical observation that male birds conduct their competitive struggles not on behalf of attractive females, but rather on behalf of attractive properties, romance died hard. He cited the case of migrant species. Among these, the males arrive in advance of the females. In a bird-world undistracted by female presence claims are staked, quarrels fought, conquests trumpeted, and the weak cast out. When the females arrive, the struggle is over.

The drive to possess and to protect what is one's own is an instinct on its own.

The reed bunting seems a sensible enough bird, as birds go. Yet Howard once observed a pair of reed buntings in a state of extreme commotion. They had a nest, and young; and the object of their anxiety was a weasel. They chorused their hysterical disapproval of the invader, flew at him, sought to distract his attention from their nest. The weasel was not to be put off by either insults or the wind of wings. He lingered. The hysterical mounted. Male and female alike resorted to all those diversionary tricks for which birds are famous. Yet three times during the course of the incident the male bird turned from his attack on the weasel to drive off a third reed bunting seeking to invade his territory. The territorial command worked in opposition to, and took precedence over, the command to protect his young.

Before we consider the methods by which various birds establish territories, let us glance at the seal. The migrant bulls, like male birds, arrive first at the intended rookery. There is a deal of shoving and hauling and roaring and gouging. Territories are established. Only then do the females arrive. Now bulls acquire harems that vary in size according to the extent of their real estate holdings, an extent already determined by the relative power and pugnacity of the individual bulls.

The seal's polygamous disposition presents him with domestic headaches unsavoured by the decently monogamous bird. He is immediately surrounded by squabbling females. Neither does he receive any proper reward for conquest and glory. The females have arrived regrettably pregnant. While gestation is polished off and the young are born and reared, the male must content himself with barking at his fellows and driving off bachelors whose invasion of territory can hardly be motivated by a desire to share his paternal role. Only when the rookery ceases to be a nursery and all infants are found seaworthy, does the female become sexually responsive. Now at last the harem may test the validity of territorial boasts.

Migratory birds establish their territories in a manner little different from the seal. The males have as a rule a fortnight before the arrival of the females in which to settle their differences and establish freeholds. Then the females come. The

male without a holding is ignored. The propertied male advertises his advantages and secures a mate worthy of his holding. Family life begins.

As late as 1923 it was still possible for a competent naturalist to write that "birdsong is an expression of the joy of life, and the mocking bird, above all, is the most joyous. Just 14 years later the anti-romantic revolution could make possible the statement from another competent naturalist that "birdsong exists either seldom or never as an expression of peace or pleasure; all or most is produced for practical purposes."

Birdsong takes place when and if the male gets his territory. So long as buntings are joined in flocks on the neutral feeding ground, the male never sings. Only when he finds that perch which will be the advertisement of his territorial existence - his alder, his gate, his willow bough - does the will to sing enchant him. Male lapwings fight and sing, and sing and fight, as they establish their freeholds apart from the flock. As we have seen, on those occasions when males return to neutral ground their hostility is suspended; so likewise is their song. Eliot Howard once kept track of a flock of turtle-doves numbering upwards of a hundred. They fed on an eight-acre stretch of field where seeds were plentiful, while flying back and forth to a nearby range where territories were being established. Not on a single occasion did Howard hear their characteristic coo anywhere but on the territorial range.

Birdsong from the female is unquestionably an announcement of sexual readiness. But it occurs in response to the male's announcement of territorial readiness. Furthermore, it is an error of observation to associate birdsong exclusively with the mating season, for it begins when the male deserts the female and goes to seek his fortune. Then and for some time he will sing as the cock crows for male ears alone. Habitually - whether before or after the arrival of females - he sings from that particular perch which he makes his throne and from which he proclaims his sovereignty. When the male leaves his territory - whether before or after mating - he rarely sings. But immediately upon his return he goes directly to his throne and announces that the king is again in residence.

Mrs. Nice has given us a careful description of a territorial conflict between two male song sparrows which she observed in Ohio. One was the owner, the other the challenger.

Mrs. Nice had premised her observations by banding 343 song sparrows seeking territories on 40 flood-plain acres near the city of Columbus. When the struggle for living space was concluded, each successful male had acquired a realm of approximately three-quarters of an acre. But this left a considerable surplus of unpropertied outcasts. And it was one of these proletarians who chose to challenge a member of the privileged class.

The challenger approached the disputed territory in watchful silence. The owner, on watchful guard, sang. The challenger, darting from bush explored all approaches while the champion, likewise darting about, blocked every avenue. Now and again the challenger made a foray onto the disputed freehold; he was repelled. Again and again he attacked; again and again he was beaten off. At last the challenger accepted defeat and retired to the moral doom of the surplus, unmated, unpropertied male, while the champion returned to his fruitful throne. Through all the long engagement the proprietor had never failed to sing eight to ten times a minute. The challenger in no single instance had broken his silence.

The male bird sings of his possession. His call is distinctive throughout all his species since it is directed to the ears of his species alone. He sings to all other males that he is a bird of property and is prepared to defend what is his own. When he signs to the female, it is not to advise her that he is sexually ready - since he is a male his readiness may be assumed - but that being a bird of property he is worthy of her notice. It is a piece of information essential to the female ear.

Eliot Howard, in all his long career, never knew of a male bird, with territory, to lose a mate; nor of a male bird without territory to gain one. By what means are the boundaries of a territory defended? And why should the proprietor almost invariably win?

As anything goes that works, concerning the character of a territory, so anything goes that provides its means of defense. It is the male, for example, who almost invariably is the bearer of the territorial instinct, although his mate may assist in territorial defense. But natural selection has tolerated exceptions even to this all-but-universal law.

The phalarope is a water bird related vaguely to the sandpiper and it frequents the Arctic in summer. It is a freak. Some

chance mutation once affected the phalarope's ancestral line and in consequence certain sexual characteristics suffered reversal. The male is dun-coloured, the female brightly feathered. The female arrives first at the breeding grounds and conducts the territorial scramble. The male arrives later and incubates the egg while she defends the home place. The system works and evolution shrugs.

Another exception to the universal rule that the male conducts territorial defense is that of the Cuban lizard. Unlike the phalarope, however, the male has everything arranged his way. The Cuban lizard is the master of a territory no more than ten or twelve square yards in extent. Like the seal he is polygamous, and on his territory he rules a harem of three or four females. But the little lizard wastes no energy on hostility's eternal demands. By the most ingenious system known to nature he allots to the female the role of territorial defender, and guarantees her cooperation by the simplest of means. He displays enormous appetite for every passing female. The harem responds to his philandering fancy by guarding the territory with a vigilance beyond anything that nature might normally demand.

For an inquiry into more normal means of territorial defense, however, we may turn to the work of the Austrian naturalist, Konrad Lorenz, whose studies have become familiar to many readers through his endearing book, King Solomon's Ring. There Lorenz describes the establishment and defense of a territorial boundary by that formidable fish, the European stickleback. It is a charming portrait applicable to many a belligerent male in the animal world.

The stickleback, like the Siamese fighting fish, is a species in which the male, not the female, undertakes the building of the nest and the care of the young. Such behaviour in the bird-world stamps a species a freak; it does not, however, in the world of fish. One may wonder, nevertheless, if both European stickleback and Siamese fighting fish might not better leave such duties to the ladies; for the males of both species, nurse, besides the young, the vilest of dispositions.

The stickleback is a dangerous-seeming creature constructed apparently for mortal combat. His back is decorated with a deadly spine. His aggressiveness appears uncompromising. His approach to family responsibilities is of a stern order, and

he entertains no romantic impulses until he has dug a hole in a sandy bottom, constructed in a nest built of plant fibre and cemented by kidney secretion, and established in the neighbourhood an unassailable territory. There is a difference, however, between the combativeness of the European stickleback and of his eastern counterpart. The Siamese fighting fish, more frequently than not, leaves either himself or his opponent a tattered corpse at the end of a watery duel; the stickleback, on the other hand, is capable of compromise. In this characteristic he is fairly typical of aggressive masculinity in the animal world. Lorenz never knew of a stickleback that dies of his convictions.

"The basic principle of his fighting," writes Lorenz, "is that my home is my castle." The fighting inclination may be stated with mathematical exactness: it decreases in direct proportion to the distance from the nest. The stickleback having built his castle prowls the adjacent water glaring about in a search for intruders of his own species. He encounters one. It is a male stickleback who has likewise finished a castle on an adjacent territory. The less-than-mortal battle is joined.

The intruding stickleback has ventured too far from home. He flees. Our stickleback pursues him with every apparent intention of ramming him with the formidable spine and disposing of the intolerable neighbour for good and all. But a mysterious thing happens. As the panic-stricken neighbour approaches his own castle, his courage returns. Simultaneously the courage of our own stickleback begins to wane; it is as if, suddenly, he began to wonder how things were going back home. As suddenly the roles are reversed. The pursued neighbour becomes the pursuer. Our stickleback is in flight. Now they return deep into our stickleback's territory until again the roles reverse. Courage rises in the one, wanes in the other. The combat turns again.

It is a process all but interminable. Yet with each death-defying excursion into enemy territory, the courage of the pursued stickleback returns perceptibly sooner, even as do the second thoughts of the pursuer. The alley of battle shortens. The fish turn more quickly. At last there is no more flight and pursuit. The sticklebacks, weaving menacingly, glower at each other through an invisible wall. It is their territorial boundary. A balance of courage -- or of cowardice -- has been struck.

Dr. Carpenter in 1934 published a similar observation in his revolutionary monograph on the howling monkey. For eight lonely months, as we have seen, he observed twenty-odd communities on Barro Colorado Island in Panama. But the months, while lonely, could scarcely have been boring, for the eminent American zoologist had found an animal worthy of his patience.

The howler, like a character in a good farce play, achieves the greatest hilarity when he is at his most earnest, and suggests the most universal implications when he is at his most hilarious. He is a creature almost black, with an old-time comedian's bare face and chin whiskers. Although he is nearly as large as the baboon, he leads a life entirely arboreal. Like most New World monkeys, he has a prehensile tail, and he uses it with equal facility to anchor himself at night when he sleeps, to brush away insects, and to manipulate his own or the next monkey's genitals. For all-round, unashamed, disgraceful conduct the howler acknowledges no equal in the animal world.

The howling monkey draws his name from a most anti-social habit of greeting the day, each dawn, with a cry as mournful as it is deafening. The Spanish conquistadores were the first to lead depressed lives in consequence. As far back as the 17th century we find colonial administrators regretting that they had ever left Spain, and recording their doubts as to the likelihood of ever being able to massacre the last of their melancholy neighbours. These were the days, of course, when birds sang for the unbearable joy of life, while howlers mourned its sadness.

The howling monkey distributed worse things than gloom from his room in the tree-tops. The early Spaniards, in their misery, frankly recorded all; and so a second trait became part of the howler's tradition. This was his unwholesome habit of urinating or even defecating on intruders beneath his tree. Carpenter found the trait no myth; frequently the objects of his observation used him as a target. Howler apologists had evolved the hypothesis that the presence of man produced fear in the animal, and fear an emptied bladder. Carpenter disagreed. On too many occasions he spotted a male who in turn had just spotted him. He observed the unscrupulous animal making his way through the branches -- now and again camouflaging the movement by tearing off leaves and pretending to eat -- until he had got the zoologist's range. Carpenter could testify to the purposefulness of the manoeuvre, to the time required, and sometimes,

unfortunately, to the accuracy of the gunnery. With an objectivity admirable under the circumstances, Carpenter concluded that an average time of 60 seconds between the sighting of an intruder and a physiological consequence was a little too long to be attributed to fear. The howler repelling a potential enemy simply subscribes without inhibition to the doctrine of any means to an end, and so makes use of those meanest weapons with which nature has endowed him.

Not all the howler's ways, however, can be regarded as deplorable; some we may even admire. The creatures live in social groups of 20 or 30, defending each a social territory of approximately 300 acres. The dawn-and-dusk vocalizing serves as warning to all neighbouring groups as to the home group's location. If the chorus is loud, it is because the territory is large. If the mood seems to human ears one of unendurable melancholy, then its quality must be ascribed more to the disposition of man than to the disposition of the howler. He is in fact an amiable sort of fellow. Seldom does physical violence mar his day. He has even developed through vocal ability a defense for his territory by means short of war.

Unlike the baboon troop which scatters far and wide in search of food, the howlers' society clusters close all day feeding in two or three trees. In the course of a month the group moves from tree-camp to tree-camp throughout its territory. Carpenter mapped the movements, and found that the closer to the territorial centre the clan is disposed, the more certain is the direction of its movements. But as the group nears the fringes of its territory, a zigzag quality appears on the chart. Familiar paths beckon; unfamiliar repel. In its hourly course the clan falls more and more into vocal dispute, into hesitation and into uncertain leadership. And when it reaches the actual border of an adjacent territory, the group sharply and invariably turns back on itself. As the stickleback draws courage from his castle, the howler draws confidence from the familiarity of his territorial heartland.

There were 23 clans on Barro Colorado Island when Carpenter studied the community, and each had its fixed estate. But while a border might be recognized by the pressure of strangeness, it was established by contact with adjacent clans.

In all his studies of primate societies, Carpenter never observed two adjacent groups living in anything but total hostility.

The howling monkey is no exception. But whereas the baboon, for example, must express his hostility by violent action, the howler like the stickleback has found means of non-violent compromise without loss of belligerent satisfaction. He vocalizes.

No flights of human invective pioneered by modern diplomacy and displayed so engagingly in the United Nations' Security Council can touch the howler in his older and more sophisticated substitute for war. When two groups sight each other, each on the fringe of its territory, all break into total rage. Males, females, juveniles and infants become ants on a hot plate, leaping through the branches, scudding through the tree-tops, screeching, barking, chattering in frenzy. The forest cathedral becomes a green asylum for its insane habitants, and the howls of apparent melancholia become the shrieks of the truly demented. For 30 minutes rage has its way; then both sides retire from the field of glory. Losses have been nil; territory has been held inviolate; anger has been magnificent and satisfaction for both sides a maximum. Carpenter records that if an intrusion has indeed taken place, then the home team always wins.

