TECHNIQUES
FOR
EFFICIENT RESEARCH

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by

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Preface

The need for increased productivity in scientific research is generally recognized. Mounting costs of research require constantly greater output "just to stay even," while at the same time the potential leverage which research can give to profits beckons toward even greater commitment to it. Many researchers, old and young, have not learned to apply good techniques. As a result of all this, efficient research, like the weather, is more talked about than improved.

The problem of how to employ good techniques as an aid to efficient research came to my attention when I was a young researcher. I first noticed my own lack of skill and then observed that many of my colleagues were as poorly equipped as I was in techniques for solving problems. At that time I questioned half a hundred Ph.D.'s in chemistry, physics, and engineering from a broad cross section of nationally recognized universities. In this group there was not one who had received organized instruction in how to do research. Moreover, a search of the literature revealed no report which treated this important question with adequate breadth and depth. There were statements on what is the scientific method but no directions on how to apply it. What is needed is renewed attention to the methodology of research—an answer to the question: How does one do research efficiently?

There was at hand no ready-made answer, but diligent search and study clarified the meaning of the scientific method and resulted in a logical and effective procedure that could be stated in a stepwise sequence. Although the procedure is based on the scientific method, it proved necessary to add steps and detail, which, although implied in the scientific method, have never before been directly stated. The problem-solving proce-

dure is proposed specifically as a technique in research, but it is broad enough to fit any type of *problem.*

Further study of the question of efficiency in research revealed factors other than problem-solving which were of importance. This led to an examination of all aspects of the management of research. The latter chapters of this book will be of special interest to management, but they will also be of interest to the researcher himself, in that it will help him to visualize his own relationship to the total program.

This book is not designed as a philosophy of research. Rather, it seeks specific answers to the HOW questions:

How does one do what one ought to do?
How does one assemble facts?
How does one arrange them in an orderly fashion?
How can creativity be improved?

This is, in a sense, a "do-it-yourself" manual for self-improvement in the selection of problems and in solving them. The examples are largely taken from the chemical industry, but the principles are broadly applicable to all types of problems. The first part of the book is concerned primarily with the problem of solving problems; the second part is directed to problems of research management.

I especially wish to express my gratitude to Dr. John J. Grebe, formerly Director of Nuclear and Basic Research at the Dow Chemical Company (now retired), for the inspiration of his example and the insight that I have gained from our many discussions through the years, not only on the philosophy and methods of research but also on a wide variety of research problems. I also owe a debt of gratitude to the many researchers on industrial psychology from whose work I have borrowed.

I wish also to say thank you to Miss Lois Hoerlein for her valued assistance in preparing the manuscript.

August 1965 LEWIS E. LLOYD

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chapter 1

INTRODUCTION

"A research man with a new problem should go to the laboratory first."

"Wouldn't it be better if he first went to the library to see what has already been done in the field?"

"Most certainly not!"

"Why?"

"Because whatever is in the literature will only prejudice the researcher and inhibit the application of his own fresh ingenuity to the problem."

"But I take the other stand. If the research worker does not go to the library first, he will waste much time repeating work already done and reported by others."

Such was part of a conversation between two experienced research workers who were discussing problem-solving methods at lunch one day. They were concerned about the more general problem of research efficiency and how to improve it. This was an unusual discussion, in one sense, because relatively little attention has been given to this problem. Billions of dollars are spent on research to improve efficiency in production and distribution, and more billions to find new products; but very little to improve the efficiency of research itself.

Perhaps this should not be surprising. The research man is too busy applying his scientific skill to fascinating problems to leave much time for developing better methods and tools. Moreover, engineers and physical scientists are sometimes baffled by problems of human relations. As they are inclined to expect people to behave logically, they are all too often unprepared for the emotionally directed behavior that is charac-

teristic of us humans. Management, to be sure, is concerned with personnel problems, but generally is not acquainted with the research worker's special problems. Thus, caught in the middle, methodology in research including the problem of *problem-solving* has not received the attention that it deserves.

Much Interest in R & D

That there is interest in the problem of efficient research is demonstrated by the many published papers with such titles as: "Research Management", "Research Organization", "Capitalizing on Research", or simply, "Research". There have also been many books written, particularly on industrial research. Some of these are statements of the philosophy of research by recognized leaders in the field of research. In others the authors have interviewed the research directors in various companies, or collected data and comments by questionnaire. By studying and summarizing such information, they have indicated what they believe to be the accepted practice in the more progressive laboratories. Finally, there is the book called *Handbook of Research Management*,[1] which is a series of chapters written, for the most part, by various consultants on different aspects of management of research. The reader must judge for himself how much is subtle advertising and how much is pet theory of the given consultant. To a large extent, however, this literature has indicated only what ought to be done, not how to do it; it has stated the objective, not the method.