The stickleback and the howling monkey has each through its history developed means of territorial defense which offer the greatest possible delight to the soul with the least possible damage to the body. The same cannot be said of all species. Even so, physical conflict between the proprietors of adjacent territories tends to be at a maximum during the period of establishment. And establishment tends to be permanent, except among species which hold territories only during the breeding season. When Carpenter returned to Barro Colorado Island the second year he found little change in the positions of the various howler clans. And there is a record of a South African farmer who faced for 35 years the same troop of baboons raiding his orchards.

Permanence of territory acts as a factor reducing conflict. But also there prevails throughout all territorial animals a varying respect for the rights of the neighbour. The respect exists despite the universal law that territorial neighbours live in eternal and unremitting hostility. The bird attacks an intruder not with the objective of destroying him or of seizing his territory in reprisal. Victory is accomplished by driving him away.

A heron will fish at a definite location. His neighbour will fish at another location. But the first heron will not trespass on the next preserve, even when the neighbour is absent. Certain predator birds have hunting territories, among them the golden eagle. This mighty hunter will on occasion condescend to share his territory with the raven. But the raven respects the sovereignty of the eagle and will not hunt while the eagle is hunting.

To use the anthropomorphic term, respect, is of course inexact. If a herd of hartebeest in Kenya grazes to a certain line and no farther, it is out of instinctual certainty that in any conflict on an opponent herd's territory the home team, as Carpenter has pointed out, has always the best of it. A South African naturalist named Fitzsimons reported in the days before the use of the term, territory, that on blue wildebeest feeding grounds each herd had an area of its own sharply marked; that trespassers were driven away; and that the promptness of a trespasser's retreat would seem to indicate some consciousness of having been caught in the wrong club-house. It is again the story of the stickleback; courage wanes in foreign parts, waxes in familiar places.

How powerful and mysterious is the pull of the home-place on animal behaviour has been the subject of many a human meditation. Some of us may recall from childhood the quickening pace of our grandfather's horse when at the end of a day's shopping in the village the turn of a single corner set a course for home. Or tales may have come to us of the dog banished to a new home a thousand miles away who unexpectedly turns up, one bright morning, on his former master's doorstep. Or we may puzzle over the inexplicable capacity of the salmon to spend years in the seas, then to return unerringly to his natal brookside, there to spawn and die. We may even meditate on the ill-defined, unremarked, rarely guessed influences of a force called nostalgia as it affects human affairs.

Eugene Marais, an untrained South African naturalist, once performed a homely experiment that by careful laboratory extension might give us a quantitative measurement for the power of animal nostalgia. Marais observed two columns of red ants moving along an African roadside. They proceeded in opposite directions, as ants do, one towards the nest and one away from it. The column leaving the nest was unburdened; each ant of the returning column carried from a neighbouring field a seed very nearly as large as itself.

To begin his experiment, Marais scratched a narrow ditch across the path of the two columns and filled the little ditch with water. On either side of the ditch there immediately gathered a milling mass of frustrated ants, confused as only ants can be when they encounter an unexpected obstacle. Marais then offered them a way. He placed a straw across the ditch for a bridge. And then he sat back to observe the startling climax.

The unencumbered ants proceeding away from the nest tried the bridge, hesitated, explored its uncertainties again, backed away, and in the end rejected its hazards. But the column of ants each handicapped by the burden of a gigantic seed hesitated not at all and proceeded nimbly and with confidence across the swaying straw. They were going home.

Territoriality is a vertebrate instinct touching fish and amphibia, reptiles and mammals and birds. While it therefore must be several hundreds of millions of years old, still it came into being after the evolutionary separation of the ancestral insect line from our own. The red ant like other insects establishes and defends no territory. But the pull of the home-place is a force that pervades us all. And there can be no doubt but that the superior power of the territorial proprietor, while benefiting from superior knowledge of familiar terrain, still finds its most profound convictions in the ancient, mysterious and perhaps unknowable headwaters of animal nostalgia.

The world of the animal is a world full of fear. There is an old saying that in a state of nature the object of existence is to obtain one's dinner without providing someone else with his. In such a world the creature who has established a trusted territory has made for himself a trustworthy ally. The alliance may benefit him in any of numerous ways, determined by the particular problems which afflict his species: it may guarantee his food supply; it may shelter his young; it may give him an edge on the leopard that inflicts delirium on his nights. Or territory may give him status in the eyes of the female, a creature necessarily dedicated to the long view of things; and so he may gain a better mate and more worthy young. Whatever the advantage that an individual animal or a particular animal society may gain from the powerful territorial drive, it is evident that chances for survival are bettered. And natural selection, as blind as a cave fish concerning ultimate purposes yet as shrewd as a cat concerning the moment's situation, lays the long finger of

survival on those in whom the drive runs strongest and the thumb of death on the remainder. So an instinct flowers (3).

6. In gathering evidence to test a hypothesis frequently new problems arise and new hypotheses are developed. Give some examples of this from the evidence collected above on territorial behavior.
7. Do you think that territorial behavior is important among human beings? Provide evidence to support your answer.
8. Discuss some of the problems involved in testing the hypothesis that territorial behavior is a basic instinct in all animals including man. What kinds of conclusions can you make on the basis of the evidence presented so far?

A Hypothesis Regarding Animal Dominance and Status

Every organized animal society has its system of dominance. Whether it be a school of fish or a flock of birds or a herd of grazing wildebeest, there exists within that society some kind of status order in which individuals are ranked. It is an order founded on fear. Each individual knows all those whom he must fear and defer to, and all those who must defer to him. Self-awareness in the limited sense of consciousness of rank seems to have appeared at some very early moment in the evolution of living things.

Whether or not in such societies as the antelope herd every individual has a separate rank, we cannot yet say. Too little study has been done. In some societies there may be classes themselves ranked which an individual achieves or to which he is relegated. But determination of rank by birth is a characteristic of the insect world alone. Among the vertebrates, from fish to apes, status is competitively determined fairly early in the individual's lifetime. That rank is rarely lost, and rarely improved upon.

Dominance occurs when two or more animals pursue the same activity. It is a type of behaviour long-observed, since all animals - wild, captive, or domesticated - pursue it. But not until zoology turned its attention to the natural state did we begin to comprehend the unyielding fabric of dominance in the texture of animal societies. The social animal does not merely seek to dominate his fellows; he succeeds. And succeeding, he achieves

a status in the eyes of the other. That status will be permanent; and oddly enough satisfying as a rule to all parties.

In the halls of science there are many doors, and the one with the sign that reads Animal Dominance is one that we have scarcely opened. We have learned much; that it is a force at least as old and as deep as territory; that like territory it benefits sex but stands independent of it; that among social animals it is universal, and among our primate family the source of society's most mysterious subtleties; and that among all animal sources of human behaviour, the instinct for status may in the end prove the most important. But while we may observe it, we still do not truly understand it. And that is why any new study of status in animal societies is apt to leave the most informed reader in a renewed state of stupefaction.

The jackdaw is an extremely intelligent bird who reaps the benefit, as we have seen, of a highly organized social life. It is logical, I suppose, that any animal who gains so much from the deathless wisdom of society will see to it that his society operates with the least possible friction. Natural selection would so decree. But I still find my credulity strained by the subtleties of the jackdaw social order. And were Konrad Lorenz a less experienced observer, I should probably wind up in stolid disbelief.

Every male jackdaw has his number, as it were. From Number One to Number Last there is not the least vagueness in the hierarchical position of the individual male bird within a flock. That position is settled upon at an early date in life. Even in chickhood a shuffling about for status begins. Food may be abundant, but quarrels flourish. Somebody pecks somebody, and gets pecked back; somebody retreats. Gradually the timid, the weak, the irresolute fall; gradually the strong and the determined rise. Before too long rivalry of body and character has determined the exact social position of every male bird in the flock. And he will keep that position, most probably, for life. Lorenz never saw a case of change in status caused by discontent from below.

Every barnyard has its pecking order, as every farmer knows. Chickens like jackdaws establish a hierarchy. And the position of the individual chicken determines all pecking rights. Who may peck whom? No chicken may peck another ranking higher in the order. This is known in zoology as a straight-line hierarchy. The high-ranking chicken may peck left and right at the feeding

pan; but there is always that lowly chicken who is pecked by all, and can peck no one in return.

Sage grouse in the American West have a curious institution known as the strutting-ground. In an area half a mile long and a few hundred yards wide the males here establish and display dominance. It is a competition very closely resembling the formal manoeuvres of the blackcock, an institution known to English ornithologists as the lek. A study of a sage-grouse strutting-ground in Wyoming has been described by W. C. Allee and demonstrates just how carefully natural selection may insure that only select male genes will colour the prospects of a future generation.

The study covered about 800 birds. After the males had sorted themselves out on the strutting-ground, the hens gathered at five mating spots each the size of a room. Dominance established 1% of the males as what Allee terms master-cocks, 2% as sub-cocks. Copulation occurred only at the invitation of the hen; in other words, female prerogative of choice was the next step in natural selection. And the result of that selection was that 74% of all matings were with master cocks, 1% of the total male population; and 13% with sub-cocks, representing 2% of the males. Rank order of dominance had insured that 87% of that season's crop of young sage grouse be fathered by only 3% of the male population.

One of the objects of Carpenter's study was dominance. He had developed in the course of other primate studies certain criteria for dominant behaviour: how often one male would be the leader in a move towards a new feeding place, and how often another; which made the first move towards food in the morning, and which towards rest at night; which took the lead in territorial disputes, or voiced the first call in an emergency. Such criteria compiled in the dossier of each male in a single society gave in sum the individual's rank order in the hierarchy. And it told more. It gave one an index or relative dominance that could be applied to a whole species.

Primates are not like jackdaws. There is no rigorous rank order in which every individual must always assume the same status in relation to every other individual. In primate societies there is simply a tendency for one male rather than another to take leadership in situations. Among gorillas that tendency is at its peak, so that one male rules and is never disputed. Among baboons

the tendency is strong; a few males in the troop will make almost all the decisions, and the dominant rank of one male in relation to another will be quite distinct. The howler, for all his violent vocabulary, asserts the least rank in relation to his fellows. His is the closest to a cooperative, live-and-let-live, equalitarian society to be found in the primate world.

The rhesus monkey falls somewhere between the baboon and the howler. In a normal society containing half a dozen males, Number One will take the lead or win the argument on perhaps four or five times as many occasions as Number Last. And Carpenter found the ration of dominance in his transported rhesus society on Santiago Island to be of such a moderate sort, differing little from that of untransported rhesus societies which he had studied in India and Siam. But while he was studying his various groups and making his calculations of dominance, an astonishing event took place. Group I embarked on conquest.

Group I seemed no different from any other troop on the island. It was average in size and contained the normal distribution of males, females, juveniles, and infants. Its territory was of the same order of magnitude, and the food supply -- which as I have mentioned was distributed daily by a caretaker -- was equally available to all. No reason for systematic aggression could at first be discovered. But conquest nevertheless occurred.

Daily Group I infringed on its neighbours - and got away with it. Daily, regularly, Group I made its feeding excursions on to the territories of not just one but five neighbouring societies. Group I was opposed, as it had to be opposed, by the injured societies. There was no weakness in the opposition. But Group I by some mysterious power broke that most fundamental of animal laws, that the home team wins. In this case the home teams, all of them, lost; and Group I had its way on opposition territory. The mystery, however, became quickly solved.

Group I contained a male of almost unbelievable dominance. He was Number One, of course, and his factor of dominance as compared to Number Last was about 50. While a normal maximum in the rhesus would be about five, Number One had as great an advantage as that even over Number Two. That all-powerful natural accident, conception, had placed in the genes of a remarkable monkey such resources of strength, of energy, of courage, and of assurance that he had become a giant of dominance. And his very presence in a society amazingly enough communicated to

all members of the society the resources of his nature. Group I was pervaded by its leader's character, and despite all laws of territorial behaviour acquired the capacity, as a society, to dominate its neighbours.

Carpenter removed the master monkey from the master society. The troop immediately fell back to its own territory. Not once during the exile of its leader did the society commit a single act of trespass. Then Carpenter restored the monkey to his fellows. Without hesitation Group I returned to its field of conquest.

How do dominated males in certain antelope species resign themselves so utterly to life without sex? And one recalls an observation from Asia, recorded by Fraser Darling, that answers the question not at all, and simply opens a wider one.

It is a very simple story. The owner of a small herd of water buffaloes had a bull incapable of serving all the cows. He bought two more bulls. Immediately the three bulls entered into a struggle for dominance. The original bull, perhaps benefited by his seniority, succeeded in so thoroughly dominating the new bulls that they became impotent. He, on the other hand, was now capable of serving the entire herd.

What is the true relation of social status to sexual powers? What physiological forces are released by hierarchical attainment? We do not know. We have just these fleeting glimpses. But again, an obscure study of dominance is recalled to one's mind, answering no question but opening others (4).

9. Do you think there is an instinct for status and dominance which influences human societies? Discuss any evidence you can think of which either supports or rejects this hypothesis.
10. Do these studies about territory and animal dominance support the theory of natural selection? Explain.

The Observation of Fossil Bones in Africa and a Provocative Hypothesis About the Origin of Man

For the 1955 report of the Smithsonian Institution, published in Washington the following year, Raymond Dart was requested to submit his case for the southern ape. The article was called The Cultural Status of the South African Man-Apes, and with

its publication Dart's creature emerged from the shadowy underground of specialized scientific publications to become a recurrent figure in the world press. In the course of that article he recalled: A miner, M. de Bruyn, had brought in a number of fossil-laden rocks blasted out the week before. When they came to Johannesburg I found the virtually complete cast of the interior of a skull among them. This brain cast was as big as that of a large gorilla; and fortunately it fitted at the front end on to another rock, from which in due course there emerged the complete facial skeleton of an infant only about five or six years old, which looked amazingly human. It was the first time that anyone had been privileged to see the complete face and to reconstruct accurately the entire head of one of man's extinct ape-like relatives. The brain was so large and the face was so human that I was confident that here indeed was one of our early progenitors that had lived on the African continent; and as it had chosen the southern part of Africa for its homeland I called it Australopithecus africanus, i. e., the South African ape.

In such an off-hand, homey, accidental fashion was one of the most significant of human adventures initiated. Buxton is a village on the fringe of the Kalahari desert near a railway station the name of which was then spelled Taungs. Dart's discovery became known as the Taungs skull. The fossil-laden rocks had come not from the deposit itself but from a cave formed within the oldest of four mantles of lime. Geologic evidence combined with the nature of the associated fossils to indicate that the infant man-ape had lived in the early part of the Pleistocene, towards a million years ago. The arid nature of the site discouraged any interpretation of the creature as a type of advanced arboreal ape. The ape is a forest creature, but forests could not have existed there in his day any more than they do in our own.

Dart had nothing but this single immature skull as companion for his meditations. But on the basis of tooth development he could assay the creature's age at five or six years. From the position of the foramen magnum - a little opening in the skull through which the spine connects with the brain - the young anatomist could tell that the creature walked upright. Quad-ruped monkeys and brachiating apes hold their heads forward on their bodies. Only a true biped can hold his head squarely on top. The southern ape walked erect or very nearly so.

On the basis of many an anatomical diagnosis Dart projected the adult creature as being four feet tall and weighing 90 pounds, with a brain about as large as that of a gorilla. He concluded that his infant's baby canine teeth would be replaced by mature canine teeth no larger than human. Out of his total anatomical diagnosis emerged a simple definition that still fits all of the hundred-odd individual australopithecines known today: They were creatures lacking the fighting teeth of apes who combined man's erect carriage with the ape's small brain.

To his anatomical description Dart added his conclusion that Australopithecus africanus had been a carnivore. . . Evidence for his revolutionary conclusion was of three sorts. First, in the arid environment of the Taungs site there could have been no sufficient source of nourishment for a fruit-eating, vegetarian ape. And secondly, there was the matter of the associated fossils. The deposit resembled that of a kitchen midden such as is left behind by primitive man. If the fossilized bones were not the remains of animals brought to the cave as food, then how had they got there?

But it was Dart's third line of evidence that concerns us most deeply as a clue to our human ancestry. The teeth of Australopithecus africanus are all but indistinguishable from our own. They are small. The enamel is not very thick. The shape and arrangement are like ours. And the crowns like our own are totally inadequate for the endless grinding and munching of a vegetarian creature who must gain from low-calorie foodstuffs sufficient daily nourishment to support a fair-sized body. All evidence combined to indicate that Dart's little infant found in a lime deposit on the edge of an African desert had once been a member of a meat-eating family of primates.

Dart's claims were crushed by northern science, as I indicated in the opening chapter, until the old zoologist, Robert Broom, attracted by the controversy came out of retirement and found fossil after fossil to confirm Dart's predictions.

As far back as 1934, when the only known remains of the southern ape had been the single infant skull from Taungs, Dart had pointed out that fossil baboons found in the same deposit showed evidence of fractured skulls. By 1946 Robert Broom's discoveries at Sterkfontein swelled immensely the reservoir of australopithecine material and revealed more damaged baboons.

Dart brought together 58 baboon skulls from three sites, 200 miles apart. All three sites were caves which through the action of dripping, evaporating water had been solidly filled with lime deposits better than half a million years ago. In these lime deposits had been preserved and fossilized those creatures, including the southern ape, who whether through choice of necessity had made the caves their last resting places. Among these creatures had been found the baboons. Of the 58 specimens, after setting aside those 16 too fragmentary for study, there still remained 42 skulls, a significant number. And every one of the 42 showed damage to the skull or muzzle.

While in such a study of fossil remains wide room for error must be granted, still even after the most cautious discount the evidence for intentional violence seemed overwhelming. Adding to the intentional nature of the violence was Dr. Mackintosh's diagnosis of the direction of the blows causing the damage, for the direction had not been random. Among 42 assaulted baboons, 27 had definitely received blows from the front; only 6 definitely from the rear. Of the remaining nine struck from the side, seven had been struck on the left side - that is, from the attacker's right. Only two had been struck from the attacker's left.

Throughout the course of this account we have paid considerable attention to the contemporary baboon. The adult is an animal dangerous even to man. Yet well over half of Dart's baboons had been adult. Also, we have noted the tendency of the whole baboon troop to defend an individual, and we have no reason to believe that extinct species differed from contemporary species in social action. Yet if these dangerous, troop-defended animals were killed by the southern ape, then they were killed by a creature who weighed 90 pounds or less, and who had fingernails and canine teeth no more lethal than our own.

Could any being other than the southern ape have been responsible for the broken baboon heads? Could man himself have been responsible? Certainly not in South Africa, at the time of Makapan, was there the least evidence that man was yet around. Could then some other agency than attack have accounted for the fractured craniums? Could by some statistical miracle falling rocks from cave roofs have scored bull's eyes on 42 out of 42 baboon heads? The proposition was absurd.

To my layman's judgement there seemed no way out. The baboons had been the victims of nothing other than the assault of the southern ape. But how could such assaults have succeeded, had *australopithecus* not been armed?

One might puzzle now as Dart had once puzzled over certain reports from his baboon morgue. Specimen One, from Taungs, contained within its clinical description: "A powerful downward, forward, and inward blow, delivered from the rear upon the right parietal bone by a double-headed object." Having digested the fate of Specimen One, Taungs, the puzzler could turn to the mortal rendezvous kept by Specimen Six, also from Taungs: "The V-shaped island of bone left standing above the obvious depression of the cranium shows that the implement used to smash it was double-headed . . . having vertical internal borders or sharp margins, and measuring approximately 30 mm between the two heads."

What had been the double-headed weapon? Not many of these early victims of violence, subjected to autopsy so long delayed, retained with such crystalline clarity the dimensions of their fate. Some had been battered by too many blows; some had been partially defaced by post-fossilization injury. Still, of the 42 showing skull damage, seven indicated clearly an assault by a double-headed instrument, and four more showed the probability. Better than a quarter of the victims retained the mark of the same lethal instrument. What had been that instrument? To follow the line of Dart's deduction, we must turn to the character of the most famous *australopithecine* site.

Limeworks Cave, in the wild valley of Makapan 200 miles north of Johannesburg, was long ago a vast empty cavern extending many hundreds of feet back into the ancient dolomite of the region. For many millions of years through the geologic era called the Pliocene, Africa had been dry. No deposits formed in the cavern. Then, with the opening of Africa's rainy Pleistocene a million years ago, water saturated with lime dissolved from the dolomite began seeping into the cave. Here it evaporated, leaving layer upon layer of white, shining lime, until the cave was entirely filled. So it remained, a solid deposit of lime, until shortly after the First World War. Then spurred by war-created shortages, South African prospectors discovered the deposit and mining operations began.

But frequently it contained bone - animal bones in unimaginable quantity - fossilized and turned to limestone throughout the unimaginable years.

The bones were largely those of extinct Villafranchian fauna, found exclusively in the first half-million years of our era. But the Breccia was of no value to the miners. And so, as they excavated the lime for the pressing demands of the building trade, they dumped the riches of man's Villafranchian origins on the sunny slopes beneath the cavern's mouth. And it is from this discarded treasury that Raymond Dart and his students, for the last 15 years, have been extracting the limestone story of australopithecus and his animal world.

When in 1949 Raymond Dart was confronted by the puzzle of the double-headed instrument which seemed to have caused such an abnormal death-rate among Villafranchian baboons, he turned to his Makapan treasury with the hope of discovering an answer. And he published that answer. The humerus bone - the upper foreleg bone - of the common antelope had been the southern ape's favourite weapon. Its heavy double-knobbed knuckle fitted perfectly the double depression in the baboon skulls.

A somnolent juryman, dreaming his way through a highly technical murder trial, would probably at this point come abruptly awake, fix the shrinking defendant with a convinced eye, and under this breath mutter, "Hang him". Any horror-drenched aficionado of the modern detective story, combating his insomnia with the deductive super-powers of his favourite private-eye, would probably at this point shrug, "That does it," and close his book and go to sleep. But deductions no matter how logical do not constitute scientific proof. And the jeers of northern science had been the answer to Dart's claim.

But as I leaned over Dart's chart - a statistical distribution according to genus and anatomical part of all the identified bones - old forgotten images scampered before my eyes. I might not know Chalicotheriidae from Ceropithecidae, or a or a metacarpel from the metatarsal - but I knew a normal distribution when I saw one. And this was not a normal distribution.

Of the 4,560 bones - a sample fairly acquired, wholly processed, and of such size that probable error could not be significant - 518 were antelope humerus bones. Of all the bones

remaining from what had once been the lively bodies of at least 433 individual animals, better than 11% were specimens of the bone which Dart, six years before, had deduced to be the southern ape's favourite weapon.

Could the startling figure be explained in terms of food preference? If this were simply a kitchen midden, could it be that the upper part of the foreleg represented nothing other than the favourite food of the southern ape? But the hind quarter of the antelope, as of other ungulates, gives the solidest meat. And of femurs there were only 101, less than one-fifth the number of humeri. It made no sense that a carnivore would have dragged back from kills in the field five times as many forequarters as hindquarters.

What if one assumed, to explain the disproportion, that the southern ape had not been a killer but a scavenger? In this case the hindquarters might have been devoured by the original killer, and the less desirable forequarters left to the scavenger. Such a situation would account for a prevalence of humerus bones in the scavenger's cave. But following this line of reasoning only led one into another statistical astonisher.

Dart, on his classification of antelope species, had made four categorical divisions, Large, such as the huge, modern kudu; Medium, such as the waterbuck; Small, such as the impala; and Very Small, such as the modern duiker. It was a classification devised by H. B. S. Cooke, South African geologist, for dealing with extinct species. Referring back to the baboon head injuries, one found that it was the humerus bone of the Medium that best fitted the double-depressed fractures. And now one encountered in Dart's chart a salient incongruity. While the Medium category contributed only 30% of the individual animals to the antelope total, it contributed 60% of the humerus bone fragments.

To my mind, no wildest improbabilities of chance could account for such a statistical distribution. Dart had made the claim that the Villafranchian baboons were killed by weapons, and that the antelope humerus bone was the most common weapon. In the southern ape's rubbish pile, he had found 11% of all bones to be the bone predicted. Among types of antelope, he had found that 60% of all humerus bones fell in the most useful size. And in the category of the most useful size, that portion of the bone which could be used as a weapon outnumbered by over 30 times that portion of the bone which could not.

The evidence was overwhelming that some sort of systematic, intelligent selection towards premeditated ends had determined which bones should be brought into the cave, and which should not. And the evidence was not confined to the spectacular confirmation of Dart's prediction concerning humerus bones.

So that the reader may enjoy - inconceivable though the possibility may seem - the drama of statistics that confronted me in a roomful of bones, let us record here a few numbers: 3, 2, 0, 0, 10, 0, 0, 21. Precisely what they refer to is of no great importance, although we are reading from the anatomical distribution of bones belonging to the category of the small antelope. We conclude the series: 36, 0, 53, 51, 34, 13, 2, 6, 40, 6, 7, 0, 8, 11, 8, 10, 44, 12, 7, 9, 10, 21, 15, 10, 4, 58, 78, 66, 191.

Is it possible to look at such figures without demanding what the 191 represents? In answer to my demand, Dart led me to a set of drawers and boxes. The figure 191 represented the portions of mandibles - or lower jaws - of the small antelope. Before me lay the specimens, mostly half-jaws with sharp teeth all in a row. Whether they had been used as slashing implements lay beyond proof. But that they could have been used for such a purpose lay beyond denial. Few throats could have resisted the saw-tooth edge. And the weapon rested easily in the hand (5).

11. Summarize the main points of the hypothesis and give examples of observations on which it is based.
12. Scientists often gain supporting evidence for a hypothesis by putting forth different explanations and then discrediting them. In other words, a hypothesis is strengthened when deliberate attempts to falsify it do not succeed. Discuss examples of this from the preceeding selection.
13. Before a scientist can be sure that a relationship exists, he must first show that a relationship between data is not due to chance alone. Give an example of this from the study of fossil bones above.

Ardrey applies his basic hypothesis to the behavior of modern man in a rather sensational manner:

A dramatist writes for a more primitive being than does the novelist or poet. He writes - whether through images on a screen or through actors on a stage - for an audience reduced by darkness and anonymity and a kind of hypnosis to a group of reacting organisms in whom ethical, moral, virtuous, or thoughtful considerations play a limited part.

The western film goes on forever. Why? Because people enjoy the sight of horses? Because the vaster vistas of the American West serve as soothing syrup for city-pent souls? Neither is unimportant. But suggest to an experienced film-maker a story in which all the standard western ingredients come into play, with one exception, that not a character goes about armed. I submit that you will receive a glacial response unrivalled in the entire million years of the Pleistocene.

The film-maker knows: it is the blazing six-shooter that the audience must see. The film-maker knows: violence, not sex, is the essence of box-office. Whether the audience be New Yorkers or New Guineans, Latins or Londoners, white or yellow or deepest Bantu brown, whether it be gathered in a Broadway, Leicester Square, Champs Elysees, or Kurfurstendamm cinema palace, or around the tailboards of an aspirin truck in the heart of the Amazon; whatever be the qualities or circumstances of that hypnotized, anonymous cinema community, its stripped-down, uninhibited, unselfconscious members may be cheated of the seduction scene, of the banquet orgy, or of the speech delivered from the monument; but they will not be cheated of that moment when the six-shooter blazes or the cannon speaks or the bomb, long-awaited, goes off. Hollywood knows more about the inner nature of Homo sapiens, viewed as species, than any other political, philosophical, or scientific school on earth. Hollywood is Hollywood, scorned and envied, feared and censored, because it has made minimum use of the romantic fallacy in its negotiations with mankind.