It is the purpose of this book to focus attention on the *how* problem—the techniques for improving efficiency in research. This is not, however, a treatise on time-and-motion studies in the laboratory. Such studies, however worthy, have been effectively covered elsewhere both for the general subject and for the laboratory experimental techniques. We are concerned with the broader, more fundamental aspects of research procedure; with factors of organization and policy, and with the mental processes involved. It is in these areas that great strides in research efficiency can be made.

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[1] Edited by Carl Heyel; Reinhold Publishing Corporation, New York, 1959.

Efficiency Is Important

Analysis of the problem reveals the major factors that affect efficiency in research. Once the problem has been broken down into its parts, each part can be examined step by step. Some factors involve primarily the research worker, and others, primarily management. The first part of this book examines ways in which the researcher himself can improve his own efficiency. Here are discussed the basic and important factors of creativity and problem-solving. The scientific method is elaborated in detail, and suggestions on how best to apply it are presented.

In the later chapters, attention is given to the importance of selecting a worthwhile problem and some criteria for the selection. Other factors of importance to effective organization and management of research are also discussed, always with the *how* question in mind.

Management everywhere seems to be concerned about trying to increase efficiency in research. Does this mean that research is less efficient than it ought to be? Are there substantial gains to be made, and if so, how? These and other questions need to be answered, not only because research is big business but also because, for twentieth-century America, research has become the Aladdin's lamp from which fabulous new things come by application of enough "polish." Practical businessmen look to research for new products and growth. National defense depends heavily on research for more effective weapons. Universities are rated by their accomplishments in research. We do research on everything from the atomic nuclei to galaxies, from the subconscious mind to rocks, from modern politics to ancient civilizations. Even grade-school children call it "research" when they go to the library. Our whole society is "research conscious".

EXPENDITURES FOR RESEARCH

The company executive no longer asks himself whether to *have* research; merely, "*How much* research?" He does not ask himself, "Can we afford research?"; he knows he cannot afford to be without it. No president would admit that his company was doing no research. In fact, this is the one part of the pro-

TABLE 1:1

EXPENDITURES FOR SCIENTIFIC RESEARCH

(millions of dollars)

Year[1]	*Total Scientific Research Expend.*	*Industry*[2]		*Nonprofit Industrial Research Institutes*	*Government (Fed., State)*	*Colleges, Universities*	*Research Institutes*
		Reported by V. Bush	Revised Est. by Y. Brozen				
1921	72.0[e]	29.4	48	–	12.0[e]	10.6[e]	1.0[e]
1922	84.0[e]	37.4	59	–	13.0[e]	11.0[e]	1.0[e]
1923	97.0[e]	44.0	70	–	14.0[e]	12.0[e]	1.0[e]
1924	110.6[e]	50.0	80	–	15.6	13.0[e]	2.0[e]
1925	124.3[e]	58.0	92	–	16.3	14.0[e]	2.0[e]
1926	138.0[e]	64.0	102	–	18.0	15.0[e]	3.0[e]
1927	147.9[e]	70.0	112	–	16.9	16.0[e]	3.0[e]
1928	158.0[e]	75.9	120	–	17.1	17.0[e]	4.0[e]
1929	181.0[e]	88.0	140	–	17.7	18.0[e]	5.0[e]
1930	217.0[e]	106.0	170	–	22.8	19.0[e]	5.0[e]
1931	235.0[r]	116.0	186	0.5	24.0	20.3	5.2
1932	268.0[e]	131.3	214	1.2	26.9	22.0[e]	5.2
1933	277.0[r]	120.0	207	0.9	40.0	24.8	5.1
1934	231.0[e]	110.2	176	0.7	30.0[e]	20.0[e]	4.8
1935	244.0[r]	124.0	198	1.5	22.2	19.2	4.7
1936	269.0[e]	136.0	217	2.4	25.3	22.0[e]	4.7
1937	305.0[r]	152.0	242	2.5	33.8	25.0	4.7
1938	327.0[e]	160.0	255	3.5	40.7	26.5[e]	4.6
1939	358.0[r]	198.0[r]	276	4.0	49.3	28.4	4.5
1940	369.0[e]	200.0	280	5.0	54.0[e]	30.0[e]	4.5
1941	441.0[r]	234.0	336	6.1	69.1	31.4	4.5

[e] = Estimated [r] = Revised datum

[1] Fiscal year ending in year indicated

[2] Vannevar Bush: *Science, the Endless Frontier;* National Science Foundation, Washington, D.C., July 1945 (reprinted July 1960). Yale Brozen: Trends in Industrial Research & Development, *Journal of Business of the University of Chicago,* July 1960

gram that is sure to be reported at the annual stockholders' meeting.