Now the British Museum publishes Kenneth Oakley's authoritative handbook on anthropology, Man the Tool-Maker, in which that definition is accepted. Any inspection of Oakley's handbook, however, should reveal that the continuity of development in man's cultural efforts is not truly that of the tool; it is that of the weapon.

Yet we dare not say so. To suggest that we find in the competition of weapons the most exhilarating human experience is to

speak a blasphemy. For the British Museum to publish a handbook entitled Man the Weapon-Maker would be to provoke in the House of Commons a question period of heroic proportions. And for a hundred responsible anthropologists gathered in a Rhodesian town to admit the scientific possibility that australopithecus had systematically used weapons, would be to invite a cultural definition of man as the creature who systematically makes them.

I recollected, in my season of ghosts, that first conversation with Dart in his office on Hospital Hill when we spoke of responsibility. In a moment of history when science reveals animal instincts evermore evidently as the basis for behaviour regarded until now as exclusively human; when we witness daily the disastrous failure to explain and solve human problems -- such as crime and race and neurosis and nations - by a frame of reference no broader than the human experience; when looming above all towers that giant mushroom, the problem of nuclear weapons and global, nuclear catastrophe: dare one, at such a moment, suggest that the weapon is mankind's primary cultural affinity, genetic in nature, the criterion of his species? And that what we are witnessing is in fact the consummation of that species' most distinctive drive? I recalled Dart's answer: that we had tried everything else, so perhaps we should at last try the truth.

West Side Story is a supreme work of art for many reasons not the least of which is truthfulness. The authors treat the romantic fallacy as if it did not exist. On a stage laid bare, and in young hearts laid naked, we watch our animal legacy unfold its awful power. There is the timeless struggle over territory, as lunatic in the New York streets as it is logical in our animal heritage. There is the gang, our ancestral troop. There is the rigid system of dominance among males within the gang, indistinguishable from that among baboons. There is the ceaseless individual defence of status. There is the amity-enmity code of any animal society: mercy, devotion, and sacrifice for the social partner; suspicion, antagonism, and unending hostility for the territorial neighbour. And there is the hunting primate contribution, a dedication to the switch-blade knife as unswerving as to the antelope bone.

I find it difficult to believe that the authors were aware of Australopithecus africanus. They observed their subject with honesty and without illusions and that is all. But the artistic consequence is an australopithecine interpretation of human

conduct. There is more, however, in West Side Story than animal behavior. We have the addition of human self-awareness, and the pitiless ridicule by the delinquent of those who would see his soul as sick. And we have the human complication of the youth touched by the inhibitions and ambitions of civilization, the struggle to free himself from animal bondage, and the tragic star-strewn failure. An accountant of a scientific revolution can add little to West Side Story in its portrait of that natural man, the juvenile delinquent.

Juvenile delinquency is a battleground where the romantic fallacy meets the new enlightenment head-on. What in adolescent conduct may be regarded as a consequence of abnormal frustration, what as a consequence of normal instinctual endowment? The delinquent today is an international figure who cannot be identified with any particular social or political system. In New York he is a JD, in London a teddy boy, in Cape Town a tsotsi, in Pekin or Mowcow a hooligan. Everywhere he is a figure arousing concern, puzzlement, sometimes denunciation, more often guilt. Nowhere, to my knowledge, is he understood.

'Delinquency is a disease of society, just as cancer is a disease of the individual.' 'Every child who feels rejected is a potential delinquent.' 'Delinquency is the prerogative of the underprivileged.' 'The hooligan of today is the reactionary of tomorrow.' 'Love is the answer.' 'Delinquency cannot be attributed to a single cause. Mental disturbance, broken homes, poverty, and parental rejection contribute equally and in combination to the problem of the streets.'

Where among these is an answer that does not speak from the spacious balconies of the romantic fallacy? Goodness, conscience, and nobility are attributes of man; and when youth fails to demonstrate such qualities, then youth must be sick or deprived or rejected. In West Side Story, youth snickers.

For the authors of such statements as those I have quoted - and to publish their names would be to bore the reader with the pages of Who's Who - there is a recent study that should provide bottomless embarrassment. It was published by Harvard University, supervised by Sheldon and Eleanor Glueck, and prepared by a large staff of physicians, psychiatrists, and other specialists. It represents the most carefully controlled examination of juvenile delinquency that to my knowledge has ever been made. In the Glueck report, the histories, behaviour, and

attitudes of 500 delinquent boys are compared with the histories, behaviour, and attitudes of 500 non-delinquents, all of comparable backgrounds. And we find the delinquent, by and large, superior to the non-delinquent in energy and physique. We find conforming children with a greater sense of insecurity, of being unloved, unwanted, or rejected, than delinquent children. And among the 500 boys who had smoked at an early age, kept late hours, played with other delinquents, frequented neighbourhoods far from their homes, persistently and seriously misbehaved at school when they did not persistently and seriously play truant, and who had rolled upon every individual history a fair record of repeated burglary, larceny, assault, and public disturbance - among the ranks of this inglorious 500 we find far fewer neurotics than in the ranks of the non-delinquents.

And why should it not be true? The citizen of the streets whom we watch in West Side Story is Rousseau's natural man, all but full grown, and by one means or another untouched by corrupting civilization. If he does not possess what society regards as a conscience, then it is because conscience is a social invention. If he displays a singular lack of neurosis, it is because his instincts have encountered few civilized inhibitions. Society flatters itself in thinking that it has rejected the delinquent; the delinquent has rejected society. And in the shadowed byways of his world so consummately free, this ingenious, normal adolescent human creature has created a way of life in perfect image of his animal needs. He has the security of his gang, and finds his rank among its numbers. He has sex, although it does not preoccupy him. Without any learned instruction, he creates directly from his instincts the animal institution of territory. In the defense of that territory his gang evolves a moral code, and his need to love and be loved is fulfilled. In its territorial combats, the gang creates and identifies enemies, and his need to hate and be hated finds institutional expression. Finally, in assault and larceny, the gang and its members enjoy the blood and the loot of the predator. And there is always the weapon, the gleaming switch-blade which the non-delinquent must hide in a closet, or the hissing, flesh-ripping bicycle chain which the family boy can associate only with pedalling to school.

Why should the delinquent not be happy? He lives in a perfect world created solely by himself. And if he is caught by that larger society against which he offends, and for which he holds the most knowing, cynical, and deserved disrespect, then

follows the last, vast irony. He will be excused. He will be understood. Society will blame itself.

For years now, hundreds of thousands of the world's most civilized, adult human beings have formed the audience for *West Side Story* and found in it a fragment of their innermost dream. Nightly, in the dark hypnotism of the theatre, we lose ourselves in envy, in yearning, and in a terrible nostalgia which we cannot comprehend. And make no mistake. That is exactly what we do (6).

14. Sometimes when direct evidence is not available to support a hypothesis, indirect evidence must be used. Discuss some of the problems involved in the use of indirect evidence as in the example above.
15. Why is it crucial for mankind to look at as much evidence as possible in relation to this problem?

Ardrey states the following conclusions in a chapter entitled "Cain's Children".

We are Cain's children. The union of the enlarging brain and the carnivorous way produced man as a genetic possibility. The tightly packed weapons of the predator form the highest, final, and most immediate foundation on which we stand. How deep does it extend? A few million, five million, ten million years? We do not know. But it is the material of our immediate foundation as it is the basic material of our city. And we have so far been unable to build without it.

Man is a predator whose natural instinct is to kill with a weapon. The sudden addition of the enlarged brain to the equipment of an armed already-successful predatory animal created not only the human being but also the human predicament.

The primate has instincts demanding the maintenance and defense of territories; an attitude of perpetual hostility for the territorial neighbour; the formation of social bands as the principal means of survival for a physically vulnerable creature; an attitude of amity and loyalty for the social partner; and varying but universal systems of dominance to insure the efficiency of his social instrument and to promote the natural selection of the more fit from the less. Upon this deeply-buried, complex, primate instinctual bundle were added the necessities and the

opportunities of the hunting life.

We can only presume that when the necessities of the hunting life encountered the basic primate instincts, then all were intensified. Conflicts became lethal, territorial arguments minor wars. The social band as a hunting and defensive unit became harsher in its codes whether of amity or enmity. The dominant became more dominant, the subordinate more disciplined. Overshadowing all other qualitative changes, however, was the coming of the aggressive imperative. The creature who had once killed only through circumstance killed now for a living.

Cain's children have their problems. It is difficult to describe the invention of the radiant weapon as anything but the consumption of a species. Our history reveals the development and contest of superior weapons as *Homo sapiens*' single, universal cultural preoccupation. Peoples may perish, nations dwindle, empires fall; one civilization may surrender its memories to another civilization's sands. But mankind as a whole, with an instinct as true as a meadow-lark's song, has never in a single instance allowed local failure to impede the progress of the weapon, its most significant cultural endowment.

Must the city of man therefore perish in a blinding moment of universal annihilation? Was the sudden union of the predatory way and the enlarged brain so ill-starred that a guarantee of sudden and magnificent disaster was written into our species' conception? Are we so far from being nature's most glorious triumph that we are in fact evolution's most tragic error, doomed to bring extinction not just to ourselves but to all life on our planet?

It may be so; or it may not. We shall brood about this in a moment. But to reach such a conclusion too easily is to oversimplify both our human future and our animal past. Cain's children have many an ancestor beyond Australopithecus afri-canus, and many a problem beyond war. And the first of our problems is to comprehend our own nature. For we shall fashion no miracles in our city's sky until we know the names of the streets where we live. (7),

16. Give examples from this selection of:

- A. Conclusions
 - B. Observations supporting conclusions.
 - C. Hypotheses.
 - D. New problems based on speculation.
17. Reactions to these controversial ideas have been quite varied. For example, Time Magazine stated that "... the conclusions are wildly wrong", and The Scientific American stated that "Ardrey's thesis is completely foolproof." Why would you expect opposition and emotional reactions to Ardrey's theories?
18. The main aim of science is to discover the truth. Why is it so difficult to discover the truth about man?

References:

- (1) Darwin, C. On the Variation of Organic Beings in a State of Nature; on the Natural Means of Selection; on the Comparison of Domestic Races and True Species. In: Great Experiments in Biology, ed. by S. Fogel, Englewood Cliffs, N. J., Prentice-Hall, 1955. p. 284, 286, 288.
- (2) Ardrey, Robert. African Genesis. New York, Dell, 1961. p. 33-37.
- (3) Ibid. Pages 38, 39, 43-58.
- (4) Ibid. Pages 89-91, 94-95, 106-109.
- (5) Ibid. Pages 175-177, 189-192, 196-198.
- (6) Ibid. Pages 203-205, 330-334.
- (7) Ibid. Pages 315-318.

E. Case Study 5: Experiments by John Mayow on
The Substance Involved in Both Burning and Respiration

John Mayow (1643-1679) studied at Oxford and at the age of 27 published his famous investigations on respiration.

After studying Boyle's work which showed that something from the air is necessary in combustion Mayow put forth his hypothesis of a "Nitro-aereal spirit" - a single substance involved in both burning and respiration. Mayow describes the following experiment to test this hypothesis:

An animal is enclosed in a glass vessel along with a lamp (candle flame) with orifice of the inverted glass immersed in water. When this is done we shall soon see the lamp go out and the animal will not long survive the fatal torch. I have ascertained by experiment that an animal enclosed in a glass vessel along with a lamp will not breathe much longer than half the time it would otherwise have lived. But since the air enclosed in the glass is in part deprived of its nitro-aereal particles by the burning of the lamp --- it cannot support long the breathing of the animal, hence not only the lamp but also the animal soon expires for want of "nitro-aereal particles" (1).

Why did Mayow immerse the glass vessel in water?

Why was it essential to place both the candle and the animal in the same glass?

To what extent do you consider the hypothesis proven? Discuss and suggest further tests.

When a moistened bladder was placed over the jar containing the mouse during this experiment the bladder bulged inward. What could be reasonably inferred from this?

Why was it a lucky accident that the jar was placed over water in this experiment?

Even though Mayow did not entirely understand the reasons for the results obtained in this experiment, he went on to state that the "nitro-aereal" spirit entered the blood from the lungs and mixed with certain particles in the blood where it "excited a needed fermentation." He also attributed the increased breathing of exercise to the need for greater expenditure of nitro-aereal salts in the many effervescences

which takes place in the muscles.

In another important experiment, Mayow found that antimony gained weight after being burned and inferred that the gain in weight came from the "igneo-aereal" particles inserted into the antimony during burning. The important advances of the 17th century in the understanding of respiration reached a high point with the work of Mayow. Some historians credit Mayow with the discovery of oxygen - others disagree. What do you think?

Reference:

1. Fenn, W. O. and H. Rahn. Handbook of Physiology Section 3: Respiration. Washington, D. C., Am. Physiol. Society, 1964. p. 38.

F. Case Study 6: The Phlogiston Theory

This ingenious theory was proposed in 1660 by George Ernst Stahl, a professor of medicine and physician to the King of Prussia, who was thought to be one of the greatest chemists of the 18th century. According to this idea all combustible materials contained a substance or principle, called "phlogiston", which was capable of transforming itself into fire on heating. Combustible materials, then, were composed of calx or ash, combined with the "fire principle" or phlogiston, which escaped during burning leaving the ash behind. When an object burns the pure air or dephlogisticated air takes up the phlogiston given off by the burning object and is thus called "fixed air" or phlogisticated air. When air is in a closed place, it becomes saturated with phlogiston, fire is put out. Some substances were thought to contain more phlogiston than others, charcoal for example, in converting a calyx (oxide) to a pure metal (reduction), was thought simply to give off its phlogiston to the calyx turning it back into a metal.

How were the results of John Mayow's experiments, discussed previously, in complete contradiction to the Phlogiston theory?

In spite of these contradictions and the upside down nature of the phlogiston theory it gained wide acceptance and pervaded all thought on respiration for a hundred years or more. Stahl ascribed these contradictions to the "negative weight" of phlogiston and oddly enough was taken seriously.

Stahl thought that the "sensitive soul" modified body chemistry; therefore he doubted that air (or phlogiston) contributed anything important to the blood. The phlogiston theory was soon applied to animal respiration, however. Priestley in 1775 stated that one great use of the blood must be to discharge the phlogiston, with which the animal system abounds, imbibing it in the course of its circulation, and imparting it to the air. The work of Crawford lent a good deal of support to the phlogiston theory and must be considered seriously since he relied more than his predecessors on experimental data.

The Scotsman Adair Crawford observed that animals with lungs are able to inspire large amounts of air and are therefore warm. Animals without lungs, however, remain at about the same temperature as the environment. He also noted that the warmest animals are those whose respiratory organs are largest in proportion to their overall bulk.

Crawford made three inferences from these observations which formed the bases of his hypothesis on animal heat:

- (1) Atmospheric air contains a larger quantity of heat than the same air after expiration from the lungs.
- (2) Arterial blood after passing through the lungs contains a larger quantity of heat than the venous blood which has not yet passed through the lungs.
- (3) The capacity of a body for heat is reduced by the addition of phlogiston and increased by the separation of phlogiston (1).

Noting the same observations above, see how many reasonable inferences you can make which are different from Crawford's.

The same observations or data seem to serve many ends. How then can we arrive at the truth?

These hypotheses seemed verifiable by experimentation, since scientists of the time were aware of the difference between temperature and a quantity of heat. Crawford's colleague Joseph Black had also developed and used the method of mixtures for determining specific heat. By immersing hot objects in equal volumes of water the amount of heat contained by the objects can be compared. Crawford developed what is probably the earliest method of determining specific heats of gases. Essentially, he filled bladders with equal volumes of gases and then immersed them in water. He found that dephlogisticated air (oxygen) holds a quantity of heat five times greater than atmospheric air. He noted further that dephlogisticated air supported life five times as well as atmospheric air.

Why did Crawford think that this experiment proved his first hypothesis?

Do you think Crawford's inference was justified? Why? Or why not?

Crawford also determined the specific heat of venous blood and arterial blood. The quantity of heat held by venous blood in proportion to arterial blood was as 10: 11-1/2. This distinction enabled Crawford to avoid a major stumbling block in his theory and provided support for the phlogiston theory. Explain.

Crawford thought that his third proposition was proved by experiments with metals and their calces (oxides). It was found that calces (from which phlogiston had been separated) have a higher heat capacity than metals. Heat, therefore, and phlogiston, according to Crawford, appear to be two opposite principles in nature. By the action of heat upon bodies, the force of their attraction to phlogiston is diminished, and by the action of phlogiston, a part of the absolute heat, which exists in all bodies as an elementary principle, is expelled.

Even though the Phlogiston theory was completely erroneous it gained wide acceptance for a long period of time. Why do you think this happened? Do you think this sort of thing could still be happening today?

Reference:

- (1) Mendelsohn, E. Heat and Life. Cambridge, Mass., Harvard University Press, 1964. p. 234.

G. Case Study 7: Joseph Black's Discovery of "Fixed-Air"

Joseph Black submitted his dissertation for the M. D. degree at the University of Edinburgh in 1754. He was studying a new drug called "magnesia alba" or "white magnesis", (known today as Magnesium Carbonate) which resembled the milk alkalis such as chalk. Black found that the milk alkali when heated lost weight, but that a liquid product could never be collected.

State several possible inferences which could be drawn from this observation.

In another experiment Black found that the milk alkalis all effervesced on the addition of acids. Does this support any of the inferences drawn above? Why or why not?

Black found that "strong" or caustic alkalis, such as limewater did not lose weight when heated or effervesced when mixed with acid. He then concluded that milk alkalis contained 'air' while strong alkalis did not. This air he called "fixed air" because it was "fixed" by the milk alkalis.

Does this experiment really prove what it is supposed to? What other things should be done before conclusions like the above are drawn?

Dr. Black knew that limewater, a caustic alkali, became covered with a white crust of chalk, a milk alkali, when exposed to the open air for sometime, and also lost its strength or caustic properties. He also knew that limewater remained caustic and did not develop a white crust when kept in stoppered bottles, even though the bottles contained some air.

State a hypothesis which Dr. Black might reasonably state at this time.

Later, Black exposed clear colorless limewater to air produced from the different processes:

The burning of charcoal, respiration, and fermentation. In each case the limewater immediately became milky or chalky. What control is necessary before anything can be proven about the three experimental variables above?

To test his ideas further, Black performed a most unusual experiment:

In the winter of 1764, Dr Black allowed a considerable quantity of caustic alkali (lime water) to filter slowly over rags into an apparatus placed above a spiracle in the ceiling of a church, in which a congregation of more than 1500 persons had continued for nearly ten hours. The caustic alkali filtering through the rags produced the chalky crust of the mild alkali.¹

Why did Black go to the trouble of carrying out such a large-scale experiment when he had already observed the effect of respired air on limewater?

Why did Black's research prove to be a turning point in development of both chemistry and biology?

Reference:

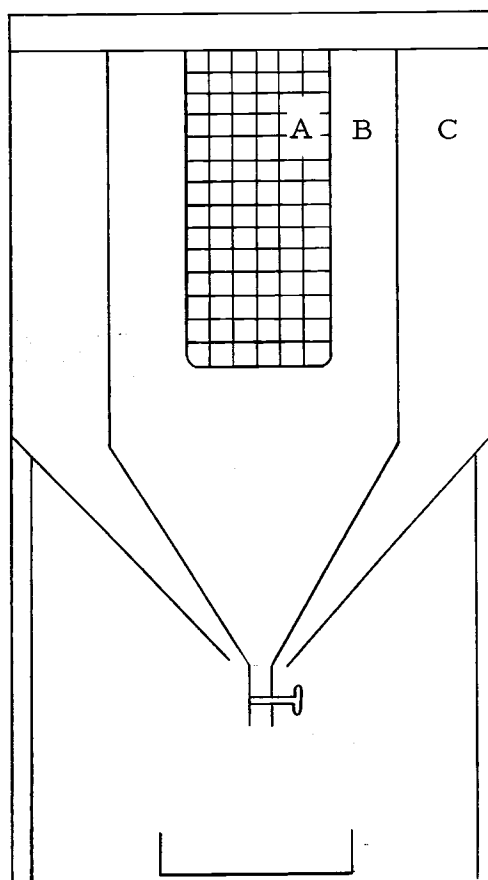
1. McKie, D. Antoine Lavoisier: Scientist, Economist, Social Reformer. N. Y., Schuman, 1952. p. 185.

H. Case Study 8: Combustion and Respiration:
Experiments by Antoine Lavoisier and Pierre LaPlace

After Black's discovery of Carbon Dioxide (Fixed-Air) oxygen was soon isolated by Pirestly (1733-1804) in England and by Scheele (1742-86) in Sweden. Even though Priestley had shown that this gas was necessary to animal life, he still thought of it in terms of the phlogiston theory. The gas we call oxygen today was therefore called "dephlogisticated air" by Priestley.

At this point there emerged a man who was able to stand above the whole scene, look at the pieces of the jig-saw puzzle and turn them into a pattern. Antpaine Lavoisier (1734-94) surveyed the studies of gases and carried out a series of experiments to bring them into unity.

Apparatus similar to the following was used by Lavoisier and Laplace to determine the amount of heat given off by an experimental object.



Double Lid

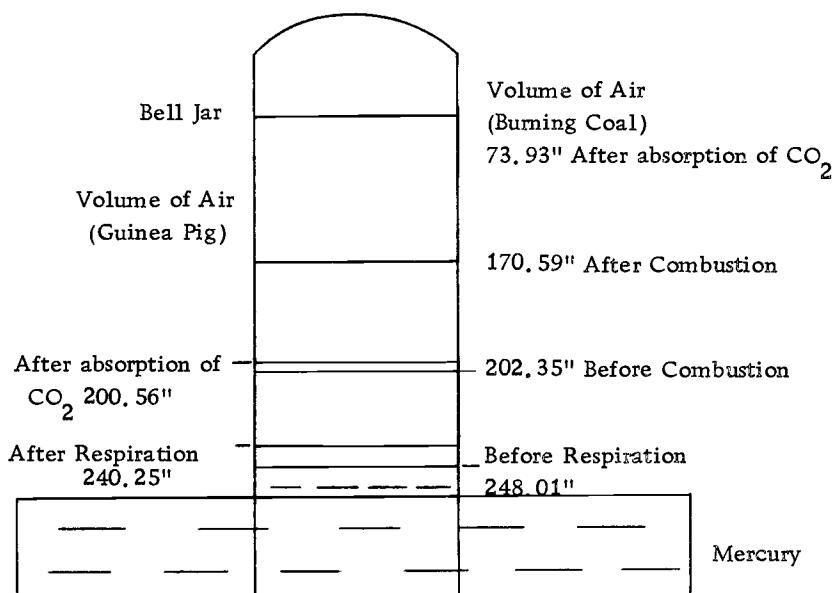
The inner chamber (A) is constructed of a meshwork of iron wire and is designed to hold the object to be tested. The middle chamber (B) is filled with ice which is in turn melted by the experimental object. The water melted is collected and weighed. Its weight measures the heat given off by the object. The outer chamber (C) is filled with ice and must be water tight.

One ounce (30.59 g.) of coal was placed in the inner chamber (A) with a small piece of phosphorous and was ignited with a red hot iron placed through a hole in the lids. Air was then blown in through a tube placed through the same hole. The coal was consumed in 32 minutes and 2,998 g. of ice were melted.

Next a guinea pig was placed in the inner chamber (lined with cotton). The animal remained for 5 hours and 36 minutes, during which time 2.4 g. of ice were melted.

1. The double lid and the outer chamber (C) were essential controls for this experiment. Explain why.
2. Why do you think the investigators chose to compare burning coal with a live animal in the same apparatus? Why were such accurate measurements of the melted ice necessary?
3. Does this experiment provide evidence to support the hypothesis that animal respiration is a form of combustion? Explain. Why is more evidence also needed to test this hypothesis?
4. Try to suggest new problems or new hypotheses which might logically follow this experiment.

Lavoisier and Laplace also investigated the composition of the air in the chamber where respiration and combustion took place. It should be remembered that the process by which pure or vital air (oxygen) is converted into 'fixed air' (CO_2) was not understood at this time and had only been discussed philosophically. The following is a description of this famous investigation:



A bell jar filled with "pure air" was placed upon a large trough filled with mercury. A small earthen jar filled with coal was placed under the bell jar, along with a small fragment of phosphorous. The jar and its contents were weighed carefully before and after the experiment. The level of the mercury was raised by suction and marked on the bell jar. The phosphorous was then ignited by a red hot iron through the mercury. Combustion lasted 20 or 25 minutes. When the air inside the bell jar had cooled to room temperature the level of the mercury was again marked on the bell jar. The mercury level rose as the volume of air trapped in the bell jar decreased. Caustic alkali $\text{Ca}(\text{OH})_2$ is known to absorb fixed air (CO_2). Some caustic alkali was introduced under the bell jar and when the mercury had ceased to rise a third line was marked on the bell jar. When atmospheric air was introduced into the bell jar the mercury level dropped to that of the outside. The volume of air at the levels marked on the bell jar was calculated from the respective weight of water which would fill these spaces.

This experiment was repeated to determine the effect of animal respiration on "pure" air. A guinea pig was passed through the mercury into the bell jar and kept there for an hour and fifteen minutes. The original volume of the bell jar was 248.01 inches of pure air. This was reduced to 240.25 inches after the guinea pig was removed and the air allowed to cool to room temperature. After the "fixed air" had been absorbed by caustic alkali only 200.56 inches of air remained.

5. Explain why this experiment supplements and provides more direct evidence than the previous experiment to support the hypothesis that animal respiration is a form of combustion.
6. Identify at least one basic assumption which is necessary if the results of this experiment are to mean anything. Explain why.
7. Identify at least one variable which had to be controlled if the results are to mean anything. Explain.
8. Do the results of this experiment support or reject the phlogiston theory? Explain how.
9. Why are these experiments considered so important in the history of biology, that is, how did they change man's thinking about the nature of life?

Lavoisier and Laplace stated the following conclusion at the close of their paper describing these experiments:

Respiration is therefore a combustion, very slow to be sure, but perfectly similar to that of carbon. It occurs in the interior of the lungs without the liberation of any perceptible light because the fire, as fast as it is freed is absorbed by the humidity of these organs. The heat developed by this combustion is transferred to the blood which passes through the lungs and thence is transmitted throughout the animal system. Thus the air which we breathe serves two purposes: it removes from the blood the base of fixed air, an excess of which would be most injurious; and the heat which this combination releases in the lungs replaces the constant loss of heat into the atmosphere to which we are subject (1).

10. Which of the above statements are conclusions based on the data and which are actually new hypotheses inferred from the data?
11. Wrong inferences are sometimes important in science in that they may lead to new hypotheses which may be tested. By next eliminating wrong hypotheses we may eventually arrive at a correct idea and an important new truth.