With this acceptance—almost worship—of research, it is not

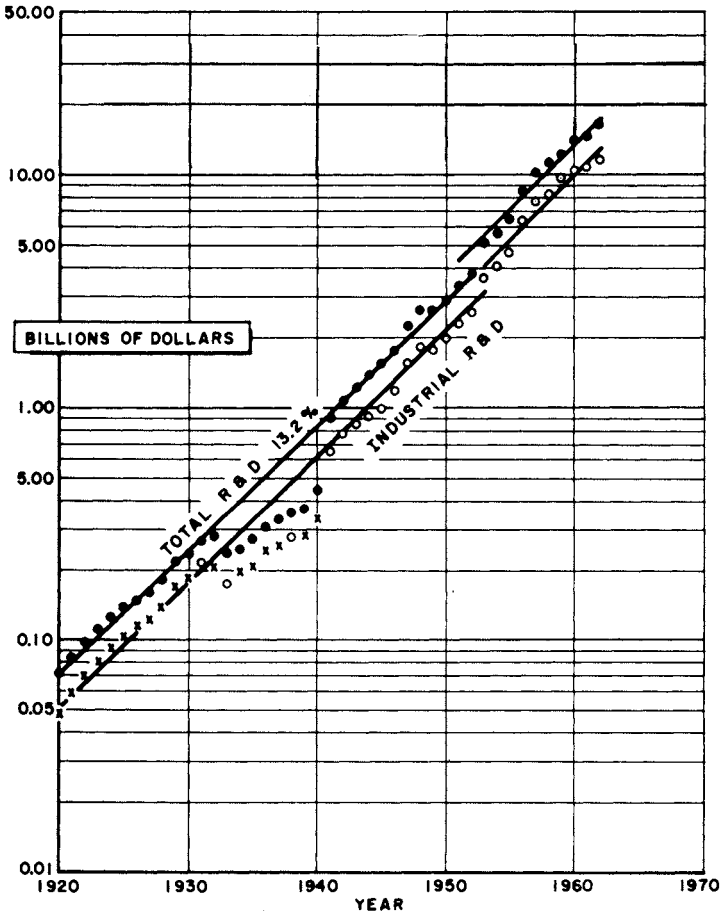

Fig. 1:1 EXPENDITURES FOR RESEARCH AND DEVELOPMENT (U.S. Totals)

surprising to find that it has grown rapidly. By 1963, total research and development expenditures in the United States had reached 16.4 billion dollars (see Table 1:1). This includes re-

TABLE 1:2

EXPENDITURES FOR RESEARCH AND DEVELOPMENT

(millions of dollars)

Year[1]	*Total*	*Sources of Funds*				*Use of Funds by*			
		Govern-ment	Industry	Colleges and Univer.	Other Nonprofit Instit.	Govern-ment	Industry	Colleges and Univer.	Other Nonprofit Instit.
1942	900	370	510	20	–	200	660	40	–
1943	1,070	490	560	20	–	240	780	50	–
1944	1,210	780	410	20	–	300	850	60	–
1945	1,380	940	420	20	–	390	910	80	–
1946	1,520	1,070	430	20	–	430	990	100	–
1947	1,780	910	840	30	–	470	1,190	120	–
1948	2,260	1,160	1,050	50	–	520	1,570	170	–
1949	2,610	1,390	1,150	70	–	570	1,820	220	–
1950	2,610	1,550	990	70	–	550	1,790	270	–
1951	2,870	1,610	1,180	80	–	570	1,980	320	–
1952	3,360	1,980	1,300	80	–	700	2,300	360	–
1953	3,750	2,240	1,430	80	–	800	2,530	420	–
1954	5,150	2,740	2,240	130	40	970	3,630	450	100
1955	5,620	3,070	2,365	140	45	950	4,070	480	120
1956	6,390	3,670	2,510	155	55	1,090	4,640	530	130
1957	8,670	5,095	3,265	180	70	1,280	6,600	650	140
1958	10,100	6,380	3,390	190	70	1,440	7,730	780	150
1959	11,130	7,170	3,620	190	90	1,730	8,360	840	200
1960	12,680	8,320	4,060	200	100	1,830	9,610	1,000	240
1961	13,890	9,010	4,550	210	120	1,900	10,510	1,200	280
1962[p]	14,740	9,650	4,705	230	155	2,090	10,870	1,400	380
1963[p]	16,400	11,000	5,000			2,700	11,600		