Discuss the following hypothesis made by Lavoisier as an example of this:

"Combustion occurs in the interior of the lungs and the fire produced is absorbed by the humidity of the organs. "

Reference:

1. Gabriel, M. L. and S. Fogel. Great Experiments in Biology. Englewood Cliffs, N.J., Prentice-Hall, 1955. p. 93.

I. Case Study 9: Justus Liebig's Research on Biological Oxidations

The famous German chemist Justus Liebig applied Lavoisier's concept of biological oxidation to a good many aspects of animal activity. The chemical processes of life were methodically investigated and published in 1852 in his book "Animal Chemistry". Liebig was able to form a structural framework in which a large number of physiological reactions could be explained. Liebig states his basic working hypothesis as follows:

Animal life exhibits itself in a series of phenomena, the connection and recurrence of which are determined by the changes which the food and oxygen absorbed from the atmosphere undergo in the organism under the influence of the vital force. All vital activity arises from the mutual action of the oxygen of the atmosphere and the elements of the food (1).

Liebig believes that conclusions should only be based on that which is capable of inquiry and proof. The percentage of carbon in various foods was calculated and elaborate records taken of food consumption for 850 soldiers. This empirical evidence was summarized by Liebig in the following statement:

If an adult man receives into his system daily 32 1/2 oz. (15, 661 grains of oxygen) and the weight of the whole mass of his blood, of which 80% is water, is 24 lbs., it then appears that, in order to convert the whole of its carbon and hydrogen into carbonic acid and water 64, 103 grains of oxygen are required. This quantity will be taken into the system of an adult in four days and five hours. Whether this oxygen enters into combination with the element of the blood, or with other parts of the body containing carbon and hydrogen, the body of a man who daily takes in 32 1/2 oz. of oxygen must receive in nourishment as much carbon and hydrogen as would suffice to supply 24 lbs. of blood with these elements, it being presumed that the weight of the body remains unchanged. This supply is furnished in the food.

From the accurate determination of the quantity of carbon taken daily into the system as food, as well as that portion of it which passes out of the body unburned, feces and urine, it appears that an adult taking moderate exercise, consumes 13.9 oz. of carbon daily. These 13.9 oz. of carbon escape through the skin and lungs as carbonic acid gas (CO₂). Thirty-seven oz.

of oxygen are required for the conversion of carbon to carbonic acid gas (2).

1. Why was it necessary for Liebig to calculate the average daily carbon intake in testing his hypothesis?
2. Can you think of any variables which Liebig either could not control or was not aware of? How might these variables have effected his results?

In comparing the heat produced in combustion to the amount of water evaporated from the body Liebig compiled the following evidence:

According to the experiments of Despretz, 1 oz. of carbon evolves during its combustion, as much heat as would raise the temperature of 105 oz. of water at 32° to 167° , i. e. $105 \times 135^{\circ} = 14,207$ degrees of heat. Consequently the 13.9 oz. of carbon which are daily converted into CO_2 evolve $13 \times 14,207^{\circ} = 197,477.3$ degrees of heat - enough to cause 13.68 lbs. of water at 32° to boil ... If 48 oz. (3 lbs.) of water are vaporized through the skin and lungs in 24 hours, then there will remain $146,380.4^{\circ}$ after deducting the necessary amount. Since in this calculation, no account has been taken of the heat evolved by the hydrogen of the food, during its conversion to water by oxidation within the body, no doubt can be entertained that the heat involved in the process of combustion of food in the body is amply sufficient to explain the constant temperature of the body as well as evaporation from the skin and lungs (3).

3. Why do you think this type of experimentation was important to Liebig in testing his hypothesis?
4. What new problems may arise in considering this data?

A good many variables which effected the amount of oxygen consumed (and combined with carbon and hydrogen) were recognized by

Liebig, for example, the size of the animal, the rate of activity, climate or temperature, age of the animal, state of health, etc.

A good working hypothesis should be generalizable to other related phenomena. Liebig therefore applied his concept of biological oxidation to the germination of seeds, the flowering of plants, and the maturation of fruits.

Liebig was able to relate biological oxidation to the function of the blood and respiration. The following is a statement of this hypothesis:

During the passage of the venous blood through the lungs, the globules change colour, and with this change in colour oxygen is absorbed from the atmosphere. Further, for every volume of oxygen absorbed an equal volume of carbonic acid is given out. The organic compound of iron, which exists in the venous blood, recovers in the lungs the oxygen it has lost and, in consequence of this absorption of oxygen, the carbon dioxide in combination with it is separated.

In support of this hypothesis Liebig describes his experiments as follows:

A man who expires daily 13.9 oz. of carbon, in the form of carbon dioxide, consumes in 24 hours 37 oz. of oxygen, which occupy a space equal to 807 litres = 51,648 cu. in. If we reckon 18 respirations to a minute, we have in 24 hours 25,920 respirations; there are taken into the blood $\frac{51,548}{25,920} = 1.99$ cu. in. of oxygen. In one minute, therefore, there are added to the constituents of the blood $18 \times 1.99 = 35.8$ cu. in. of oxygen, which at room temperature weigh less than 12 grains. If we now assume that in one minute 10 lbs. of blood pass through the lungs and that this quantity of blood measures 320 cu. in., then 1 cu. in. of oxygen unites with 9 cu. in. of blood, very nearly. 10 lbs. of blood contain 61.54 grains of peroxide of iron in arterial blood = 55.14 grains of protoxide in venous blood, which in passing through the lungs take up in one minute 6.40 grains of oxygen (the quantity necessary to convert it into peroxide). But since, in the same time, the 10 lbs. of blood have taken up 12 grains of oxygen, there remain 5.6 grains of oxygen which combine with the other constituents of the blood. 55.14 grains of protoxide of iron combine with 34.8 grains of carbon dioxide, which occupy the volume of 73 cu. in. It is obvious that the

amount of iron present in the blood is sufficient to furnish the means of transporting twice as much carbon dioxide as can possibly be formed by the oxygen absorbed in the lungs (4).

5. What is Liebig trying to find out here and why are a good many measurements essential in testing this type of hypothesis?
6. To what extent do you consider the hypothesis proven and what new problems do you see arising from the data?

Liebig, in synthesizing a good deal of information into a plausible theoretical framework, had a pronounced effect on the development of physiology in the 19th and even 20th centuries. Metabolism was clearly established as an oxidation process and related to a good many other aspects of life.

Two important problems raised by Liebig's work, however, remain unanswered.

1. He indicates that only in the parts of the body supplied with arterial blood and oxygen is heat produced, but he does not pin down the site of heat production in an organism.
2. In gathering the evidence above that enough heat is produced from combustion to account for the temperature of an animal, the temperatures resulting from combustion were not considered.

References:

1. Liebig, Justus. Animal Chemistry. Philadelphia, T. B. Peterson, 1852. p. 76.
2. Ibid. p. 93.
3. Ibid. p. 95.
4. Ibid. p. 128.

J. Case Study 10: Edward Buchner and the Discovery of Enzymes

During the last half of the 19th century a good deal of controversy involved the question of whether or not fermentation was bound up with the life of the yeast, as Pasteur had suggested. Experimental evidence was not available to prove or disprove the idea that fermentation was a physiological process accompanying the life of the yeast, i. e., a vital act commencing and closing with the yeast itself.

Edward Buchner's discovery of the enzyme Zymase in 1897 provided a solution to the problem mentioned above and also pointed out an experimental method which was to be used to unravel some of the mysteries of fermentation and intermediate metabolism. A major difficulty involved the separation of the cell contents from the mixture of cell membranes, cells and grinding materials such as sand. Buchner's assistant, Martin Hahn, suggested that "Kieselguhr" should be added and the liquid squeezed out by means of a hydraulic press. Sugar was added as a preservative to the yeast juice so obtained, and Buchner noted that fermentation was proceeding in the absence of yeast cells.

From his experiments on this yeast juice, Buchner made the following observations:

Yeast-juice free from cells is capable of producing the alcoholic fermentation of glucose, fructose, sucrose, and maltose. The fermenting power of the juice is neither destroyed by the addition of chloroform, benzene, or sodium arsenite, by filtration through a Berkefeld filter, by evaporation to dryness at 30° to 35°, nor by precipitation with alcohol. The fermenting power is completely destroyed when the liquid is heated to 50°C.

From these observations he made the following inference:

The production of alcoholic fermentation does not require so complicated an apparatus as the yeast-cell, and the fermentative power of yeast-juice is due to the presence of a dissolved substance, zymase (1).

Alternative hypotheses which were used to explain Buchner's observations include the possibility that dissolved micro-organisms or fragments of living protoplasm might have caused the observed fermentations. Further tests by Buchner, however, showed that the

amounts of fermentation was almost unaffected by the presence of such antiseptics as chloroform or toluene, although some others such as arsenites and flourides decreased it, but only when added in comparatively high concentrations. A powder (called zymine) obtained by drying the precipitate after adding a mixture of alcohol and ether was also found to be capable of producing the fermentation. Buchner concluded the following from the above mentioned experimental evidence:

These facts clearly show that the various phenomena adduced by the supporters of the theory of protoplasmic fragments are quite consistent with the presence of a dissolved enzyme as the active agent of the juice, and at the same time that the properties demanded of the living fragments of protoplasm to which fermentation is ascribed are such as cannot be reconciled with our knowledge of living matter. If living protoplasm is the cause of fermentation by yeast-juice, a new conception of life will be necessary; the properties of the postulated fragments of protoplasm must be so different from those which the protoplasm of the living cell possesses as to deprive the theory of all real value (2).

Buchner's work introduced a new experimental method by which the problem of fermentation could be attacked. After the turn of the century, a considerable amount of information was gained with regard to the nature and conditions of enzyme action in the yeast cell. Buchner's work provided a clue to the mechanics of metabolism. Other investigators then, in a slow and piecemeal fashion began to find other enzymes and intermediate compounds involved in metabolism.

1. Reagents such as chloroform, benzene and arsenic compounds were added to the yeast juice. In addition the mixture was filtered and evaporated to dryness. Why were these tests essential in Buchner's test of his hypothesis?
2. How did Buchner's work make it easier for later investigators to consider metabolism in terms of chemical reactions?

References:

1. Buchner, E. Alkoholische Gärung ohne Hefezellen. Berichte 30: 1110-1113. 1897.

2. Buchner, E. Bemerkungen zu Arbeit von A. MacFedyen, G. H. Morris und S. Rowland; Ueber Ausgepresstes Hefegellplasma. Berichte 33: 3311-3315. 1900.

K. Case Study 11: The Search for
Intermediate Compounds in Metabolism

With the approach of the 20th century biologists became interested in a search for intermediates between the intake of oxygen, carbohydrates, fats, and proteins and the production of carbon dioxide and water. This line of inquiry eventually led to some important answers to the question of how energy is utilized for life. The search for intermediates which are not necessarily oxidized completely proved to be a difficult task. Many intermediates exist for only a fraction of a second, and isolation procedures are difficult. Knowledge developed in a piecemeal fashion and to a large extent involved the study of enzymes and fermentation.

In a study of the alcoholic ferment of yeast juice in 1906 Arthur Harden and W. J. Young made the following observations (1):

It was observed that the alcoholic fermentation of glucose by yeast-juice is greatly increased by the addition of yeast-juice which has been boiled and filtered, either when fresh or after having undergone autolysis, although this boiled liquid is itself incapable of setting up fermentation. The total fermentation produced is doubled by the addition of an equal volume of the boiled juice. A further increase is produced when a greater volume is added.

Yeast Juice cc.	Water cc.	Boiled Juice cc.	Glucose g.	Time hrs.	CO ₂ (g)
25	25	0	5	72	0.137
25	0	25	5	72	0.378
20	20	0	4	44	0.115
20	0	20	4	44	0.368
25	25	0	5	120	0.424
25	0	25	5	120	0.959
25	25	0	5	70	0.246
25	0	25	5	70	0.356
25	50	0	7.5	70	0.180
25	0	50	7.5	70	0.431
25	75	0	10	70	0.141
25	0	75	10	70	0.515

1. How does this data show that there is something in the yeast-juice-glucose mixture that is effecting fermentation besides the enzyme?
2. Why were measurements taken for different quantities of boiled yeast juice and glucose, and over different periods of time?

This co-ferment discovered in the boiled yeast juice (later to be called a co-enzyme), although unable to catalyze the reaction by itself, none the less seemed to be essential for the optimum functioning of the enzyme zymase.

In attempting to determine the nature of the co-ferment, Harden and Young noted the following (2):

As a result of a large number of attempts to isolate the constituent of the boiled juice which brings about the increase in fermentation, it was found that whenever an increase was produced phosphoric acid in the form of a soluble phosphate was present. The effect of the addition of soluble phosphates to yeast-juice was therefore examined and it was found that a well marked initial rapid evolution of carbon dioxide was thus produced.

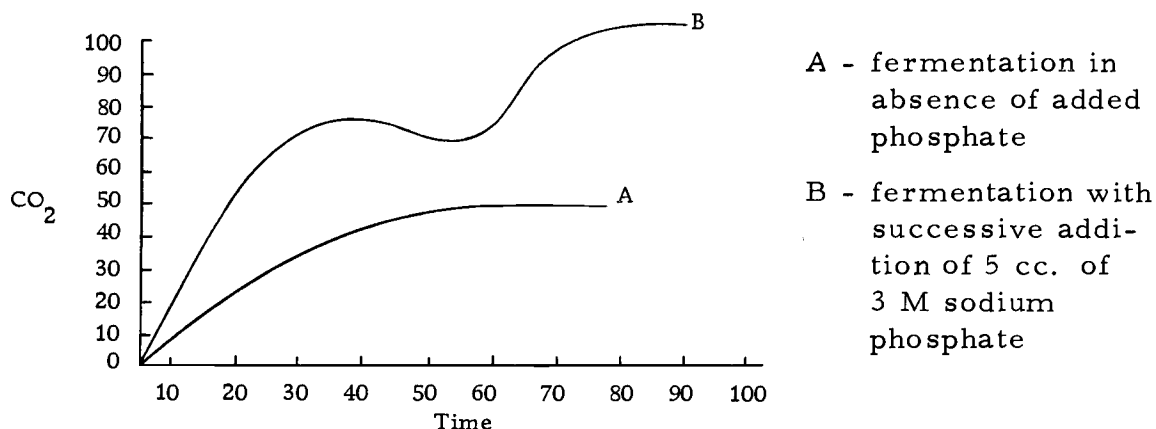
Since the boiled juices invariably contained phosphates, there can be no doubt that it is to the presence of these that this initial phenomenon is due. Quantitative estimations revealed the somewhat surprising fact that the extra quantity of carbon dioxide evolved in the initial period when a phosphate or a boiled juice is added corresponds with the evolution of one molecular proportion of carbon dioxide for each atom of phosphorous added.

3. The inference that the action of the co-enzyme was due to the phosphates, since the boiled juices invariably contained them, was probably premature and based on too limited evidence. Why?

The importance of phosphate in metabolism was indicated, however, and a new and important line of inquiry was defined. In the same study Harden and Young gathered more evidence about the role of phosphates and summarized their data as follows (3):

If the fermentation in presence of phosphate be allowed to continue until a steady rate is attained and a second quantity of

phosphate then be added, a second period of rapid evolution of carbon dioxide sets in and proceeds in a similar manner to the first.



When the fermented liquid is boiled and filtered almost the whole of the phosphorous present is found in the filtrate, but it is nearly all in a non-precipitated form. At this stage in the research the picture was far from clear. Harden and Young were searching for clues to explain a then unknown phenomena.

4. What was the advantage in recording data in the form of a graph?
5. What possible inferences could be made from the data on this page and what new questions are indicated?

In another paper also published in 1906, Harden and Young report on the addition of phosphate to the inactive residue (4):

In every case the solution of the phosphate was saturated with CO₂ at 26° C. and added to the solution of the inactive residue in glucose solution, and in no case was any evolution of gas observed.

These experiments throw no light on the actual chemical nature of the co-ferment but show that most probably it does not consist of a phosphate. They also indicate that substances, which, like phosphates, increase the total fermentation produced by yeast juice, are not necessarily capable of setting up fermentation when added to a mixture of inactive residue and glucose.

6. Why was it necessary to put forth new hypotheses at this stage in the research?

In a paper published two years later, in 1908, Harden and Young put forth a new hypothesis that the phosphate exists in the form of a sugar phosphate which is uncoupled and regenerated in fermentation. Harden and Young stated this hypothesis as follows (5):

The reason for this increase in the amount of sugar decomposed in the long period following the short initial period of acceleration appears to be that the phosphorous compounds first formed, which is a hexose phosphate of the formula $C_6H_{10}O_4(PO_4R_2)_2$ is slowly hydrolysed, probably by an enzyme, with the production of a phosphate and a hexose. The phosphate is thus slowly regenerated and then again undergoes the reaction, causing an increased fermentation in the same manner as when it was originally added.

The following experiment provided some evidence in support of this hypothesis:

This recurrence of phosphate is clearly shown by the following experiment. A known amount of phosphate was added to yeast-juice containing glucose . . . At the close of the initial period a sample was removed, boiled and filtered, and the free and total phosphate in it estimated.

Time in Hrs.	Free Phosphate/10 cc.	Total Phosphate/10cc.
5.5	0.021	0.266
18.0	0.093	0.269
66.0	0.133	-----
138.0	0.175	-----
426.0	0.226	0.273

It is to be noted that during the fermentation only a small increase occurs in the amount of free phosphate (0.075 g.), while after the cessation of fermentation the increase amounts to about three times as much (0.249).

At the close of the initial period, 25 cc (yeast juice, free phosphate, and glucose) yielded only 0.04 g. of phosphate, so that practically the whole of the added phosphate must have been converted into a salt of hexose phosphoric acid.

7. Why did this experiment support the idea that phosphates were coupled and uncoupled with sugar during fermentation?

8. Why was this an important discovery even though many aspects of the problem were not understood at the time?

Any good working hypothesis should be generalizable to other situations, therefore, Harden and Young compared the phosphates produced from three different sugars. These comparisons lead Harden and Young to new hypotheses regarding the formation of sugar phosphates (6):

The hexose phosphates produced from glucose, fructose, and mannose appear to be identical and have an important bearing on the chemical interpretation of the decomposition by fermentation of the hexoses into carbon dioxide and alcohol. The identity of the hexosephosphates from these three sugars may possibly be explained in either of two ways - (1) These three sugars have a common enolic form, and the hexose phosphate may be a derivative of this. (2) It is possible that the two molecules of sugar which are involved in the reaction may be decomposed into smaller groups, and that the hexose-phosphate may be formed by a synthesis from these. As the formation of the hexose-phosphate is invariably accompanied by that of an equivalent amount of carbon dioxide and alcohol, the second explanation appears the more probable, as it provides a source for the simultaneous production of these substances. According to this view two molecules of hexose are each decomposed into two groups. Of the four groups thus produced, two go to form alcohol and CO_2 , and the other two are synthesized to a new chain of carbon atoms which forms the carbohydrate residue of the hexose phosphate.

With the publication of studies such as this interest developed in the problem of how the carbon chain is broken during the degradations of six carbon sugars in fermentation. Particular interest centered on the chemistry of two and three carbon compounds which might be involved. In C. Neuberg's laboratory in 1911 the following was observed about the decomposition of the three carbon compound pyruvic acid (7):

The phenomenon can readily be exhibited by shaking up 2 g. of pressed yeast with 12 cc. of 1 percent pyruvic acid, placing the mixture in a fermentation tube, closing the open limb by means of a rubber stopper carrying a long glass tube and plunging the whole in water at $38^\circ - 40^\circ$. A comparison of yeast and 1% glucose may be started at the same time, and it is then seen that the pyruvic acid is decomposed, but less

rapidly than glucose . . . The production of acetaldehyde can be readily demonstrated by distilling the mixture at the close of fermentation and testing for the aldehyde (blue color with dilthylamine, or precipitation of hydrozone) . . . equal weights of carbon dioxide and acetaldehyde can be almost completely accounted for.

It may be inferred from the observations above that in fermentation the six carbon sugar is degraded to a three carbon fragment (pyruvic acid) which is in turn degraded to a two carbon fragment (acetaldehyde) in the process of forming carbon dioxide and alcohol.

In 1909 W. J. Young made the following observations on the reducing properties of hexose phosphate (8):

It reduced Fehling's solution only after some hours in the cold, rapidly on boiling. This reduction may be due to the hydrolysis of the compound with formation of a reducing hexose. This is known to take place, as an alkaline solution of the sodium salt that had been left standing for two or three days at room temperature was found to contain free phosphate . . . The same change was brought about more rapidly when the solution was boiled When the solutions of the acid were boiled, phosphoric acid was gradually set free, the reducing power increased.

Young tested this reducing substance and found it to be fructose. He also postulated other reducing compounds of small molecular weight. In 1914 Harden and Norris reported the following investigation on reducing enzymes in fermentation (9):

When Zymin or dried yeast was washed several times with cold water and thus rendered incapable of fermenting sugar, it also lost its power of reducing methylene blue or sodium selenite. It seemed therefore of interest to ascertain the cause of this loss of reducing power and also whether any substance capable of restoring it would at the same time restore the power of alcoholic fermentation. . . . As a result it was found that the addition of certain aldehydes or of bouillon restored the reducing power but not the fermenting power, whilst the boiled washings restored both. It seems probable, therefore, that washing removes some substance which acts as an acceptor for the oxygen activated during the reduction process and that the place of this can be taken by certain aldehydes or by a constituent of bouillon.

9. What is the evidence here for an acceptor molecule which does not directly cause fermentation?
10. What does this indicate about the nature of biological oxidations in living cells?

These studies by Harden, Young, and Morris pointed out a new direction for biological research - a search for compounds which can act as acceptor molecules in oxidation-reduction reactions. Several compounds were soon listed which are able to act as acceptors in this way. These included: Citric Acid, Lactic Acid, Glyceric Acid, Succinic Acid (Positive) and Glucose, Acetaldehyde, and Pyruvic Acid (Negative).

References:

1. Harden, A. and W. J. Young. The alcoholic ferment of yeast juice. Proceedings of the Royal Society 77: 405-420. 1906.
2. Ibid.
3. Ibid.
4. Harden, A. and W. J. Young. The alcoholic ferment of yeast juice: Part II - The coferment of yeast juice. Proceedings of the Royal Society 78: 369-375. 1906.
5. Harden, A. and W. J. Young. The alcoholic ferment of yeast juice: Part III - The function of phosphates in the fermentation of glucose by yeast juice. Proceedings of the Royal Society 80: 299-311. 1908.
6. Harden, A. and W. J. Young. The alcoholic ferment of yeast juice: Part V - The function of phosphates in alcoholic fermentation. Proceedings of the Royal Society 82: 321-333. 1910.
7. Neuberg, C. and L. Karczag. Ueber zuckerfreie Hefegarungen. Biochemische Zeitschrift 36: 76-81. 1911.
8. Young, W. J. The hexose phosphate formed by yeast juice from hexose and phosphate. Proceedings of the Royal Society 81: 528-545. 1909.
9. Harden, A. and Norris, R. V. The enzymes of washed zymon and dried yeast II reductase. Journal of Biochemistry 8:100-106. 1914.

APPENDIX II: THE BURMESTER TEST OF ASPECTS OF SCIENTIFIC THINKING

Form A

Mary Alice Burmester

Purpose:

This test has been devised to measure ability to think scientifically. It is divided into several parts, each of these parts testing a different phase of scientific thinking.

Directions:

1. Place your name, age, and sex in the spaces provided on the answer sheet.
2. On the space marked "school" place your major.
3. In the space marked "1" below "school", give courses you have had in science in high school, in the space marked "2" give any courses you have had in science in college in addition to biological science.
4. Answer all items; if you don't know -- guess.
5. Do not mark on the test booklet. Use scratch paper if you wish.
6. Be sure to mark heavily on the answer sheet; the machine may not pick up light markings.
7. Each item has only one answer; select the one best answer and mark no more than one.

Instructions: This portion of the test is designed to measure your ability to differentiate phases of thinking. These steps include major problems of perplexities, possible solutions to problems, observations which are not results of experimentation but rather preliminary observations, results of experimentation, and conclusions.

The following key is to be used for the succeeding paragraph. Certain parts of the paragraph are underlined, and each underlined item is a question. Choose the proper response from the key and blacken the appropriate space in the answer sheet.

Key:

1. A major problem (stated or implied).
2. Hypothesis (possible solution to problem).
3. Result of experimentation.
4. Initial observation (not experimental).
5. Conclusion (probable solution to problem).

The (1) sense least understood is the sense of smell. It has been generally believed that (2) the nose identified odors by chemical analysis. Some scientists suggested (3) that it is more likely that smelling is a measuring of the infrared (heat) rays absorbed by odorous vapors. It has long been known that many gases absorb certain wave lengths of infrared. Chemists shoot infrared rays through vapor and note what wave lengths are absorbed. (4) Why shouldn't the human nose do the same? In a study of substances which have odors and those which do not have odors it was found that all waves 7-1/2 to 14 microns long which do have odors can absorb infrared whereas those without odors do not absorb these infrared wavelengths. Since the human body at normal temperature radiates heat waves chiefly at the 7-1/2 to 14 band it may be that the ability to absorb heat waves is what makes vapors smellable. (5) But how does the nose do the smelling? The smell receptors in the upper nose lie across air passages. These scientists suggest that (6) when pure air is passing through the nostrils the cells give no signal; they get rid of their heat at a standard rate. (7) But when an odorous vapor is present in the air it absorbs certain wavelengths of heat from the cells. (8) The cells feel the change and the stimulus produces a sensation of smell. To confirm this, these scientists studied cockroaches which have their smell receptors on their antennae (hence outside the body). Cockroaches were known to be attracted by oil of cloves. The scientists put cockroaches in a gas tight box with a window made of a material which was transparent to infrared (heat) rays. (9) The cockroaches responded just as strongly as if the window were not there, they swarmed toward the window. Then a window of glass, which does not allow infrared rays to go through it was put in as a barrier. (10) The cockroaches showed no more interest in the window than if the oil of cloves were not there. Next the scientists tried bees. (11) The bees crawled all over the heat-transparent window with sweet smelling honey vapor behind it, whereas (12) they ignored the

window which did not allow the heat waves to pass through. The experiments indicated that (13) in some insects, at least, there is some relationship between smelling and absorption of heat by vapors. Both (14) cockroaches and bees could smell vapors at a distance from their antennae. This may explain how some animals seem to be able to detect odors from considerable distance.

Instructions: This portion of the test was designed to measure your understanding of the relation of facts to the solution of a problem. The overall problem involved in this test is presented. This is followed by a series of possible solutions to the problem (hypotheses). After each hypothesis there are a number of items, all of which are true statements of fact. Determine how the statement is related to the hypothesis and mark each statement according to the key which follows the hypothesis.

GENERAL PROBLEM: What factors are involved in the transmission and development of Infantile Paralysis (Poliomyelitis)?

Hypothesis I. In man the disease is contracted by direct contact with persons having the disease.

For items 15 through 22 mark space:

1. If the item offers direct evidence in support of hypothesis.
2. If the item offers indirect evidence in support of the hypothesis.
3. If the item offers evidence which has no bearing on the hypothesis.
4. If the item offers indirect evidence against the hypothesis.
5. If the item offers direct evidence against the hypothesis.

15. Monkeys free from the disease almost never catch infantile paralysis from infected monkeys.
16. The curve of number of cases of the disease in a given area is the same shape as the curve for the fly population in that area, the infantile paralysis incidence curve lagging behind the fly population curve by about two weeks.

17. The virus has never been isolated from the blood.
18. The virus is not found in the nasal secretion, nor in the saliva.
19. The incubation period for infantile paralysis is from 4 to 21 days.
20. Most persons in contact with the diseased individual do not develop the disease.
21. The incidence of infantile paralysis is higher in rural districts than in the cities.
22. Even during epidemics cases are spotty, it is usually impossible to trace one case from another.
23. What is the status of hypothesis I?
 - (a) It is true.
 - (b) It is probably true.
 - (c) The data are contradictory, so the truth or falsity cannot be judged.
 - (d) The hypothesis is probably false.
 - (e) It is definitely false.