[p] = preliminary

[1] Fiscal year ending in year indicated

Source: *Statistical Abstract of the United States:* 1953, 1958, 1962, and 1964 editions.

TABLE 1:2 (*Continued*)

EXPENDITURES FOR RESEARCH AND DEVELOPMENT

(millions of dollars)

Calendar Year

Cal. Year	*Total*	*Sources of Funds*				*Use of Funds by*			
		Govern-ment	Industry	Colleges and Univer.	Other Nonprofit Instit.	Govern-ment	Industry	Colleges and Univer.	Other Nonprofit Instit.
1953	5,160	2,760	2,240	120	40	1,010	3,630	420	100
1954	5,660	3,120	2,365	130	45	1,020	4,070	450	120
1955	6,200	3,500	2,510	140	50	950	4,640	480	130
1956	8,370	4,820	3,330	155	65	1,090	6,610	530	140
1957	9,810	6,105	3,455	180	70	1,280	7,730	650	150
1958	10,810	6,840	3,700	190	80	1,440	8,390	780	200
1959	12,430	8,070	4,070	190	100	1,730	9,620	840	240
1960	13,620	8,770	4,540	200	110	1,830	10,510	1,000	280
1961	14,380	9,220	4,810	210	140	1,890	10,910	1,200	380
1962	15,610	10,045	5,175	230	160	2,220	11,540	1,400	350
1963	17,350	11,340	5,565	260	185	2,400	12,720	1,700	530

Source: *Reviews of Data on Science Resources*, Vol. I, No. 4, May 1965; National Science Foundation, Washington, D.C.

search done by industry, by profit and nonprofit research institutes, and by federal and state governments.

The total expenditures for R & D in the United States for the past forty years are shown in Table 1:1 and Figure 1:1. A trend-curve through the data shows a rate of growth around 13.2% a year. The second curve in Figure 1:1 shows the expenditures for R & D by U.S. industry. The relationship of this curve to the total indicates that an essentially constant portion of the R & D has been done in industrial laboratories. In recent years, however, a sizable portion of the R & D by the aircraft, electronics, and some other industries has been financed by government through research contracts and not out of corporate earnings.

Figure 1:2 shows R & D by source of funds. Here the divergence between the industrial R & D and the total is evident. The drop in expenditures for R & D during the early 1930s came primarily in the industrial sector. Research funds from universities and government appear to have remained essentially on a plateau. It is probable, however, that effort in R & D did not decrease in direct proportion to the reduction in dollars that were reported as spent, because of the reductions in wages and salaries during the period.

The data indicate a surge ahead in R & D at the beginning of World War II. Suddenly there was the need to be self-sufficient in products like rubber, and the need for rapid improvement in military aviation and equipment. This wartime impetus carried expenditures up to a level in line with the growth trend of the 1920s. This trend has continued. Recently, the National Science Foundation published revised data back through 1953. For these most recent figures the coverage has been extended so that expenditures appear to show a 60% increase over data previously reported. A trend-line through the data for the eight years for which revised coverage is available, however, shows the same rate of growth as the long-term trend.

The data on expenditures for research and development are expressed in current dollars and so overstate the growth in research effort to the extent of the inflationary increase in wage rates. That this might be sizable is indicated by a fivefold increase in the average annual cost per researcher from 1920 to

1960 (1920 = $2,800; 1960 = $14,000).[1] We know that during the 1950's wage rates increased about 6% a year, which is about

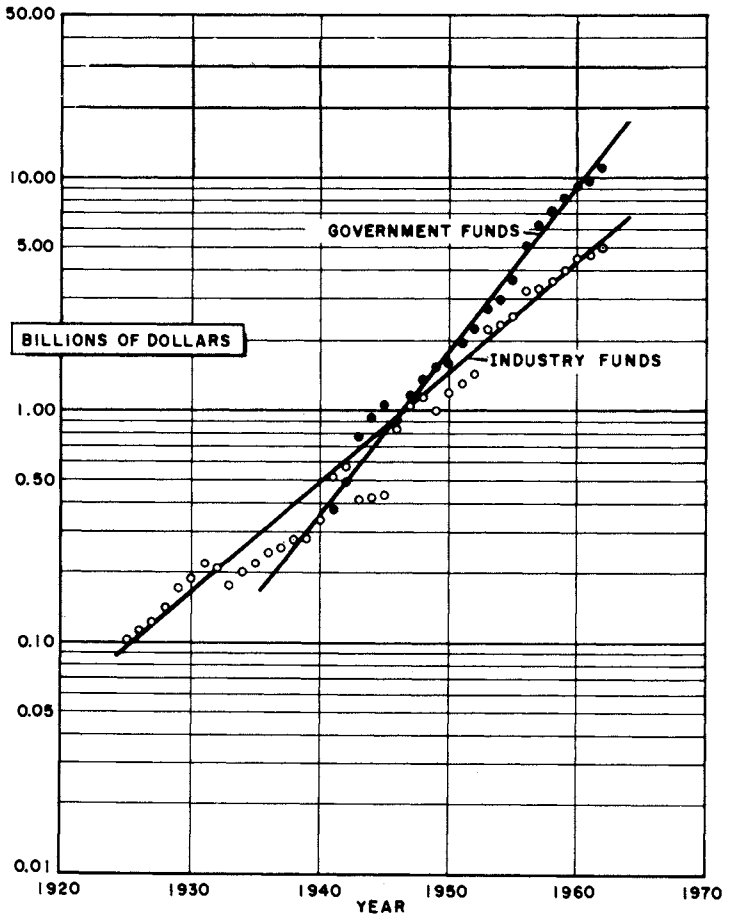

Fig. 1:2 SOURCES FOR FUNDS FOR RESEARCH AND DEVELOPMENT (U.S. Totals)

twice as fast as average gains in productivity. Since 1960, wage increases have more nearly matched gains in productivity.

To remove the effects of inflation, the expenditures in re-

[1] Unpublished report.

search dollars should be corrected for the inflationary change in the dollar. This might be done by using the Consumer Price Index, or a suitable commodity price index, or some index of change in labor rates.

TABLE 1:3

RESEARCH PERSONNEL IN INDUSTRIAL LABORATORIES*

Year	No. Professional Personnel	
1940	–	37,000
1941	62,000[a]	–
1946	80,000	56,000[b]
1947	84,000	–
1948	90,000	–
1949	94,000	–
1950	100,000	70,577[b]
Jan. 1951	–	77,500[b]
1951	104,000	–
Jan. 1952	118,000	95,694[c]
1953	130,000	–
Jan. 1954	–	157,300[d]
1956	–	–
Jan. 1957	–	222,800[e]
Jan. 1959	–	277,000[f]
Jan. 1961	–	307,300[g]

[a] A. L. Lyman, Estimated Volume of Research and Development Expenditures by Industry in 1955, in *Papers of the Fourth Conference on Scientific Manpower;* National Science Foundation, Washington, D.C.: 1954.

[b] *Research and Development Personnel in Industrial Laboratories, 1950,* p. 11; Government Printing Office, Washington, D.C., 1952. 1950 figure is for first half of year.

[c] Bureau of Labor Statistics and Department of Defense, *Scientific Research and Development in American Industry,* pp. 59, 68, 82, 88. Government Printing Office, Washington, D.C., 1953. Nonprofit agencies excluded from this figure.

[d] National Science Foundation, *Science and Engineering in American Industry,* pp. 68, 78. Government Printing Office, Washington, D.C., 1956.

[e] National Science Foundation, *Science and Engineering in American Industry,* p. 62. Government Printing Office, Washington, D.C., 1959.

[f] National Science Foundation, *Foundation Releases Estimates on Employment of Scientists and Engineers in American Industry,* January 1, 1960.

[g] National Science Foundation, *Research and Development in Industry,* 1960.

* Source (thru January 1959): Excerpt from Yale Brozen's article: Trends in industrial research and development; Reprinted from *The Journal of Business of the University of Chicago,* Vol. 33, No. 3, July 1960.

Another method of removing the inflationary distortions caused by the loss of purchasing power of the dollar would be to use the record on the growth in the number of research workers. Table 1:3 and Figure 1:3 show the number of em-

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