Hypothesis II. The disease is spread by the excrement (excreted material) of persons harboring the virus.

For items 24 through 30 mark space:

1. If the item offers direct evidence support of the hypothesis.
2. If the item offers indirect evidence in support of the hypothesis.
3. If the item offers evidence which has no bearing on the hypothesis.
4. If the item offers indirect evidence against the hypothesis.
5. If the item offers direct evidence against the hypothesis.

24. The virus is always found in the stools of persons who have the disease; while in the stools of persons not in contact with

persons with the disease the virus is found in one one person in a hundred.

25. During an epidemic nonparalytic cases out-number paralytic cases ten to one.
26. The curve of number of cases of the disease in a given area is the same shape as the curve for the fly population in the area, the infantile paralysis incidence curve lagging behind the fly population curve by about two weeks.
27. Nine out of fourteen adult contacts had virus in the stool, almost all child contacts have virus in the stools.
28. The virus has been isolated from streams carrying sewage.
29. The virus of the disease has been found in the stools and vomit of flies up to two days after eating an infected meal.
30. It is usually impossible to trace one case from another.
31. What is the status of hypothesis II?
 - (a) It is true.
 - (b) It is probably true.
 - (c) The data are contradictory, so the truth or falsity cannot be judged.
 - (d) The hypothesis is probably false.
 - (e) It is definitely false.

Instructions: This portion of the test was designed to measure your ability to interpret data and to test your understanding of experimentation. In each case the numbers in the first column are the numbers which you will use as your answer. Thus the table presented becomes both the source of data and your key for the questions which follow it. In each case where a test tube number or group number is called for the one which gives positive evidence for the statement should be given. Below this the control or comparison is called for. This is the test tube or group number of the data which offers a comparison. For example:

1. Leaf in dark - no starch.
2. Leaf in light - starch.

"Light is necessary for the production of starch." You would mark space 2 because this is the positive evidence, but it would be meaningless if it were not compared with the leaf in the dark. Therefore, the following item, "What is the control (comparison) for item 1?" would be marked space 1.

Items 32 through 46 refer to the data presented below. Five test tubes, each containing a gram of protein, were set up. Mark each item according to the test tube number called for. All substances were dissolved in water. All test tubes were kept at 37 degrees Centigrade (water boils at 100 degrees Centigrade). For test tube 5, Substance X was boiled and then cooled before it was added to the protein.

<u>Test Tube</u>	<u>Contents of Tubes</u>	<u>Amt. of Substance W present after 24 hrs.</u>
1.	Protein + Substance X	0.05 gram
2.	Protein + Water	0.00 gram
3.	Protein + Substance X + hydrochloric acid	0.08 gram
4.	Protein + Hydrochloric acid	0.00 gram
5.	Protein + Substance X (boiled)	0.00 gram
32.	Give the number of the test tube which acts as a control (comparison) for the entire experiment.	
33.	Give the number of the test tube which gives evidence that protein does not break down spontaneously into Substance W.	
34.	Give the number of the test tube which gives evidence that Substance X is the active substance in the breakdown of proteins.	
35.	Give the number of the tube which is the control for item 34.	
36.	Give the number of the test tube which shows that a temperature of 37 degrees Centigrade does not cause protein to break down into Substance W.	
37.	Which test tube gives evidence that Substance X is not a stable substance?	
38.	Which tube is the control for item 37?	

39. Which tube gives evidence that acid accelerates the activity of Substance X?
40. Which tube is the control for item 39?
41. Which tube gives evidence that Substance X is a substance whose properties can be destroyed?
42. Give the test tube number of the control for item 41.
43. Which test tube gives evidence that acid affects the protein in some way so that Substance X can act upon it more easily?
44. Give the tube number which is the control for item 43.
45. Give the number of the test tube which indicates that hydrochloric acid alone is ineffective in breaking down proteins.
46. Give the control for item 45.

Instructions: This portion of the test was designed to measure your ability to make conclusions. When facts are analyzed and studied they sometimes yield evidence which help in the solution of a problem. However, any conclusion must be checked before it can be accepted. The following key includes four ways in which conclusions may be faulty. Each of the items present a question or problem, a brief description of an experiment and one or more conclusions drawn from the experiment. Each experiment was repeated many times. Read each problem, experiment and the conclusions. Where several conclusions are given evaluate each conclusion separately. Is the conclusion tentatively justified by the data? If so, mark space 1 on your answer sheet. If the conclusion is not justified determine whether 2, 3, 4, or 5 in the key is the best reason for it being faulty and mark the proper space on your answer sheet.

Key:

1. The conclusion is tentatively justified.
2. The conclusion is unjustified because it does not answer the problem.
3. The conclusion is unjustified because the experiment lacks a control comparison.

4. The conclusion is unjustified because the data are faulty or inadequate, though a control was included.
5. The conclusion is unjustified because it is contradicted by the data.

PROBLEM: To determine the cause of disease X. One thousand persons with the disease were examined. Bacteria Q was found in the mouth of all of the persons with the disease.

47. Conclusion: Bacteria Q is the cause of the disease.

PROBLEM: What are some of the requirements for seeds to sprout? The same student planted two groups of seeds of different types in pots and placed one group of the pots in the light, the others in the dark. Those plants in the light were green, those in the dark were yellow. Other conditions were the same for both groups.

48. Conclusion: Light is necessary for sprouting of seeds.
49. Another conclusion: Plants require light to mature properly.
50. Another conclusion: Light makes the plants green.

PROBLEM: Investigator A wanted to know what caused people to become ill if confined in large numbers to a small closed area. He found on repeated tests that the air in very crowded closed areas contained about 5% carbon dioxide, while normal air contains 0.03% carbon dioxide.

51. One investigator concluded that the illness was caused by insufficient oxygen.

PROBLEM: Investigator B in an attempt to solve the same problem repeated the experiment done by investigator A but in addition had people in uncrowded rooms breathe air containing 5% carbon dioxide. No ill effects were noted among those in the uncrowded rooms.

52. He concluded that excessive carbon dioxide caused the illness.
53. Another investigator claimed that this showed that the disease was caused by insufficient oxygen.

PROBLEM: To determine whether a certain bacteria uses oxygen. The Winkler test is an oxygen test. A broth in which bacteria were grown was tested for oxygen. The broth was shown, by the Winkler test, to contain oxygen.

- 54. Conclusion: This type of bacteria does not use oxygen.
- 55. Another conclusion: This type of bacteria gives off oxygen as a waste product.
- 56. Still another conclusion: The presence of oxygen does not stop the growth of bacteria.

PROBLEM: An investigator wished to determine whether temperature increased the rate of a certain reaction. On repeated tests he found that if he started out with a certain amount of his original substances he would obtain, after one hour, 1 gram of the substance produced by the reaction at 0° C, 2 grams at 20° C, 5 grams at 40° C, and 3 grams at 60° C.

- 57. He concluded that increased temperature increased the rate of the reaction.
- 58. Another person claimed that this indicated that light increases the rate of reaction.

Instructions: This portion of the test was designed to measure your ability to interpret data. Following the data you will find a number of statements. You are to assume that the data as presented are true. Evaluate each statement according to the following key and mark the appropriate space on your answer sheet.

Key:

- 1. True: The data alone are sufficient to show that the statement is true.
- 2. Probably true: The data indicate that the statement is probably true, that it is logical on the basis of the data but the data are not sufficient to say that it is definitely true.
- 3. Insufficient evidence: There are no data to indicate whether there is any degree of truth or falsity in the statement.

4. Probably false: The data indicate that the statement is probably false, that is, it is not logical on the basis of the data but the data are not sufficient to say that it is definitely false.
5. False: The data alone are sufficient to show that the statement is false.

Analyses were made of the vitamin C content of red ripe and green tomatoes as soon as they were picked. Mature green tomatoes were stored at the temperatures indicated in the following table. Those which had ripened by the end of the first week were analyzed for their vitamin C content; those ripened at the end of the second week were analyzed at the end of the second week, etc. In addition, some mature green tomatoes were analyzed each week.

<u>Condition when taken from field</u>	<u>Temp. when stored</u>	<u>No. of weeks stored</u>	<u>Stage of ripeness when analyzed</u>	<u>Vitamin C mg/100 grams</u>
mature green	not stored	0	mature green	15.0
red ripe	not stored	0	red ripe	16.2
mature green	70°F.	1	red ripe	14.4
mature green	70°F.	2	red ripe	12.9
mature green	70°F.	3	red ripe	8.2
mature green	80°F.	1	red ripe	14.0
mature green	80°F.	2	red ripe	9.8
mature green	80°F.	3	red ripe	7.1
mature green	70°F.	1	mature green	10.0
mature green	70°F.	2	mature green	7.2

59. Tomatoes ripened at 90°F would have less vitamin C after three weeks than those stored at 80°F.
60. Tomatoes could not be stored at 90°F because at this high temperature they would rot or spoil.
61. The lower the temperature at which tomatoes are stored the less is the breakdown of vitamin C.
62. Heat causes a breakdown of the vitamin C molecule.
63. After four weeks of storage tomatoes stored at 70°F would contain less than 7/100 grams of vitamin C.

- 64. Some mature green tomatoes ripen in storage within a week.
- 65. The green tomatoes which did not ripen in a week had lost about the same amount of vitamin C as those which ripened during the week.
- 66. Vitamin C is manufactured some place else in the plant than in the fruit (tomato) and is stored in the fruit.

Items 67 through 70 are a reevaluation of some of the items 59-66. Reread items 59, 62, 63, and 64 and determine whether they are generalizations, extensions of the data, explanations of the data or merely restatements of the data, etc. Each of these items is to be answered according to the following key:

Key:

- 1. A generalization, that is, the data says it is true for this situation, a generalization says it is true for all similar situations.
 - 2. The data indicates a trend which if continued in either direction would make the statement true.
 - 3. An explanation of the data in terms of causes and effect.
 - 4. A restatement of results.
 - 5. None of the above.
- 67. Item 59.
 - 68. Item 62.
 - 69. Item 63.
 - 70. Item 64.

This phase of the test is designed to measure your understanding of assumptions underlying conclusions. A conclusion is given. (This conclusion is not necessarily justified by the data.) The

statements which follow the conclusion are the items which are to be evaluated according to the following key. These items will relate to the data presented for items 59 through 66.

Key:

1. An assumption which must be made to make the conclusion valid (true).
2. An assumption which if made would make the conclusion false.
3. An assumption which has no relation to the validity (truth) of the conclusion.
4. Not an assumption: a restatement of fact.
5. Not an assumption; a conclusion.

CONCLUSION I: Sunlight causes an increase in the vitamin C content of tomatoes as they ripen on the vine.

71. The tomatoes which were analyzed when green-ripe would have contained more vitamin C if they had been allowed to ripen on the vine.
72. The test used to measure the amount of vitamin C accurately measures the amount.
73. The vitamin C content of ripe tomatoes on the vine was higher than the vitamin C content of the green-ripe tomatoes on the vines.

CONCLUSION II: Vitamin C breaks down spontaneously at room temperature.

74. Vitamin C reacts similarly in all plants in which it is found.
75. When the tomatoes were stored at room temperature the vitamin C content decreased.
76. All vitamins react similarly to storage at room temperature.

APPENDIX III: THE NATURE OF SCIENCE SCALE

Mark A if you agree, and B if you disagree with each of the following statements.

1. The most important scientific ideas have been the result of a systematic process of logical thought.
2. Classification schemes are imposed upon nature by the scientists: they are not inherent in the materials classified.
3. Thanks to the discovery of the scientific method, new discoveries in science have begun to come faster.
4. The primary objective of the working scientist is to improve human welfare.
5. While a scientific hypothesis may have to be altered on the basis of newly discovered data, a physical law is permanent.
6. The scientific investigation of human behavior is useless because it is subject to unconscious bias of the investigator.
7. Science is constantly working toward more detailed and complex knowledge.
8. A fundamental principle of science is that discoveries and research should have some practical applications.
9. While biologists use the deductive approach to a problem, physicists always work inductively.
10. The ultimate goal of all science is to reduce observations and phenomena to a collection of mathematical relationships.
11. The best definition of science would be "an organized body of knowledge".
12. Science tries mainly to develop new machines and processes for the betterment of mankind.

13. Any scientific research broader than a single specialty can only be carried out through the use of a team of researchers from various relevant fields.
14. Investigation of the possibilities of creating life in the laboratory is an invasion of science into areas where it does not belong.
15. Team research is more productive than individual research.
16. Many scientific models are man-made and do not pretend to represent reality.
17. Scientific investigations follow definite approved procedures.
18. Most scientists are reluctant to share their findings with foreigners, being mindful of the problem of national security.
19. The essential test of a scientific theory is its ability to correctly predict future events.
20. When a large number of observations have shown results consistent with a general rule, this generalization is considered to be a universal law of nature.
21. The scientific method follows the five regular steps of defining the problem, gathering data, forming a hypothesis, testing it, and drawing conclusions from it.
22. One of the distinguishing traits of science is that it recognizes its own limitations.
23. The steam engine was one of the earliest and most important developments of modern science.
24. Scientific research should be given credit for producing such things as modern refrigerators, television, and home air-conditioning.
25. If at some future date it is found that electricity does not consist of electrons, today's practices in designing electrical apparatus will have to be discarded.
26. By application of the scientific method, step by step, man can solve almost any problem or answer almost any question in the realm of nature.

27. Scientific method is a myth which is usually read into the story after it has been completed.
28. Scientific work requires a dedication that excludes many aspects of the lives of people in other fields of work.
29. An important characteristic of the scientific enterprise is its emphasis on the practical.